OCTOBER 15, 2020

SWARMFARM ROBOTICS DOCK AND REFILL STATION

4TH YEAR HONOURS PROJECT – MECHANICAL ENGINEERING

MATTHEW BURGE
UNIVERSITY OF SOUTHERN QUEENSLAND
[redacted]

ABSTRACT

The SwarmBot 5 platform developed and operated by SwarmFarm Robotics, has multiple autonomous applications, spot spraying being the most common. Autonomous spot spraying is primarily employed to reduce operating costs, and negative impacts on soil and the environment. Typically even multiple autonomous passes result in reduced chemical usage, human interactions, and highly effective weed elimination, at less cost than a single blanket spray.

Currently, the platform is refilled via manual handling of hoses/drums/nozzles etc. This process results in downtime where the platform is waiting for human interaction, and risks exposing personnel and the environment to hazards such as toxic chemicals. In an effort to properly meet the key intentions of the platform by reducing downtime, increasing operational efficiencies and further eliminating personnel interactions, the current limitations of the refuelling/refilling processes have necessitated the development of an autonomous solution. Several solutions exist for both automated fluid transfer and quick/simple manual connections, however there are no desirable or cost-effective solutions for the intended application. William Holcombe, a SwarmFarm employee, previously conducted his dissertation on this topic, with promising yet unsuccessful results.

This project aims to develop a systematic solution that is capable of completely autonomously coupling with the SwarmBot 5 platform in order to refill with chemical solutions. A broad literature review encompassed all aspects of current processes and existing solutions, after which client and supervisor discussions yielded several preliminary coupling concepts. These concepts were analysed against set criteria, before finalist couplings were physically experimented with and/or modelled. Evaluation against key design criteria resulted in a coupling upon which a holistic autonomous refilling system was conceptually designed.

A coupler for connecting to the SwarmBot 5 platform, was successfully prototyped and its performance evaliated. The design satisfied design parameters, and the complete system shows promise to meet client expectations of improved efficiencies, independencies and safety.

Further experimentations will be conducted on board the SwarmBot 5 platform, with refinements to the design and manufacturing of the coupling system. Development of the complete system, and implementation into the software will also be necessary. The coupling developed is capable of reliably coupling with the platform, and a complete system is likely to greatly increase the efficiency of operations.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled "Research Project" is to contribute to the overall education within the student's chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses 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.

Matthew Burge

[redacted]

ACKNOWLEDGEMENTS

Thank you to my family, friends, fellow students and University staff who have contributed to my life and studies over the last 4 years.

I would also like to thank Andrew Bates, William (Tom) Holcombe and Dustin Van Nek for the chance to work alongside you and your team at SwarmFarm Robotics, and for the offering of this project.

A big thank you is also owed to Dr Craig Lobsey in particular, for his assistance throughout my studies and this project.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1 - Introduction

1.1. PROJECT BACKGROUND

Agriculture is arguably one of, if not the oldest of the world's occupations. An internationally collaborated research project has unearthed evidence of "trial plant cultivation", the foundational practise of traditional farming, from 23 000 years ago in Israel (American Friends of Tel Aviv University, 2015). It is also one of the few industries that comprises an integral part of the economical and societal construct of most countries.

According to numerous sources, in particular a 2016 report by the World Bank, one third of those in economically active populations obtain their livelihoods from agricultural employment (Global Agriculture, n.d.). The Food and Agriculture Organisation of the United Nations (FAO), along with the World Bank and American Economic Association reported in 2015 that over 1.3 billion jobs are created by the industry, generating a combined $2.4 trillion GDP (FAO et al., n.d.). Agriculture is a large component of the Australian economical construct as well, with the gross value of the 2018-2019 season recorded at $69.208 billion ("Farm facts," 2020). However, in more developed countries such as Australia, the percentage of the working population employed directly in agricultural drops from between thirty-five to sixty-five percent for Asian and African countries, to around two percent (FAO et al., n.d.).

This is due partially to developed countries having greater ranges of occupational avenues, and more opportunities for individuals to pursue a different career. This greater freedom combines with jobs that offer much more lucrative pay/conditions/benefits to deplete the labour force willing to work in the agricultural industry. A general trend within the agricultural industry, since at least the 1940's, began due to the increased availability and power of tractors, along with a depleted labour force due to the war. This trend of increasing the size of operations, machinery/equipment and inputs in order to pursue greater productivity and efficiency continues, with farm machinery now capable of planting in 214-foot widths, or spraying widths of 167 feet covering up to 372.4 acres per hour (Agrifac, 2017).

One of several issues with industrial and large-scale farming practises is the effects on the soil. Vehicles have increased in weight significantly in the last sixty years. For example, the typical wheel loads of headers have increased from 1.5 to 9 tonnes, and the wheel loads of tractors from 1 to 4 tonnes (Keller et al., 2019, p. 10). This has been proven to increase the soils mechanical resistance, decrease root elongation rates, reduce water storage and soil porosity, resulting in decreased yields and likely contributing to natural disasters such as the rising flooding phenomena in Europe (Keller et al., 2019,

p. 10). Researchers from the Pennsylvania State University (Duiker, 2005) found that the most effective way to reduce sub soil (see figure 1) compaction (the most difficult and expensive to repair) was to reduce axle loadings to 6 tonnes or less.

The challenges that originally spurred the adoption of new and larger machinery, along with more modern farming practises, still exist in agriculture today. Despite the rise of corporately owned farming enterprises, more than 570 million farms are small and/or family run, with about 75% of land used for farming globally being operate as family farms (Lowder et al., 2016). Unlike corporate farms, smaller

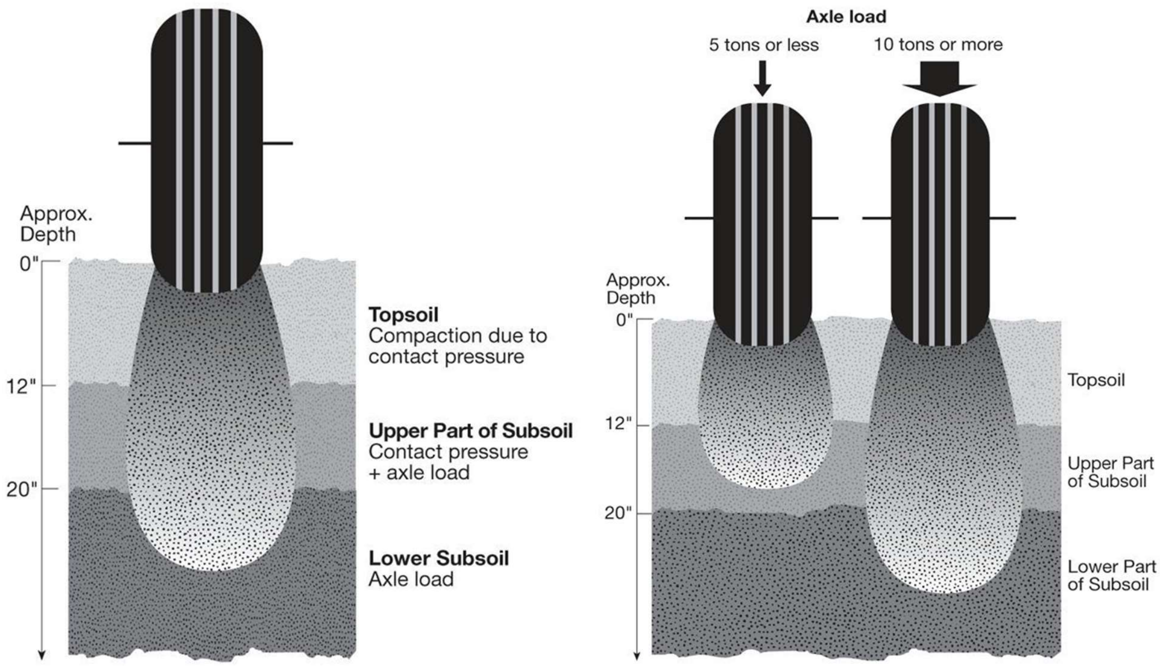


Figure 1: Effects of axle loadings on different sections of soil – illustrations by Duiker (2005)

and/or family farms are often unable to sustainably purchase and implement the same industrial farming tactics to the same degree into their operations, as capital is limited, and returns are more gradual/lower.

In addition, outside of one or two hired hands and family members, employees are often only seasonal. Seasonal employees are largely comprised of backpackers or other typically inexperienced workers, who often require a lot of training and supervision. Even after training, a lack of experience and knowledge results in many seasonal workers causing losses due to operational inefficiencies, lack of confidence, and mistakes resulting in errors/break downs. In the context of this project, employees are exposed to highly toxic and hazardous chemicals commonly used in spray applications, and when inexperienced and/or seasonal workers are involved in the mixing/handling process the risk of personnel exposure/contamination increase significantly.

Agriculture also has a massive effect on the environment, both in the immediate locality and in regions/areas “downstream”. According to the FOA, farmland occupies around fifty percent of the land on Earth deemed habitable, which is over fifty-one million square kilometres (Ritchie, 2017). In Australia, around 51 percent of landmass is occupied and/or managed by agricultural businesses, and as such they are at the forefront of achieving environmental outcomes on behalf of the population ("Farm facts," 2020). Environmental impacts of the Australian agricultural industry have been drastically reduced in some areas in an effect to reduce the nations impact on climate change, such as the significant reduction of 63 percent of the intensity of greenhouse gas emissions recorded between 1996 and 2013 ("Farm facts," 2020).

However, one of the most controversial and ongoing impacts is the reported run off of herbicide and pesticide chemicals into water systems, and ultimately the oceanic/wetland ecosystems. Run off is primarily caused by over application and incorrect application of spray chemicals in a blanket spraying operation. The same drivers behind the increasing size of machinery have led to an increase in the use of and dependence on chemicals such as herbicides and pesticides. Industrial farming practises typically see a large self-propelled boom spray travelling at high speeds, spraying a dosage of chemical intended to effectively target the thickest and toughest patches of weeds/insects, whilst the rest of the paddock (which may be bare or less affected) is saturated with unnecessary quantities of chemical. This then proceeds to either run with the next rainfall into the water system, and/or penetrate the soil and severely degrade the micro-bacterial health.

To address the aforementioned issues, numerous entrepreneurial ventures around the world have been developing methods of implementing automation into agriculture. Controlled traffic farming (CTF) is now considered best practise, and widespread across the globe, thanks to the development of GNSS (global navigation satellite systems) guided steering systems. GNSS guidance lightbars were first developed in the 1990’s, but the highly accurate systems necessary for CTF real time extended (RTX) and real time kinematic (RTK) became available around 2007, with a pass to pass accuracy of 4cm and 2.5cm respectively (Dietz, 2012).

The precision and repeatability of RTK guidance systems has encouraged and enabled the development of fully autonomous equipment, such as driverless tractors, and ‘agbots’, such as SwarmFarm Robotics’ SwarmBots. A common-sense definition of the term agbot was published by Margaret Rouse and Corinne Bernstein (2017) stating that “An agbot, also called an agribot, is an autonomous robot used in farming to help improve efficiency and reduce reliance on manual labor.” For this project however they will simply be referred to as robots.

SwarmBots have been designed as a versatile and adaptable platform to carry out numerous tasks, however their original design and that of many other similar platforms is to carry out spot spraying.

These smaller robots (typically twelve metre booms) operate at lower speeds of around ten kilometres per hour, accurately spraying only clumps of/weeds that are above an adjustable threshold. The benefits of spraying paddocks with these configurations are immense, as spot spraying alone reduces chemical usage typically between eighty and ninety-eight percent (Fulwood, 2019), and the fuel usage per area is reduced by an average between thirty and forty percent by using the robotic platform (Neales, 2020). Proven by contract trials and other tests amongst other benefits, the reduction in chemical usage and overall cost is to the extent that spraying can be conducted every three weeks instead of once or twice a year, allowing preservation of critical soil moisture for the next crop whilst remaining (often increasing) cost effectiveness (Neales, 2020).

However autonomous machinery/robots are only part of the solution, as they are part of a farm wide operation composed of many systems, interconnected by methods all requiring human input/interaction. For platforms such as SwarmFarm's SwarmBots, and competitors, to be truly autonomous and maximise potential benefits for clients/farmers, these interactions must also be automated, so the platform provides a more holistic solution. To address the first and primary of these interactions it is necessary to develop an autonomous docking and refilling module/station. By enabling the robots to detect when they are running low on resources, pack up/travel to a station, connect and refill before returning to work, the robots will be able to become truly autonomous. Currently, most robotic platforms are capable of detecting when they are approaching the end of their onboard resources, however none are capable of refilling themselves autonomously, thus still requiring personnel to monitor and interact with the platform throughout the day to refill with fuel and mix/refill with chemical.

Eliminating this interaction will reduce the labour requirements almost completely and increase the effective spraying time of the robots as there is no waiting or delay due to human inputs and errors. Environmental and personnel exposures will also be reduced by the implementation of a precisely automated process, eliminating the potential for human error or accidents to result in chemicals being spilled onto either employees or the ground etc.

In summary, the ability for the robots to autonomously dock and refuel/refill will greatly advance the progress towards a holistic autonomous operation. Providing benefits such as enabling robots to be smaller and lighter thus impacting the soil less, along with increasing the safety of personnel and the environment, amongst many others, there is a lot of incentive to invest in such a development. (Groeneveld & Bates, 2020).

1.2. PROJECT AIM

This project aims to contribute to a holistically autonomous system for agricultural activities, to increase system efficiency and viability, whilst maximising the other potential benefits offered by such a system. A key capability of such an autonomous platform is the ability to automate their interactions with external objects/tasks which typically require human input, in order for the robotic platform to approach holistic autonomy. The foremost example of such an interaction for the SwarmBot platform concerns herbicide/pesticide solution transfer/refilling applications, therefore this work will focus on the system of docking and refilling with fluids.

This project aims to solve one of the key challenges in the development of such a system, that is the development of a robust and reliable mechanical coupling mechanism for the intended usage of agricultural chemical transfer, within an automated docking and refilling module.

Via collaboration with SwarmFarm Robotics, their SwarmBot 5 platform will be utilised as the targeted design base, with the project based around the selection/design of a coupler. This coupler will be designed/selected with many contributing factors take into consideration, such as the method and position of refill, actuation and pumping, sensing and positioning etc.

1.3. PROJECT OBJECTIVES AND SCOPE

Expanding upon the primary aim as detailed in the previous section, this project has several objectives and will be comprised of several stages of work. However, it is essential that the project has a defined scope and limitations, to ensure that a meaningful result can be achieved, and to a satisfactory level of detail and professionalism within the allocated time. The design of an entire docking module/station is a considerably hefty undertaking, and there are many components/subsystems that comprise such a device, many of which are interdependent on several others for their own design requirements/restrictions.

As such, the primary element of the coupling/connector will be the focus of this project. However, the research and design of the coupling will consider the most affected/effecting of the other subsystems, such as the filling position, coupling actuation, and positioning. These elements, and others if time permits, will also be preliminarily researched, and developed in partnership with the coupling, however the design and testing will initially focus primarily on ensuring the coupling meets the set design requirements.

The key objectives of this project can be summarised as:

- Analyse previous dissertation on topic and research/tests conducted by SwarmFarm. Identify areas of weakness in original system and coupling design.
- Discuss with SwarmFarm and establish requirements relating to location and style of refill method, and accuracy of the positioning of the robots at a refill point.
- Review and evaluate potential fluid couplings suitable for chemical and autonomous application.
- Review and evaluate potential solutions for robotic refilling (system).
- Identify a suitable coupling and automation approach that satisfies requirements (e.g.refill style / positioning accuracy, environmental protection e.g. dust).
- Develop a conceptual design for onboard and external systems for refilling the robot.
- Develop preliminary design and models of a robotic filling system.
- Evaluate the performance of the design against requirements using modelling/simulations or prototyping as appropriate.
- Acquire and test several of the shortlisted couplers, along with prototypes of alternative designs. Select best design based upon criteria set by self and client (SwarmFarm).
- Build and test prototypes of the components of the robotic system for proof of concept functionality

1.4. DISSERTATION OVERVIEW

1.4.1. PROJECT OUTLINE

This report has been divided into several chapters, to aid in understanding the research and design process employed throughout. Chapter 1 introduces the background behind and reasoning for this project, whilst outlining how the report will be structured and what the project hopes to achieve. Chapter 2 is a literature review of the current practises within industry, and similar/potentially viable solutions that exist within other industries, along with an initial evaluation of concepts relating to safety and adaptability.

Chapter 3 outlines the development of the overarching key design parameters, and design preferences, before detailing the methodology, design and testing of an experiment concerning a tank top refilling method. This experiment was split into two trials, the first testing a new suspension method, and the second a new geometrical design along with the previously tested suspension method. Chapter 4 details the design reasoning and concept selection for an alternative coupling method. The development of the chosen concept/adaptation is summarised before several tests were conducted and the coupling performance evaluated.

Chapter 5 provides an overview of several of the additional factors that will be essential to developing a holistic and fully functional system/module. Factors such as an actuating dust sealing lid/cover, pumping of the solution along with the control and purging of fluids from the system throughout the process of docking refilling and disconnecting. Chapter 6 concludes the report by summarising the key findings and opportunities/needs for further work.

1.4.2. PROJECT IMPLICATIONS

This project will have numerous implications for both the partnering company SwarmFarm and other companies who are/have developed autonomous platforms for agricultural and other applications. The development of a low cost and simple mechanically based system that can be adapted to suit numerous mounting methods/positions etc whilst providing repeatable and reliable connections will enable companies to expand the features of their platforms, and approach a more holistically autonomous system.

In particular, the development and validation of a coupling method through testing will enable SwarmFarm to pursue their now short-midterm goal for the SwarmBot 5 and earlier platform. The goal is to utilise the platforms existing capabilities to detect when they are low on chemical and drive to a point for manual refilling, and then position, connect and refill itself with chemical, before returning to it's tasks. Such an outcome with significantly improve the productivity of spraying operations, essentially eliminate human interactions, therefore greatly increasing the independence, value and practicality of the platform to both SwarmFarm and their clients.

The project will also provide solid foundations for future goals of SwarmFarm, which are for the robots to have the capability to refuel in a similar manner, and for a towed behind multipurpose spreader to be refilled with granular fertilisers by a module adapted from the fluid transfer project. Other industries and companies are quite likely to also find applications for/value from a low cost, simple and robust automated fluid transfer process. Applications such as refilling liquid nitrogen/seed/granular products on agricultural equipment, along with refuelling in various industries such as rail/freight/mining etc, all present potential avenues that such a product could be marketed to with minimal adaptation.

1.4.3. SAFETY CONSIDERATIONS

Project orientated

This project is centred around a coupling for automated transfer of fluids used in agricultural activities. Such fluids include water which is non-hazardous, along with diesel fuels, pesticides, herbicides, and liquid fertilisers which are toxic and therefore hazardous to both personnel and the environment. Diesel fuel is a flammable oil, which poses fire risks, along with soil/habitat contamination if spilt. Pesticides, herbicides and liquid fertilisers are chemicals which pose significant health risks to personnel if spilt

To eliminate the potential for exposure to hazardous fluids, all testings will be conducted with pure water. This safety measure will still ensure accurate results during testings as the chemical mixes pumped into sprayers are typically a dilution of chemicals in water, often at a rate of around 5-20mL of chemical per 1 Litre of water (Nufarm & Monsanto, 2011). Most chemicals have a similar viscosity to water, and a wetting agent is also often used in mixes to increase viscosity/reduce hardness, and as such the viscosity of a pure water mix is essentially the same as most chemical mixes.

Testings will also be conducted on a test rig in an isolated and controlled environment initially, so that if a component fails there is no chance of damage to a SwarmBot platform or a farms environment or infrastructure etc. The pressures that a spray pump runs at are also relatively low, and the the pressures that the components will be tested at during refill and therefore testing are even lower, as they are flowing to a vented vessel, and the process is a lower pressure high flow operation.

Also, any dye or visual aids used to assist in leak detections will be nonhazardous, such as food dye. On farm visits to the SwarmFarm Robotics base outside of Emerald QLD hold the potential for various hazards, as it is an operating farm. However, due to personal experience on farm, and SwarmFarm's WHS plans and safety measures etc these are essentially non-existent or largely mitigated.

Product orientated

It is essential that any designs prototyped and/or developed for this project are safe to use. Despite designing for an automated operation, personnel safety must be considered. Hazards such as pinching points, crushing points, electrocution high pressure fluids and etc need to be managed and mitigated throughout the design so that personnel exposure is as limited as possible. This will be a key secondary design requirement to be considered through the following chapters. Along with the potential inclusion of a human detection system, to ensure that when the actuation is operating, no foreign objects such as hoses/hands etc enter the path of the apparatus.

CHAPTER 2 - Literature Review

2.1. INTRODUCTION

The literature review is split into several subchapters. Firstly, the current methods of transferring chemicals and other fluids in an agricultural operation will be analysed, with their strengths, limitations and safety/environmental hazards reviewed. Secondly, other industries such as the rail freight and mining sectors will be investigated for their current methods of connecting and transferring bulk fluids, both petrochemical and non-hazardous.

Next, the systems developed with the purpose of autonomously refilling equipment with liquids that are both existing and prototyped throughout various industries will be researched. This is critical to this project as any faults and strengths from their solutions can be built upon, whilst their approach to the task in general can be evaluated to find concepts and ideologies that are likeminded and ideal for this projects applications. Building upon the previous sections, the fourth will investigate the various methods of sensing and manipulation/actuation commonly used and available within industry. This will include both the positioning of the vehicle itself and the couplers both into position, along with actuation of the couplers into a locked state.

Lastly, the literature review will explore the SwarmBot platform, covering the basis of the operational setup, evaluating the various aspects of the design against the previously covered topics, such as chemical storage and positioning. This review will also cover the current methods of refilling employed by SwarmFarm concerning their SwarmBots, and outline several of the issues associated with said practises.

2.2. CHEMICAL TRANSFER AND STORAGE IN AGRICULTURE

There are numerous methods employed by spray rig operators and farmers internationally, however several common trends are constant across all operations. Best practise has also not undergone many fundamental changes in recent years, as new technologies and products primarily offer improvements within the existing solutions. These trends and best practises will be explored through an analysis that is compartmentalised using the subsections as outlined below. For both stationary and mobile operations.

2.2.1. STORAGE

As previously stated, the current best practise for chemical and water storage has not changed significantly for many years. Water is sourced and stored pure (or "clean") in bulk quantities in tanks such as that shown in Figure 2 below. These tanks are typically polyethylene (poly) tanks, constructed from a food grade UV stabilised polyethylene using a roto moulding process (Rainwater Tanks Direct, 2018). Due to the inherent properties of polyethylene and the manufacturing process, these tanks are typically the cheapest, easiest and most common solution, and are viable for a wide range of uses.

Figure 2: Industrial poly tanks (Rain Again Tanks n.d.)

Poly tanks are extremely light and durable, allowing for easy transportation and installation of the tanks. A seamless construction due to the plastic welding involved in roto moulding and material thickness thanks to the lightweight materials results in the tanks having a high impact strength, and resistivity to rust, corrosion, and petrochemical attacks. (Sprigg, 2019). As such, multiple fluids can be stored within, and they are safe for use around petrochemicals and fertilisers etc which commonly attack and/or corrode weaker plastic and steel objects.

Alternatives to poly tanks include corrugated iron tanks and concrete tanks. Until recently iron/steel tanks were an outdated and therefore noncommon choice due to rust and other reliability and safety/contamination issues. However, steel tanks are now the most common alternative for large scale industrial setups. This is partly due to new modular designs with onsite assembly, allowing large tanks to be built without transportation hassles. ("Steel vs concrete vs fibreglass vs poly tanks," 2018). Other improvements associated with the new modular designs and materials increase the purity of water stored, reliability and strength/durability of the tanks.

Concrete tanks are a common choice for drinking/rainwater supplies, due to the exceptional insulation and non-permeability of the material. This results in the highest purity of water storage out of the three mentioned. However, concrete tanks are especially fragile with stress from poor construction, impacts and even a moving foundation pad often resulting in cracks or collapse. ("Poly vs steel vs fibreglass vs concrete water tanks," 2019). Small repairs are simple enough with tape or gel-based sealants, however their cost, weight and fragility often result in other tank options being chosen for on farm activity based usages.

Industrial steel tanks require a proper foundation for the frames of the modular design to be erected firmly and correctly. Concrete tanks are similarly grounded through their immense weight and fragility. Mobile steel tanks, such as semi-trailer tankers do exist, however these are heavy duty, and along with standard steel and concrete tanks, quite expensive. Both steel and concrete alternatives are also comparatively quite expensive compared to poly tanks, a 20 000L poly/steel/concrete tank for example typically costs $2500/$5000/$7000 respectively. ("Tankulator - Tank materials > price Comparision," n.d.). As such, poly tanks are the most common choice for agricultural applications, and the only for mobile solutions such as sprayers and fluid carting trailers. Self-propelled spraying rigs and water carting trailers (apart from road going semi-trailers) all use poly tanks, as they provide a lightweight, strong and robust solution.

The flexibility of the poly side and construction, along with its seamlessly welded construction allow some flexing and therefore shock absorption combined with a low material/surface hardness resulting in a low fracture rate design. Thus, allowing the vehicles to carry a larger quantity of water than other tank designs, with less risk of tank cracking or failure.

Compared to water, spray and other ag chemical are typically stored in a variety of plastic containers differing in both design and size. 0.5-5L plastic bottles, 10-20L plastic drums, and 1000L plastic shuttles (see figure 3 below) within a steel cage/frame are the most common variants.

Figure 3: 1000L shuttle/container - food grade (Paramount Browns, 2020)

The size/type of container depends largely on the chemical and the quantity being purchased. Certain chemicals only come in smaller containers due to being highly potent and large quantities not being required. However, most chemicals that are used in spot spraying procedures come in either a 20L chemical drum, or a 1000L shuttle as above.

2.2.2. CONNECTIONS

The most common connections employed on farm for fluid transfer (excluding fuels and oils) are the camlock fittings as pictured in Figure 4 below. These fittings are available in a wide range of sizes and orientations (straight to 90deg and adaptors etc), and are typically constructed either from polyethylene or brass (sometimes steel).

Figure 4: Camlock fittings (irrigation box & spray shop australian, n.d.)

Camlock fittings are the most common fluid coupling in the agricultural industry, due to their simple and foolhardy design. There are however many problems associated with these couplings. Perhaps one of the largest issues in the lack of a check valve/tap etc within the couplings. The male and female couplings are both open, which whilst resulting in little obstruction to high fluid flow, allows contaminants ease of access into the system.

These open ends also provide a large problem with environmental and personnel safety, as disconnecting often results in any fluids left in the lines running out due to the sudden vent to atmospheric pressure/lack of a seal. This can result in the handler getting water and/or chemicals on themselves, and spillage to the environment. This is further exasperated if a tap or pump is left open elsewhere in the system, as there is nothing to prevent run/pump out unless the system is well designed.

Camlock fittings are the most common on mobile suction/pressure hoses, and as adaptors onto mixers/shuttles/tanks/equipment etc. Usage on shuttles is common practise, as it allows the operator to simply connect the fitting, and turn on the associated valves, instead of trying to pour/suck etc the chemical via more manual methods. Other fittings/connectors include the threaded drum spear, which is used to replace the cap on a 20L drum to enable the suction of fluids straight out of the drum. This is a less common place method, as it is more time consuming than simply pouring the drum into a hopper, however it significantly reduces the exposure of the operator to the risk of injury through spilt chemical or strain from the weight.

In recent years, the camlock fitting has been modified to address several of the previous issues discussed above. The Banjo Dry-Mate fittings follow the same principle of the camlock, however with numerous safety features built in. In similar fashion there is a male and female coupler, with two over-centering cam levers actuation the connection. However, each coupler has a ball-valve that seals the end of the hose/coupler with a flush face. The handles and therefore the valves/seals can only be opened when the two couplers are correctly fastened together, thus eliminating the potential for fluid run/pump out and personnel or environmental exposure. (ALSCO, 2017).

Figure 5: BANJO DRY-MATE Polypropylene Dry Disconnect (ALSCO, 2017)

Another solution that is less commonly employed is the simple hose fill. By running a hose through the lid of whatever container is being pumped into, filling is quick, simple and easy. However, there are great risks associated with this method, as factors such as the stiffness and force of a high pressure/volume hose will often result in the hose escaping the tank and spraying fluid. Manual handling of the hose, especially after submersion in the tank, is another way in which this method exposes the personnel to the potentially hazardous chemicals being transferred.

However, all these fittings require mechanical positioning and actuation/engagement, of a high tolerance. Whilst simple for personnel to carry out, for automation of the process this adds complexity to the solutions requirements in terms of the number of operations and the accuracy of each.

2.2.3. PUMPING

There are two types of pumps commonly used in agricultural applications, a centrifugal force pump and an internal piston/diaphragm pump. These are each examples of the two main classes of pumps available, positive displacement and non-positive displacement. A centrifugal pump (non-positive displacement) excels at high volume flow, typically with low head pressure as the pumping performance drops with an increase in head pressure after a point (Pump Fundamentals, 2019). A diaphragm pump (positive displacement) however is typically used for high pressure applications, and the ability to include multiple pistons per pump allows a medium volume flow as well. Also, the output is dependent on pump speeds, not head pressure, allowing a more consistent and controllable output. ("Selecting the right pump," 2019).

On board spraying systems typically use diaphragm pumps due to their ability to output a high pressure relatively independent of the flow volume and move adequate quantities of fluid when necessary. However, diaphragm pumps are susceptible to pressure spikes, which can fatigue the plumbing infrastructure and cause uneven output via the varying spray pressure at the spray nozzles. As such, an air charged diaphragm is often included as close to the pump as possible, to act as a shock absorber and reduce the pressure spikes. The inclusion of multiple pistons per pump reduces the time between pump outputs, and therefore smooths the output. (LEWA GmbH, 2018).

Centrifugal pumps although typically used for bulk fluid transfer, are becoming more commonplace onboard sprayers. New pump designs and sprayer systems use a higher-pressure output pump to provide a constant pressure to the plumbing of the sprayer, with the centrifugal pump ensuring there is plenty of volume flow capacity when necessary. Utilising the higher flows of the centrifugal pump, filling sprayers with water/chemical via the onboard pump takes significantly less time.

2.2.4. MIXING

The mixing of chemicals into the bulk water to create a batch for spraying is typically the most important, time consuming and hazardous task of refilling a sprayer. There are numerous methods employed to complete such a task, the three main categories of which are mixing hoppers, in tank mixing, and a manifold drawing system. The selection of which of these methods depends greatly on several factors, which will be discussed throughout.

A mixing hopper is typically a conical poly tank, with a sealed lid and internal apparatus useful for various tasks. The hopper can either be mounted on the refilling trailer, spray rig, or stationary at the main refill point. Typically, a hopper is used for pouring various chemicals into, where they are mixed with water before being transferred into the sprayers tank. Hoppers provide several benefits, as they allow personnel to pour drums and bottles of chemicals into a container that is at a comfortable height, before external taps direct the fluids into the sprayer. This reduces the risks of spillage onto personnel or the environment, along with physical strain and potential falls often associated with lugging heavy drums or hazardous chemicals up onto the top of a tank. However, manual measuring and handling of the drums/bottles/powders is required to lift and pour into the hopper. Hoppers also contain apparatus that allows drums to be thoroughly rinsed and fluids mixed with minimal manual involvement. This method varies greatly in measurement accuracy, as it relies largely on the operator to correctly use measuring jugs or count drums/bottles of chemicals etc.

In tank mixing refers to the process of pouring or hosing chemicals and water into a tank directly. As above, the accuracy of this method varies greatly depending on the personnel. This method is also the most hazardous to personnel, as in tank mixing often requires the carting and pouring of chemicals up to and into the top of the tank. This exposes personnel to strains from lifting, potential falls due to muddy ground/boots and/or wet and slippery equipment. Personnel are also at great risk of coming into contact with chemicals due to the manual handling and pouring of chemicals, often in precarious positions.

A manifold setup ranges from a simple system of hoses and valves to a computer-controlled measuring and handling system. Typically, most operations have a manifold of hand valves and a system of hoses which run to water tanks, 1000L shuttles and drums of chemical, which can be drawn from directly with the opening of a valve (see figure 6 below)

Figure 6: Chemical Handling (Burando Hill, n.d.)

The manifold drawing system can be setup to various levels of precision and automation, the highest level of which is a computerised version known as a quick draw. The primary example of such technology is the quick draw spray tender system by SureFire Ag Systems (Atwood, KA, USA) as pictured below in figure 7. The product is a complete solution (minus a pump) which includes several inputs from shuttles and drums, a main water line input, and a single output to the sprayer. The task of refilling the sprayer is reduced to simply connecting the main output to the input of the sprayer, and then entering the desired mixture/batch quantity.

Figure 7: QuickDraw Spray Tender System (SureFire Ag Systems, n.d.)

The on-board computer then automatically measures and controls up to six fluid inputs, along with 5 manually added fluids, in a highly accurate and speedy process. The system as pictured is designed to be 0.5% accurate, and capable of flow rates of over 200 gallons per minute (757L/min). (SureFire Ag Systems, n.d.). Quick draw systems are currently considered the ultimate, or ideal solution to refilling a sprayer, largely due to the almost complete removal of human interaction from the process. Chemical drums and hoppers are stationary, and already connected for suction. Only one hose (often equipped with a dry-mate fitting) needs to be connected and disconnected each refill. No calculations or manual measurements are required.

Therefore, the potential for personnel to make errors, resulting in either a bad batch, or chemical wastage/spillage and personnel/environmental contamination is essentially eradicated. However, such systems are extremely expensive, especially in countries like Australia where they must be imported. This combined with the perceived complexity of setting up the computer results in such systems often deemed unnecessary apart from in largescale operations where inexperienced workers are employed and efficiency is key.

Typically, a combination of all three is employed, with a basic manifold drawing system allowing direct suction from several shuttles, past a hopper for smaller quantities of chemicals from drums, before they are all agitated together using the in tank mixing by pump recirculation.

2.2.5. Spray trailer/mobile refill station

The primary water storage is typically one or more large poly tanks situated next to sheds at central or strategic locations on the farm. A common practise is for a spray trailer to transport water to a location to refill the sprayer (thus reducing sprayer travelling without working time). A spray trailer is generally composed of a combination of all the elements discussed so far in this review. One or more poly tanks occupy the majority of the space on the trailer, to store and cart fresh water in strong and cheap tanks that are not affected by the flexing associated with off road usage or susceptible to chemical/corrosive attacks. Several 1000L shuttles and chemical drums are then situated close to a pump (typically centrifugal for high volume quick refills), and a hopper. Most trailers have a manifold drawing setup for the 1000L shuttles, with 20L drums and etc simply being poured into the hopper for mixing, before the batch is agitated in the sprayers tank.

Such a setup allows the trailer to be shifted along the paddock to each refill point as required, reducing the amount of nonworking travel, dependency on others and wear on the machinery.

2.3. TYPES OF COUPLINGS IN OTHER INDUSTRIES

Many industries deal with the transferring of bulk fluids and gaseous substances. This subchapter will explore the rail freight, mining and aviation industry for their unique solutions to bulk fluid transfers in challenging environments and various situations.

2.3.1. RAIL

Fluids transported by rail freight are carried in large steel tanker cars, which are typically filled and emptied through a large singular connection on the bottom of the tanker. Gas and liquid tankers use a similar setup, however there are slight product/operational safety differences. Banlaw produce several products for rail fluid transfer, ranging from locomotive refuelling to tanker car bulk fluids and gas transfer. Their system is based around quick coupling nozzles and receivers, which can have breakaway, flush face, check valve etc capabilities. The most applicable of their products are the dry break nozzles, and the check valve receivers. The nozzles feature an actuating handle, which after the caps are removed and the nozzle pressed firmly onto the receiver, is pulled back to engage the lock and open the valve, enabling fluid flow. ("Banlaw products," n.d.).

A very durable and efficient design originally targeted towards the refuelling of long-haul locomotives, the coupling can deliver up to 1000L/min through a 2 inch fitting, whilst maintaining a firm seal despite vibrations/forces and movements. Safety features within the design ensure that the coupling cannot "fly off" without being uncoupled manually, and adjustable automatic shutoffs ensure that the no damage or spillage occurs through over filling or pumping against a blockage. ("Dry break Fitting - Diesel refuelling nozzles - Banlaw," n.d.).

Figure 8: Banlow Dry Break Fuel Nozzle & Check Valve Receiver (Integrated Fuel Services and Solutions, n.d.)

The dry break system (along with all other Banlow systems) were designed for manual operation by personnel, and as such require too much precision concerning the alignment of the two coupling halves (both positionally and rotationally) to be easily automated. Other likely difficulties associated with automating the dry break system include the complexity and extra stages required to actuate the couplings via the levering handle, and removing the contamination cap etc.

Banlow offer several other ranges of fitting series, such as the flush face fitting range, the intentional lack of exposed recesses on the mating surfaces allows personnel to simply wipe the couplers clean of contaminants before coupling, ensuring that only clean fluids are transferred ("Flush face range," n.d.). This feature would be quite beneficial in the dusty and debris prone agricultural environments, however the fittings are limited in sizes, originally intended for smaller quantity oil transfers, and as such would be too limiting to the flow rate. The operation of the flush face range is a lot simpler, after alignment the only input required is that of a forceful linear push to mate the two couplings, thus reducing the complexity of the automating process, however the positional accuracy is slightly higher than the dry break range, as the flat faces do not allow any mechanical self-aligning.

The bulk fluid fitting is a simpler system that draws from and provides benefits from both the dry break and flush face ranges, capable of delivering up to 500 litres per minute. However, sizes are restricted to only 1.5 inch, and as the system is designed for unattended refuelling/long term connections, a positive twist lock is included as a safety feature to ensure couplings do not separate. The couplings are proven to remained sealed even under extreme vibration and load, and include check valves in either halve to ensure that any residual line pressure does not result in fluid leakage. ("Bulk fluid transfer coupling," n.d.). However, the male nozzle is quite open and likely to accumulate large quantities of dust and debris, which would require cleaning before usage. Automating the actuation of this coupling would also be relatively difficult, due to the need to twist the nozzle after mating to engage the positive lock, which combined with the aforementioned factors results in this coupling also being less than ideal.

2.3.2. MINING, CHEMICAL AND FUEL INDUSTRIES

Commonly used in chemical plants, the Carbis Loadtec Drylok Dry-Disconnect coupling is similar to a Banjo Dry-Mate fitting in concept. Made of either stainless steel or comparable alloys, the coupling features one handle, which is on the nozzle. Upon mating the nozzle to the receiver, the handle is turned, which locks the two halves together, and pushes the flush faced check valve in the nozzle out, pushing inwards it's counterpart on the receiver, allowing the fluid to flow. ("Drylok dry-disconnect couplings," 2019).

*Figure 9: Drylok Dry-Disconnect Couplings (*Carbis Loadtec Group*, 2019)*

Actuation via a single handle is a beneficial design, as it removes the confusion/hesitation often associated with the Banjo dry-mate style as to which lever is to be operated first. Other benefits include the almost spherical flush faced design, which eases cleaning and allows fairly adequate mechanical self-aligning. This would reduce the required accuracy of the automation positioning system, and due to the simple rotational manner of the actuation lever, automating the actuation of the coupling would also be comparatively straightforward.

API couplers are the most commonly used internationally for connecting to road based fuel tankers, and are many rail freight tankers as well. The operating principle is quite similar to several of the previously discussed couplers, in particular the Drylok above. The API style features a five pin camlock that is activated by the actuation of the handle after mating, locking the two couplers together. The mating surfaces of the couplers are flush faced and sealing to serve as check valves when disconnected.

Figure 10: API Coupler (Carbis Loadtec Group, 2019)

There are numerous designs of API couplers, however they all must meet the API RP1004 specifications. (Carbis Loadtec Group, 2019). Thus, variations primarily concern orientations and sizing, figure 10 above is a 4 inch bore bottom loading fitting. Such fittings are rated to 150 PSI, 2271 L/min throughout a wide range of temperatures and for a large variety of petrochemical fluids (Dixon Valve US, n.d.). Within both the rail and road freight industries, bottom loading has become standard, due to the increased personnel safety as a result of working on ground level. This is reflected in the agricultural industry.

2.3.3. AERONAUTICAL

Refuelling aircraft mid-flight is known as air-to-air refuelling, or AAR. First preformed between two biplanes in 1921, the practise is now commonplace for air force operations, particularly those involving fighter jets. The probe-and-drogue system as it now known was officially developed by Sir Alan Cobham (UK) in 1950, and involves a flexible hose being extended from the leading tanker. The hose has a funnel like basket, or drogue attached to the end of the hose, and the receiving aircraft pilots its fixed (but retractable) probe into the drogue. Upon positioning, the two lock together and up to 1590 L/min of fuel can be transferred. (Mackenzie, 2020).

Figure 11: Probe-and-Drogue AAR System (Rosales, 2016)

A second form of AAR is the telescoping tube system developed by Airbus in the 1940s. A more expensive system, the method is known to be more accurate, as the receiving aircraft is simply required to cruise at a constant speed and heading, whilst a boom operator from the tanker guides a telescopic boom with a winged tip into the receiving port on the trailing jet. (Mackenzie, 2020). Although more expensive, the flying boom method enables fluid transfer speeds close to twice that of the probe-and-drogue system. The flying boom systems greater accuracy largely results from the use of wings on the end of the boom to manoeuvre the boom. The system is controllable, unlike the comparatively uncontrolled drogue. (Daly, 2018).

Figure 12: Flying boom AAR System (Kale, 2014)

On the 20th June 2018, Airbus proved the controllability of the flying boom system, by completing a 15 dry contact Automated Air-to-Air refuelling (A3R) operation. The new system uses AI and computer vision to track the trailing jet, before the boom is guided into it's port and the fluid transferred. When full, transfer stops and the boom retracts. Entirely without human interaction from either pilot. (Daly, 2018).

As proven by Airbus with the A3R, AAR systems have the potential to be automated. The flying boom system is more controllable and therefore easier to automate, however there are benefits to the probe-and-drogue system as well. However, neither are directly applicable to an agricultural environment, as both rely on the cleanliness of the environment due to air travel, and the high air speeds to control/manoeuvre their associated components into position. However, a combined concept of having the receiving vehicle stationary (relative) and the tanker telescoping a boom into the receiving drogue would be easy to automated, due to the reduced positional accuracy requirements and the lack of any actuating outside of the probe/boom positioning.

2.4. AUTOMATED REFILLING SYSTEMS

Numerous companies have invested in automated refilling/refuelling solution developments in the past decade, throughout various industries and for differing classes of fluids. In this chapter, several of the most notable and applicable solutions/prototypes have been researched to evaluate their weaknesses and strengths, success, and potential for applicability and/or adaptability. As is to be expected, there are not many details available regarding the specifics of operation or design, so as aforementioned, this review will focus on the concepts/ideas and general approach of the solutions towards automated fluid transfer.

2.4.1. Scott automation + robotics

Known as the Robofuel, the sophisticated and relatively widely adopted automated fluid transfer system developed by Scott automation + robotics can be seen in figure 13 below.

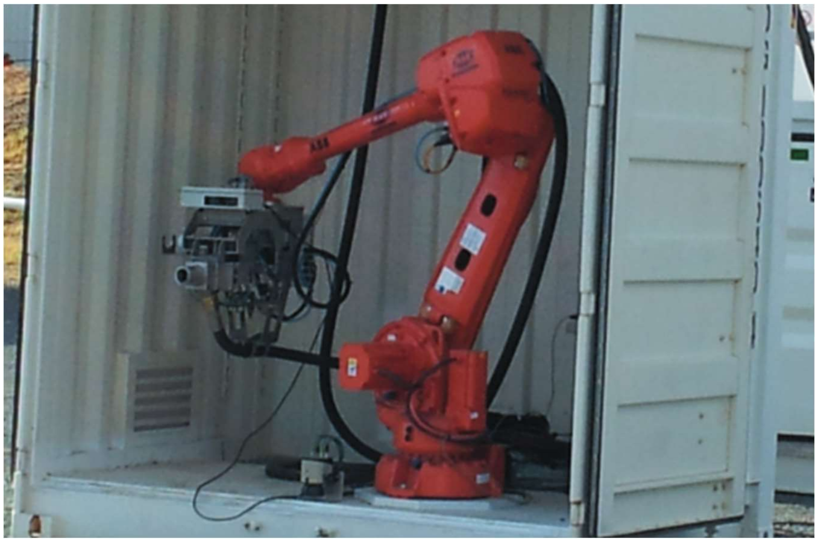


Figure 13: Scott Automation

The system is constructed from two modules, the Robofuel module, and a modular fuel tank from an outside companies product range, most typically Global Industries. Publicly attainable details are quite scarce, due to IP rights and company wishes, however the Robofuel module consists of a 5 degree of freedom robotic arm, such as those offered by Fanuc, with a customised component fitted as the manipulator on the end of the arm. The arm is mounted inside a small square shipping container, which presents a cost effective, strong and largely sealable storage and protection unit, which is also easily transportable. The module also contains the necessary control and communications devices, which allows the mining vehicle operators to communicate and refuel wirelessly from within their vehicles cabins.

After reviewing footage (Scotts Automation + Robotics, 2016), the systems operational procedure has been analysed and will be briefly explained. Upon the parking of a vehicle alongside, the operator instructs the process to start, and the Robofuel module begins by using computer vision and AI to locate the filling cap. The arm is then positioned, and the custom manipulated rotated 90 degrees, which allows the plunger and catcher to press and pull the cap off of the filler. Rotating back 90 degrees, the manipulator now positions the fuel nozzle into the filling pipe, and pumps fuel until a desired quantity or overfill safety parameter is reached. The cap is then placed back on, and the arm packed up into the container.

As confirmed in the Robofuel informational brochure (Scotts Automation + Robotics, n.d.), the module has been developed with safety and efficiency as the two key criteria. By reducing the need for a fuel station operator, human delays/errors, and increasing the flow rate itself, Scott's estimates that each mining truck will often complete an extra run per shift. Other benefits include elimination of personnel exposure to large equipment and hazardous chemicals, whilst reducing spillage and contaminations etc.

However, this automated fluid transfer solution is overly sophisticated, and extremely expensive. The AI guidance system, along with the robotic arm and custom manipulator provide numerous layers of complexity and flexibility that is unnecessary and illogical to purchase or replicate.

2.4.2. LEWIS WATER TRANSFER

Lewis Australia is an Australian automation engineering company established in 1968. They specialise in developing high volume turnkey production solutions for manufacturing and automotive industries, along with unique and individualistic equipment for the heavy metals and mining industries, all to very high standards. (Lewis Australia, n.d.). One of the more recent projects was the *Mobile Automated Fluid Transfer System* (which will be referred to as the MAFTS) for Rio Tinto mining corporation. The MAFTS can be seen in figure 14 below.

The MAFTS is designed to transfer bulk quantities of water from the mobile water truck, into the storage tanks on core drillers and other equipment. Water is used for both lubrication and cooling purposes in such operations, as well as to turn the debris into a dampened sludge that can be extracted more easily. This requires a constant supply of water in relatively large quantities, however overly large tanks or shifting the tracked machine for refills is illogical and inefficient. Thus resulting in the need for a mobile filling solution. Due to operational safety guidelines, there is an exclusion zone of five meters around any plant equipment or machinery operating in the mines.

Figure 14: Lewis Australia's Mobile Automated Fluid Transfer System (Lewis Australia, n.d.)

For personnel to refill the driller with water via traditional methods, the plant would need to be shut down, resulting in expensive down time. Lewis Australia worked with Rio Tinto to develop the MAFTS, to enable robotic water refilling, keeping personnel at a distance to reduce the exposure of personnel to loud noises, dust, and large equipment. Although details are quite scarce, it was determined that the MAFTS consists of a typical water tanker truck, with a 5 degree-of-freedom robotic arm, such as those offered by Fanuc.

Mounted to the manipulator of the arm is a several meter-long spear, which is guided via laser position identification and AI, or manual controls, into a funnel on the driller. It is assumed that there is a rubber ball like object on the end of the spear, that when pushed seals with the base of the funnels cone, allowing a leak free transfer of water from the tanker into the driller. By approximation, it was assumed that the spear and the pressure hoses used in the system are of a 3-inch diameter, which is quite common in most industries, and allows a high flow rate of water at safe pressures.

With the exception of the robotic arm, the MAFTs design is simple and relatively inexpensive. The concept presents similarities to that of the probe-and-drogue and flying tube AAR systems as discussed in chapter 2.3.3. Several benefits of this design were already mentioned resulted from the removal of personnel from the environment, as the operations are conducted from within the truck's cab. There are also operational benefits including the reduced down time that is allowed by keeping the driller running whilst refilling happens.

2.4.3. SWARMFARM'S PREVIOUS ATTEMPT

William Thomas (Tom) Holcombe conducted a research dissertation project on a similar topic, also with SwarmFarm Robotics, in 2018. His project focused largely on similar topics, with more of a focus on the software and positional side of operations. Several designs were proposed, and one tested. Unfortunately, due to manufacturing and positional errors, Mr Holcombe was unable to achieve a successful or promising result. The design tested by Mr Holcombe used a cam arm on the end of the existing swing boom, or gantry arm, to achieve a vertical travel of 1m. On the end of the cam arm was a suspended hose with a rolled steel funnel, which was intended to mate into a slightly counterpart mounted to the onboard tanks lid. The initial and final stage of the process can be viewed below in figure 15, which was used with permission from Mr Holcombes Dissertation.

(a) The alignment of the refill hose prior to being lowered

(b) The refill hose lowered into the spray tank in the second testing position

Figure 15: Mr Holcombe's Final Physical Testing Results

As can be seen, the cam arm worked as intended, and lowered the funnels into each other at the right height. The funnels, intended to act as mechanical self-aligning guides, slid into each other as intended. However, the funnels did not for a seal, as they did not concentrically align, and were skewed.

This is quite likely due to the rigid nature of the suspending hose, and the fixed attachment of the funnel to the end of the hose, both of which disallow any rotating of the funnel. Due to the nature of the funnels acting as guides, the funnel on the end of suspended hose will travel horizontally as it descends, till the bases of each cone are sitting within each other. Due to the nature of the cones attachment to the hose and the hose itself, the top of the cone was unable to be forced/freely travel horizontally, resulting in the skewed mating.

Several minor design alterations may result in this method being viable and successful, however this will be discussed in chapter 3.

2.5. TYPES OF ACTUATORS

There are numerous methods of actuation used throughout many industries and trades, however this review will focus primarily on the methods of actuation used in industrial robotics and agriculture. The most commonly used within these fields are:

- Hydraulic rams,
- Cable winches either electrically or hydraulically powered,
- Linear electric actuators,

- Pneumatic rams,
- Electric and hydraulic motors.

Hydraulic and pneumatic rams along with linear electric actuators are very similar in functionality, offering linear extensions with a predetermined stroke length and adjustable force, however their operating characteristics differ significantly. Hydraulic rams are extremely strong due to the high pressures of hydraulic systems exerting great force on the ram's piston; however, they are heavy and typically slower than alternatives, requiring expensive and bulky hydraulic pumps, fluid storage and controls etc. Hydraulic systems also offer significant controllability, due to the incompressible fluid and adjustable flow rates.

Pneumatic rams are much lighter, although typically slightly bulkier due to the bracing required to withstand air pressure and leaks. Pneumatic systems are capable of exerting great force; however, their movements are typically much harder to control due to the compressible nature of the air used to operate them, which results in very quick and often instant actuation speeds. A compressed air source, usually a powered air compressor and storage tank are required for operation, which adds bulk and complexity to the system if not already present.

Linear electric actuators, depending on sizing and style can be the most expensive solution due largely to the built-in encoders and reduction gearings. Many electric actuators are manufactured to hospital grade specifications to increase the range of applications the components can be used for; however these specifications result in a highly precise and sealed unit that is quite expensive. Due to the precision manufacturing, sealed design and inbuilt encoders, electric actuators are the easiest to accurately control and digitally observe. The sealed nature is also beneficial for the intended application of this project, as any spray chemicals that enter the component will not only cause damage due to the moisture, but also the corrosive nature of the majority of chemicals.

Cable winches powered by either a hydraulic or electric motor are a cheap and easy solution for many applications, as the cable allows flexibility with mounting of both the components being forced and the winch itself. Winch cables can also be easily repaired; however, their exposed nature often results in accelerated deterioration due to weather and chemical influenced corrosion. The largest drawback to winches is their single acting nature, as the system is only capable of providing tension through the cable. The release of tension can be controlled, say against gravitational/spring pressure, however no force can be applied in the reverse direction.

Electric and hydraulic motors, such as those powering cable winches are utilised in other applications where an attached worm drive, reduction gearbox or other drivetrain/apparatus transfer force. Hydraulic motors require a high volume of high-pressure hydraulic oil to operate effectively and are a comparatively uncontrolled actuator. External rotational counters can be used to monitor rotational counts and speeds, with an external controller then able to adjust the hydraulic flow rate accordingly. Electric motors are a high torque component which can either be a free spinning component like hydraulic motors, or a controlled and monitored process similar to linear electric actuators. Such motors are not particularly applicable to this project, with the possible exception of powering a separate pump in chapter 5.

The design criteria and preferences as summarised in chapter 3.1 will be used to determine the most appropriate actuator for each application throughout chapters 3 to 5.

2.6. SWARMBOT 5 PLATFORM

2.6.1. LAYOUT AND CHEMICAL STORAGE

The SwarmBot 5 platform is structurally composed of two SHS frames, which hydraulically in the middle. The front frame hosts the bonnet, underneath of which is the engine and hydraulic pumps, on top of which is the onboard computers and navicational and communicational equipment. The rear frame, depending on application houses the work apparatus. For spraying operations, this is a poly tank mounted on top of the frame, and a 12m or 13m attached with the three-point-linkage on the rear.

The poly tank is used for the onboard storage of the chemical and water mixtures to be sprayed. Sizes vary, however at the time of writing, a 1000L poly tank was the most common option for onboard storage. As discussed early on is the report, this is a limiting factor, and the size of the tank and the efficiency in which it can be refilled is needed/planned to increase in the near future.

2.6.2. CURRENT REFILLING PRACTISE

Currently the refilling of the SwarmBot's is done via a mobile spray trailer. The trailer contains a tank full of clean water, along with a few shuttles and several bottles of chemicals. Currently, the spot spraying done is primarily applications of the herbicide glyphosate, and as such the current refilling practise is quite simple due to the simple chemical mixture required. Currently, the operator will receive an alert on their mobile device (iPad or iPhone) warning of the robot approaching a low batch level. A task is then set, commanding the robot to stop at the end of this or the next run, depending on chemical levels and usages. The operator then connects to and drags the spray trailer up to robot, parking on the path as close as practical. The mobile device is then employed to manually drive the robot alongside the spray trailer, where the operator either manually connects a 3-inch hose with camlock fittings to the bottom loading port of the robot, or positions a swing arm boom over the top of the tank. A centrifugal pump is then started on the trailer, pumping water into the onboard tank of the robot.

Whilst the pumping is occurring, the operator calculates and measures out the required quantities of chemicals, and either pours them into the hopper on the trailer, or more often directly into the tank of the robot. Once the desired level is reached, the trailer is packed up, and the robot told to continue its work list.

This process possesses many of the issues as discussed in previous chapters surrounding couplings and filling styles etc. Not only is the operator exposed to personal harm via exposure to chemicals and physical strain/injuries, there is great potential for chemical spillages and therefore wastage and environmental contamination. The SwarmBot platform requires continuous operation to be efficient and worthwhile, however the time consumed whilst the robot waits at the end of the field, is manoeuvred, gets refilled, and then is repositioned before recommencing work drastically reduces the efficiency of the operation. The manual interactions also counteract the primary incentives of the SwarmBot platform, the ability to "set and forget" robots to autonomously complete tasks whilst personnel are engaged elsewhere.

As such, it is clear the SwarmBot platform needs to be able to autonomously dock and refill with chemical.

2.6.3. Positional accuracy

As discussed in chapter 2.4.3, Mr Tom Holcombe previously completed a project on the automation of refilling the SwarmFarm SwarmBots. Part of his project included conducting experiments and repeated testings to determine the accuracy and consistency of stopping positionings of the robotic platform. These results were necessary to define the parameters of which any proposed design solution must be able to operate within, and were obtained from tests at various speeds, orientations and tasks etc.

The results from his findings are included in the appendices, as appendix one. However, in summary his findings indicated that at a speed of 0.5m/s, the SwarmBot platform was capable of stopping in a distance of no more than 50mm from the intended waypoint (Holcombe (2018), p.52). This distance the total/line of sight distance, as viewed from above, using longitude and latitude from a set waypoint to calculate a universal transverse Mercator (UTM) value.

In the years since his testings however, the robotic platform and the software have changed significantly. Modifications include the restructuring of the steering and drive system geometry and layouts amongst other physical alterations, along with several new guidance systems and dramatic software reworks. A large portion of which are directly associated with and affect the tasks of steering, driving and stopping the platform. As such, there is a high risk that these results are no longer valid. However, during a week of work and investigation onsite, it was evaluated that the platforms are more accurate than during the past tests, as proven by several previously conducted in house trials. As such, if time permits retesting may be conducted to determine the design parameters necessary, however, for the initial stages it will be more than adequate to use the previously reported values as a worst-case scenario.

2.7. SUMMARY

SwarmFarm Robotics is in need of, and would greatly benefit from the development of an automated docking and refilling module for their SwarmBot platforms. Several solutions for automated docking and transferring of bulk fluids exist in other industries, however the cost and complexity of these systems is unideal to the agricultural industry, in particular the application of this project, which concerns comparatively small quantities of fluids.

Many couplings exist for the purpose of safe, efficient and/or unattended transferring of fluids, from petrochemicals to water to gasses. However, the majority of said couplings do not present well for the process of automated coupling in a simple and lower cost operation, due to manual interactions required for cleaning, actuation, or due to a high tolerance alignment. Thus, it is necessary to develop a solution for SwarmFarm Robotics, as there are no ideal solutions readily available. The solutions used for the Lewis mobile automated fluid transfer system and air-to-air refuelling however present interesting and potentially adaptable concepts which will be explored in the later design chapter.

CHAPTER 3 – Experiment 1

3.1. GENERAL INFORMATION ABOUT EXPERIMENTS

For maximum capability, precision, adaptability/customisation and repeatability of the system, components such as a quickdraw computerised batching system and the Lewis automated bulk fluid transfer solution would be more than ideal due to the reasons discussed in the relevant literature review sections. However as discussed, these components are all quite expensive and bulky/complex. For the scope of this project, alternative designs of couplers and relevant systems will be explored for potential solutions that meet the required parameters but are much more affordable and/or suited to the intended workspaces and situations.

The next two chapters of this report are dedicated to two alternative coupling designs and their experimental evaluations. After initial discussions and research, two primary concepts were decided upon as the most likely to meet the client's requirements regarding design and functionality. These decisions, along with the design requirements and preferences are outlined in the relevant sub-sections below. The subsequent chapter (chapter 5) explores the development of the conceptualisation of (and partial design/testing) for the rest of the components required to complete the autonomous refilling module.

Although as outlined in chapter 1.3 the scope of this report is primarily concerned with the design and validation of the coupling itself, throughout the process the mechanisms in which the coupling is actuated, positioned, and the fluid transferred, along with additional components such as dust covers must be considered, as they are highly influential on the operation and integration of the coupling. Failure to consider such additional factors will quite likely result in a design individually quite promising, however upon attempts to integrate into/design the rest of the system around, largely inefficient/inapplicable.

3.1.1. KEY DESIGN REQUIREMENTS

The key requirements for any solution/design in general that must be met were recorded after initial discussions with the client/sponsor, *SwarmFarm Robotics*. These concern factors that if not met, will result in a design that is unsafe, undesirable, and inapplicable for its intended purpose.

The first and foremost requires that the solution be leakproof. This is crucial for both safety and effectiveness, as leakages of hazardous chemicals poses a great risk to personnel and the environment.

As previously discussed in chapter 2, many chemicals used in agricultural spray applications are linked to birth defects, ill health and/or deaths, along with severe damage/disruption to local environments. Eliminating leaks also prevents the loss of expensive chemicals/solutions.

Secondly, any design must be simple and robust. Despite this project being centred around robotics, which in itself is far from simple, a reduction in complexity of any component provides several benefits. Firstly, simpler designs/mechanics are easier to design and manufacture, and typically cheaper to do so as well. The fewer sensors and actuators/moving parts etc, both lower the cost of componentry and time/complexity of assembly and setup. Also, there are less items or inputs relied upon for the systems successful operation, as a failure of any one input/output could render the rest of the system inoperable. Simpler systems also tend to rely upon physical interactions, the mechanics of which are easier to repair and diagnose, especially in the field. Due to the reduced number of components and inputs etc, simpler systems are often much less complicated (albeit less precise) to automate, which is another key design requirement.

Another of the projects key design requirements concern the dust and debris typically present in the agricultural environment. Chemical spraying systems operate by high pressure fluids being released through a shaped nozzle to develop a specific spray pattern, which is essential for an even application and a correct application rate. Any dust/debris/contaminants that enter a spray system can block and/or damage filters/taps/nozzles, and the pump in worst case scenarios. As such, it is imperative that the design solutions do not reduce the integrity of the on-board spraying system by allowing contaminants to enter the fluid system or storage during connections and fluid transfer.

As mentioned previously, another key design requirement is that the solution must easily be able to be integrated into/designed around to form a fully automated refilling module. This project mainly concerns the coupling itself, however aspects of the actuation/dust seal/pumping and storage etc will be considered in order to ensure that the designs are able to be opted in or out for all new machines, or retrofitted to earlier models, without requiring extensive modifications to either the robotic platforms or the farmers current refilling apparatus and structures. Another benefit/reason behind the modular design is that componentry will be easier to diagnose and repair/replace. This is inline with the SwarmFarm Robotics "swapnostics" design mentality employed throughout the development of their platforms, where the majority of components on the SwarmBot 5 platform can be relatively easily and quickly swapped out to aid in diagnosis', or to restore a platform to operational status.

3.1.2. Design parameters and preferences

From discussions with the sponsor/partner (SwarmFarm Robotics) several preferences, or secondary requirements were established. In summary, for the scope of this project it is preferred, if possible, that the solutions be:

- low profile and unobtrusive,
- cost effective/economically viable,
- able to utilise existing hardware where possible.

Low profile solutions do not contribute as greatly towards detracting from the styling of the platforms, and unobtrusiveness ensures that integral operations such as pivoting/steering/boom folding and setup etc are not impaired. The solutions should be cost effective, as excessive added costs will deter potential clients from either the entire robotic platform, or from upgrading to automated refilling, if the costs outweigh the advantages. This is a secondary preference, as SwarmFarm has a principle of not avoiding a perfect solution if it exists simply due to costing, unless they are considerably outlandish. Lastly, if it is possible, it would be beneficial to use existing hardware, such as the boom arm currently utilised on farm for refilling, where possible to reduce modifications and aid integration.

3.2. Experiment introduction

This chapter will detail the revisitation and advancement of the design previously attempted/employed by William (Tom) Holcombe in his dissertation *Robotic Docking* (2016). The design as developed and tested by Mr Holcombe underwent several iterations, three for the female side of the coupling and two for the male.

These iterations saw a reduction in sizing of both sides, to suit the smaller diameter required for combining the female side with the plastic thread typically fastened in the hole on top of the solution tank. This allowed the operators, after opening the lid of the tank, to simply screw the female coupling in by hand, instead of removing the threaded lid assembly. Other changes saw the inclusion of a bottom flange plate on the male side, and a rubber gasket/flap on the female side, both intended to reduce the amount/possibility of splash back due to high rates of water flow, especially when the tank is nearly full.

This design concept was chosen for revisitation, due to meeting most design parameters, both primary and secondary. The design allows the repurposing of the boom arm and existing refill trailer, is relatively low profile, low cost and simple, and does not interfere with any integral operations. In addition, due to the nature of an open hose draining into a tank for this vertical coupling, no residual fluid will be left in the coupling (such as for a horizontal coupling), eliminating the need for a dry break connection/check valves etc. Also, the space on top of the solution tank is unused, and as such there is plenty of room available for a sensibly large coupling, to aid in misalignment correction via “catching”.

3.3. DESIGN

3.3.1. PROBLEMS WITH OLD DESIGN

As shown in Figure 16 below, the primary issue encountered with all, but indeed the final iteration, of Mr Holcombe’s design, was the inability of the two funnels/coupling sides to self-align and seal correctly when the machine and the suspending arm where slightly out of alignment. These misalignments were largely due to a mispositioning/moving of the free to swivel boom arm, and less so due to the nature of stopping a robotic platform at a waypoint (Holcombe, 2018). There are several factors that are believed to contribute to the ineffectiveness of the self-aligning, most of which concern the geometry of the design.

Figure 16: Example of primary issue with old design (Figure 6.2.3, Holcombe 2018)

The large diameter of the cones is both beneficial and detrimental. Firstly, it provides a large catchment area to accept misalignment of the male cone and self-align the male into its resting/mated position. However, the large male cone diameter and thus surface area creates a larger area for factors such as friction and imperfections to cause binding/catching and result in the male cone sitting askew within the female cone.

But the largest of issues is the method suspension of the male/inner cone. The final iteration of the components used in Mr Holcombe's tests involved the male cone being hung from solid 2" Chemflex hose, as typically used in most fluid transfer applications in agricultural situations. The hose was mounted to a base plate (see figure 17 below) joined into the bottom of the male cone, which acted as a mounting plate and a splash back prohibitor. Chemflex has a typical wall thickness of around 5mm and is constructed from chemical resistant hard poly-composites, with an integral braid for kink resistance. As such, the nature of a rather hard, very kink resistant hose mounted rigidly to a steel component rather reduces the range of motion available to the suspended male cone to seek its correct resting position.

Figure 17: Male and female cone designs by Mr Holcombe (Figure 4.5.1, 2018)

This design is also very susceptible to dust and other contaminants entering the solution storage tank and/or the fluid system. The female cone mounted onto the tank replaces the standard lid, which screws into threaded component mounted to the tank, sealing the tank. As the female funnel was designed firstly to replace the entire lid assembly, threaded component included, and the later iterations to screw into the thread, the lid is no longer a viable option. During operation, or simply residing in an agricultural environment, the dust and debris stirred up by the wind and other vehicles is likely to be collected in the increased surface area of the cone and transferred into the tank.

3.3.2. TARGETS FOR NEW DESIGN

The new tank top refill designs are intended to meet all the key design requirements as set out in chapter 3.12, along with as many of the preferences as possible. The two trials within this experiment primarily aimed to meet/improve upon the ability of the coupling to tolerate misalignments and seek out the correct seating/sealing point, and to eliminate the possibility of any splashback. Chapter 6 will address the dust sealing and spill proofing concerns.

3.3.3. SOLUTIONS

Trial one

Two prototypes/tests were developed for this experiment. The first was a straightforward evaluation of a new suspension method, using two identical cones the same geometry as the final iteration of Mr Holcombe's male cone design. Mr Holcombe used 1.6mm steel sheet for the construction of his cones, however 1.2mm mild steel sheet was used for these new prototypes, due to availability and ease of working. 1.2mm sheet allows the material to be rolled/shaped manually, as rolling thicker sheet metal into a cone requires a complex tapered setup of a steel roller, and often results in imperfect shapes if not done correctly, especially when combined with welding for the join. To increase the flexibility of prototyping, and reduce cost and dependence on outside sources, the 1.2mm sheet was chosen. The only alterations to the design for the first trial concerned the lack of a base plate, the inclusion of tabs for riveting instead of welding, and the method of suspension.

The primary aim of the new suspension method is to allow a greater range of motion/freedom of rotation for the male cone to seek into the female cone. To do so, the suspenders cannot provide any force, especially torsional onto the male cone when the weight is no longer being supported by the boom arm. As such, light chains were chosen for the suspension, due to being:

- Low cost, easy and common to source,
- durable, and easily repaired/replaced,
- incapable of compressive forces or torsional resistance,
- collapsing when not in tension.

Figure 18 below is an image of the male cone and chains for the first trial. The flat pattern drawing, and cone dimensions can be found in appendix two. Referring to the inner surface, the cones had a lower diameter of 125mm, an upper diameter of 350mm, with a height of 275mm. 5mm x 2.5mm chain was used for the suspenders, due to being commonly available, with suitable weight and strength characteristics. Lighter chain would also have been suitable, as the 5mm chain was rated to 365kg and the weight of a cone is only several kilograms. However, as 5mm was not expensive or too heavy, and offered enough bulk for welding, withstanding chemical attack and general rust for long periods of time, with enough load rating for when/if the cones are made of thicker sheets, the chain was adequate and chosen for these trials.

Figure 18: 1st trial - Male cone with chains, female cone is identical without chains

Trial two

During this trial, a combination of the chain suspension method, along with new cone geometry was tested. In order for the cones to seat correctly within themselves, a steep taper is required, as when the angle of the contact surface is closer to vertical, frictional and horizontal forces are largely eliminated, and the inner cone is forced via gravity to seat within the outer cone. However, a shallower cone geometry is required to achieve a sufficient catchment area, without an excessive height. Mr Holcombe and the first trial utilised simple cones with a single section, however a compromise with the angle had to be made to achieve a balance of both catching and seating.

A dual tapered female cone allows both tapers to be more effective/specialised, meeting the two goals with less compromise. The second stage of the female funnel, the catching area, was designed to surpass the level of misalignment tolerance of the first trial, increasing from 112.5mm (4.4”) to 167.5mm (6.6”).

Figure 19: Trial 2a

The first section, the sealing/seat section, had a steeper geometry than the first trial with an angle of 15 degrees from vertical compared to 22.3 degrees. The height and diameter were reduced to a 200mm larger diameter and 150mm height. The second section for catching was much shallower at an angle of 42.9 degrees, with a height of 140mm and large diameter of 455mm. The male section was identical to the seating/sealing section of the female receiver.

The diameter of the tank lid hole when the thread is removed is 210mm, and the new female dual section receiver was designed to partially sit inside of and mount to the tanks hole. In chapter 5 a replacement for the threaded lid assembly for a stronger semi-permanent mount for the receiving cone and any apparatus (such as a dust lid) will be fastened in, hence the consideration of the holes diameter, not the threaded lids diameter. The large diameter of the catching area of the female cone was influenced by the commonly available sizing's of spun silo lids, as these were likely to be explored as a concept for an actuating lid and sealing component. The smallest commonly available lid diameter is 20", which is designed for an opening 2" smaller, hence the approximate 18" (455mm) diameter.

3.4. METHODOLOGY FOR TESTING

3.4.1. TRIAL ONE METHODOLOGY

For the first trial, the two identical male cones were constructed as per the drawings. The female cone was made with the flush face of the rivets on the inside surface, whilst the male cone had the flush face of the rivets on the outside to minimise friction and protruding edges from interfering with the cones sliding into position. The male cone was then suspended via three short chain lengths, which connected to a longer primary length. The primary length of chain and a length of 2" Chemflex hose were suspended from an old hills hoist style service parts lift, which was used to simulate the raising and lower of the cam arm on the SwarmFarm refill setup. The female cone was secured inside an LPG cylinder mount, which was clamped onto a stack of brake drums, to simulate being mounted into the opening of the tank, as no tanks with a 210mm diameter opening were readily accessible.

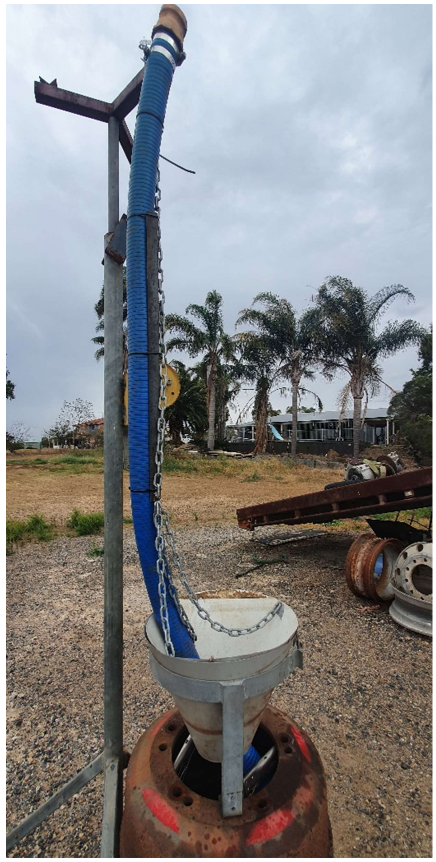


Figure 20: Trail one testing setup, with maximum misalignment

Figure 20 above shows the testing setups hoist, which was positioned in various locations ranging from concentric (0mm offset) to the pictured maximum misalignment (110mm) and beyond. Thus testing the ability of the cones to self-align and seat correctly in scenarios with various positioning errors.

3.4.2. TRIAL TWO METHODOLOGY

The three cone sections were constructed from the same 1.2mm mild steel sheet as used in trial 1, and the same hoist was used to simulate the raising and lowering of the cam arm. However a board was mounted to the top of the hoist to extend the dropping point further away from the centre, as the wider cones were interfered with by the hoists mast. The receiver was again mounted in the LPG cylinder clamp on top of the brake drums. 2” hose Chemflex was used again, however an additional length of angle iron was added below the existing piece to forcefully straighten out the residual curve. The hoist was then positioned at various distances from the receiver and the mast lowered to evaluate the effectiveness of the new design for catching and seating.

3.5. EVALUATION OF RESULTS

3.5.1. TRIAL ONE EVALUATION

The various offsets tested for, and the results can be seen in table 1 below. For all misalignments less than the maximum designed offset of 110mm (rounded down from 112.5mm) the male cone was successfully able to self-align and seat within the female cone. At any offset greater than maximum designed 110mm the connection failed. This was due to the bottom lip of the male cone (125mm diameter) not falling inside of the upper lip of the female cone (350mm diameter), thus the male cone was able to fall and be guided by the inner surface of the female cone, and simply rested upon the upper lip of the male cone.

Table 1: Experiment 1 - Trial 1 - Results

Misalignment	Outcome
0mm	Success
50mm	Success
110mm	Success
115mm	Failure

It was observed that the new suspension method was the key factor in achieving these results, as the male cone was able to freely rotate with respect to the suspenders. This enabled the male cone to have a greater surface area sliding over the inner surface of the female cone reducing the effects of frictional forces and protruding edges of rivets etc. The male cone was then able to freely rotate into the correct orientation (vertical) required, seating correctly and effectively. This is a marked improvement upon the results from Mr Holcombe's testings which were unable to correctly seat if the variation/misalignment was greater than 77mm (Holcombe, 2018).

Figure 21: Successful seating at 110mm offset

Also proven successful by trial one was the new method of allowing the extension of the hose through the male cone when seated. As seen in figure 22 below, when the chains are taking the weight of the male cone, aka when free hanging/before connecting, the 2” hose is hidden within the male cone. This prevents the hose from interacting with female cone during connections. However, when the two cones are seated, the chains are slack, and the 2” hose extends through the base of the male and female cones, into the tank, as seen in figure 21 above. This offers several benefits, the largest of which is the intended purpose of distancing the point of fluid free flow from the opening of the tank, reducing the likelihood of splashes or spray of solution exiting the tank lid.

Figure 22: Positioning at 110mm offset before lowering

However, despite the success of the new suspension method and hose mounting, the inherent nature of the 2” Chemflex hose to retain a curled form and impart residual forces caused several issues still. When the male cone was suspended, the 2” hose was within the confines of the male cone, and the curl pushed the cone to one side, away from the point of suspension. The length of hose along the longer length of suspending chain also was interfered with by the curl of the hose, and resulted in even greater static rotation and distancing of the male cone when suspended from the intended point. A small piece of angle iron fastened between the greater length of chain and the hose mostly eliminated the negative effects along the length of the chain and reduced the amount of curl within the male cone whilst suspended.

Chemflex and similar hoses typically come in rolls and would require heating and straightening to eliminate this issue, as such it was decided to include lay flat hose for future uses and trial 2. As the hose is no longer required to support and position the male cone, the strength and thickness of the Chemflex is not necessary and lay flat or similar hose will be sufficient.

3.5.2. TRIAL TWO EVALUATION

Table 2 below shows the different offsets tested for and the result. The design proved effective up to the designed 167.5mm (rounded down to 165mm) offset, however as with trial 1 after exceeding this limit it was physically unable to connect due to the male component resting atop the edge of the receiver. Observations concluded that the shallower catchment angle did not hamper the sliding of the male cone into the seating section of the receiver, despite a slight decrease in the speed at which this movement occurred. There were no indicators observed throughout testing that suggested more repetitions of raising and lowering/connecting and disconnecting would reveal factors likely to prevent an adequate seating.

Table 2: Experiment 1 - Trial 2 - Results

Misalignment	Outcome
0mm	Success
100mm	Success
165mm	Success
180mm	Failure

Figure 23 below shows the two new components, the male being suspended from the chains and the female mounted in the LPG cylinder bracket. The left image displays the setup at the maximum successful offset of 165mm before testing, whilst the right image displays the setup after a successful test at this offset. Not the chains collapsed, the Chemflex protruding through into the "tank", with the cones concentrically aligned.

Figure 23: Trial 2 setup at maximum offset (LEFT), with successful connection (RIGHT)

3.5.3. SUMMARY AND FURTHER WORK

In conclusion of this chapter and experiment one, both of the new tank top refill methods are successful and may be adapted into the SwarmBot 5 platform if desired. Both designs from trial 1 & 2 provide more than adequate misalignment tolerance to suit the average total misalignment observed by Mr Holcombe of the SwarmBot 5 platforms when stopping at a waypoint. Both designs will direct the flow of water into the tank and away from the opening via the protrusion of the hose when connected. However, the second design as tested in trial 2 provides an extra 55mm (2.15”) misalignment tolerance with an extra height of 25mm. The overall diameter of the second design is also much better suited to the conceptual design work as explored in chapter 5 for an actuated dust seal/lid which will likely use a spun silo lid.

As such, the second design is recommended for the tank top fill solution. Further work will be done to further develop a completed solution for this second trial, as the design for the mounting into the tank itself needs to be considered. Also, the inclusion of an actuated dust seal is essential, as the larger area of the exposed female cone receiver will trap dust and debris, leading to contamination and potentially blockages within the onboard solution pumping and spraying system. This will be explored in chapter 5.

CHAPTER 4 – Experiment 2

4.1. Experiment Introduction

This chapter will explore the development and design of an alternative coupling method for the docking and refill station. As explored in chapter 3, the tank top mounted refill is by far the easiest and simplest for the on-farm adaption at SwarmFarm headquarters. However, many farmers do not have access to/utilise an overhead boom for refilling their sprayers. Thus, alternative designs that can be more easily integrated onto existing SwarmBot platforms and farmers refill stations will be explored. These designs will be largely based upon the concepts of the existing solutions and similar products currently employed in both the agricultural and other industries as explored in the literature review.

4.2. Design and Manufacturing

4.2.1. Design aims

As with the first experiment (chapter 3), the alternative solution is intended to meet the key design requirements and preferences as outlined in chapters 3.1.1 and 3.1.2, however to a greater degree. The alternative design solution aims to provide a more professional solution than the tank top fill approach explored in chapter 3, in terms of both aesthetics and performance. As discussed above, this alternative design aims to ensure that integration into numerous existing farm setups is relatively straightforward. However, for the scope of this project and experiment, the alternative design will be focused primarily on the coupling itself. Dust/debris sealing, actuation, positioning and pumping/fluid control of the system, whilst considered and a part of the concept selection process, will be developed to suit in the event of a successful or promising coupling.

4.2.2. Design concept selection

After evaluation of the existing solutions reviewed in chapter 2, no single design was suitable/ideal. Several, such as the Scott Automation Robofuel and Lewis Mobile Automated Fluid Transfer System (MAFTS) (chapters 2.4.1 and 2.4.2 respectively) are perfectly functioning systems, yet unideal for this application. As discussed in their reviews, due to the use of a complete robotic arm with multiple degrees of freedom, the systems are extremely expensive, unnecessary and largely impractical. The arm provides numerous degrees of manipulation to a very high level of precision, which is not required, and adds complexity to the programming/setup, maintenance and operation of the refilling system.

As such, various combinations and adaptations were conceptualised and evaluated, with a focus on simple actuation/positioning. The chosen design concept is largely based upon the Lewis Mobile Automated Fluid Transfer System (MAFTS) as pictured in figure 14 and discussed in chapter 2.4.2. The Lewis MAFTS in turn is essentially a combination of the telescoping boom system employed by aviation air to air refuelling (chapter 2.3.3) and Scott Automation's Robofuel, (chapter 2.4.1).

The concept involves a similar setup to the Lewis and telescoping boom systems, where a probe is extended and forced into a female receiver that is fixed on the vehicle being refuelled. This male prove and female receiver cone style of connection was chosen over quick connect and drybreak fittings, despite said fittings being readily (expensively) available and proven fittings, as no positive lock/activation is required to connect/lock/engage the two fitting halves together. This once again reduces the complexity of system actuation and control.

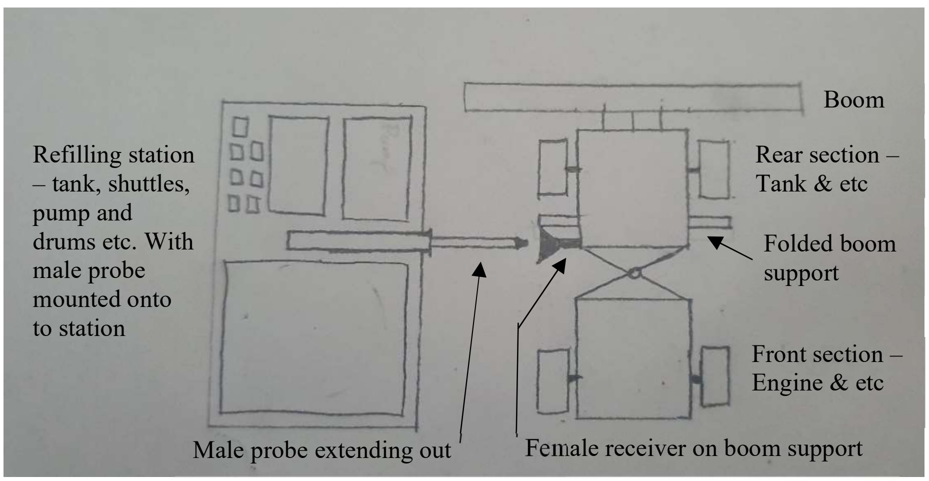


Figure 24: Chosen concept sketch for alternative design

The probe is mounted to a device that extends linearly out from the refill station, along a single axis. This would essentially eliminate two dimensions from the positional requirements of the system, reducing the likelihood and severity of misalignments. Height is set manually via fitment of the receiver to the machine and the telescopic probe to the station. Depth is irrelevant, as the system accommodates for this in the extension of the boomed probe, and not a concern as the accuracy and repeatability of sideways displacement was proven by Mr Holcombe and his experiments. Thus, the stopping distance of the robotic platform is the primary concern. This in turn reduces the requirement for precision in the actuation/positioning of the probe during connecting before a refill, and thus the need for numerous sensors and degrees of freedom in manipulation.

The receiver/female component is positioned on the rear half of the SwarmBot 5 platform, where the tank is located. The receiver may be mounted in locations such as in front of the tank above the steering pivot point, below the tank frame, or alongside the support for the booms when folded, which can be seen in figure 24. The latter location was chosen as it offered good protection from impacts alongside greater accessibility. A pipe channels fluid at low pressure directly from the receiver into the top of the onboard solution tank. The female receiver has a two-stage tapered design, the outer shallower for catching of the probe, and the inner steeper for seating and sealing of the connection. The seal will be formed by a readily available rubber seal, likely of a soft largely compressible compound, which was explored throughout the design concept development following this subsection.

4.2.3. DEVELOPMENT OF DESIGN

Seal

A wide variety of seals were considered for the primary sealing of the coupling halves. The three most heavily considered were the irrigation vee rubbers used in stationary lateral irrigation pipe sections, large cross-sectional area/oversized and soft o-rings as found in filter housings, and camlock flat rubber gaskets, seen left to right respectively below.

Figure 25: 2" Vee rubber, oversized 2" o-ring, 3" camlock flat gasket left to right

Vee rubbers are typically housed in the female housing on one end of irrigation pipes, and only operate under pressure. The hollow face of the vee is directed towards the centre of the pipe the seal is housed in, and when the pipes are placed under pressure the water back pressure pushes into the seal, flattening the inner flap of the vee into the male section which has been connected through the centre of the seal. Vee rubbers provide strong and reliable sealing, which improves with greater pipe pressure. However, they are known to leak until there is adequate back pressure against the seal (some are even designed to drain/empty the pipes when there is no active pressure). This is unideal for this design's application, as there will be minimal back pressure, and leaks are unacceptable.

Camlock gaskets are an extremely common part, simple flat rubber gasket/seal. Used in the female coupling, the seal is formed when the over-centering lobes of the camlock levers apply force to the male component, forcing its flat face into the gasket. Due to the flat face, perpendicular to the axis of the coupling being used for the seal it is imperative that the coupling halves are perfectly aligned, as the hard gasket does not compress enough to sink the leading edge, allowing the trailing edge to reach the sealing surface.

O-rings with a soft composition and large cross-sectional area can be harder to source, however a few warehouses stock them as a common part for older irrigation systems, and many filter housings/lids. Large cross-sectional area o-rings, especially when made from a soft compound enable a greater sealing effect at lower forces, and under misalignment. O-rings work under compression and deformation, as the compressive force deforms the o-ring into its groove and against the other surface.

After consultation with several local spray and irrigation specialist stores, and the aforementioned o-ring was chosen as the primary seal for the coupling. This is due to the greater likelihood of creating an effective seal at lower fluid pressures, low coupling force, and likely slight misalignments.

Male component

The most common piping size for spray rig setups and fluid transfer in agricultural applications is 2", which are capable of delivering over 960L/min over a 10m length, at a pump pressure of 7 bar (102psi). Thus, the selected oversized soft o-ring selected was 2". The groove to seat the selected 2" oversized soft o-ring was designed from a collaboration of multiple charts, following the SAE AS-568 standard. The intended placement most closely resembled a static radial piston seal gland design. The ID of the groove (dimension C) was determined from an o-ring of 2" ID (1.989" closest charted size), and the gland/groove width (dimension G) from an o-ring of 0.255" (rounded up to nearest charted size of 0.275"). (Apple Rubber, n.d.).

Thus, the groove required an ID of 2.05" and a gland width of 0.35", or 52.07mm and 8.89mm respectively. These were adjusted up slightly to allow for printing errors and discrepancies due to the tapered design, to a 53mm ID and 9mm gland width. AS-568 also requires that the glands side surfaces have an outwards taper of 0 to 5 degrees, this was applied to the rear surface of the gland/grove, reducing the risk of the o-ring being worn against a sharp leading edge.

The leading edge of the male component/"piston" chamfer was increased from the specified 15 degrees to 35 degrees to increase the contact area during self-aligning, reducing friction/wear, and to eliminate catching on any lips/seals etc. The taper for the male component was 7 degrees, with this applied to the OD surface between the leading edge and the o-ring gland, and on the ID surface of the gland. The secondary sealing was provided by a 35-degree tapered wedge further back, at a position where the middle of the wedge engages with a 3" camlock flat gasket to provide a backup seal in case of the primary seal 2" o-ring perishes/collapses etc, resulting in the probe sliding further into the tapered section of the female component and engaging the secondary seal.

A 2” hose barb minus the traction ridges and sealing lip with a wall thickness of 3mm, along with a 60mm OD mounting block are behind the secondary sealing taper. The mounting block was designed to suit 60mm exhaust clamps, which provide excellent grip, and a range of mounting options for the testing rig.

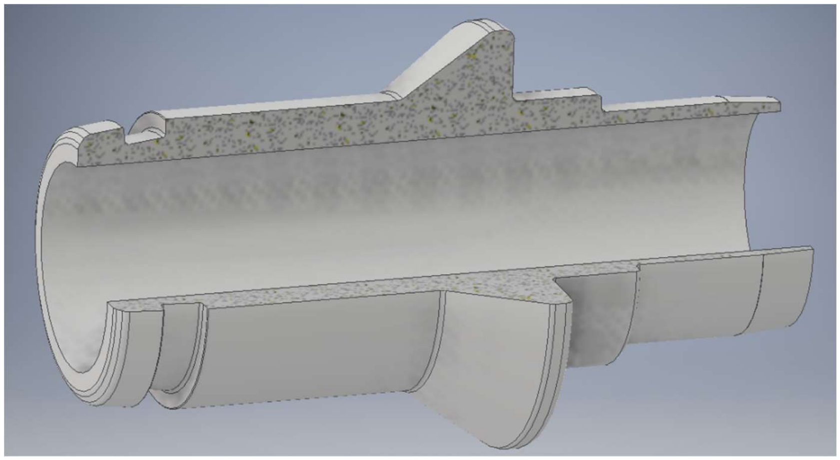


Figure 26: Male component, aka “piston”/probe cross sectional profile

The ID throughout the male coupling was 44.8mm diameter instead of the 50.8mm of 2” piping, however this results in a negligible head loss of 1.2psi, in a system where pumps typically max out at 90 psi, resulting in minimal head loss or drop in flow rate.

Female component

The female component was designed as a receiver for the male probe. The main design concerns were the parameters of the catching area, and the tapered section for sealing. The sealing section had an internal taper of 6 degrees, compared to the 7 degrees of the male, dropping from a 77mm ID to a 45mm ID along 150mm. The more gradual taper of the sealing section ensures that the no other section of the probe is likely to bottom out, preventing actuators force from being applied solely to the o-ring, and reducing the sealing pressure. The catchment areas greater diameter of 250mm reduces to 77mm at an angle of 48 degrees. At the entrance of the tapered sealing section, a 96mm OD by 8mm wide recessed gland provided the seat for the secondary seals 3” camlock gasket.

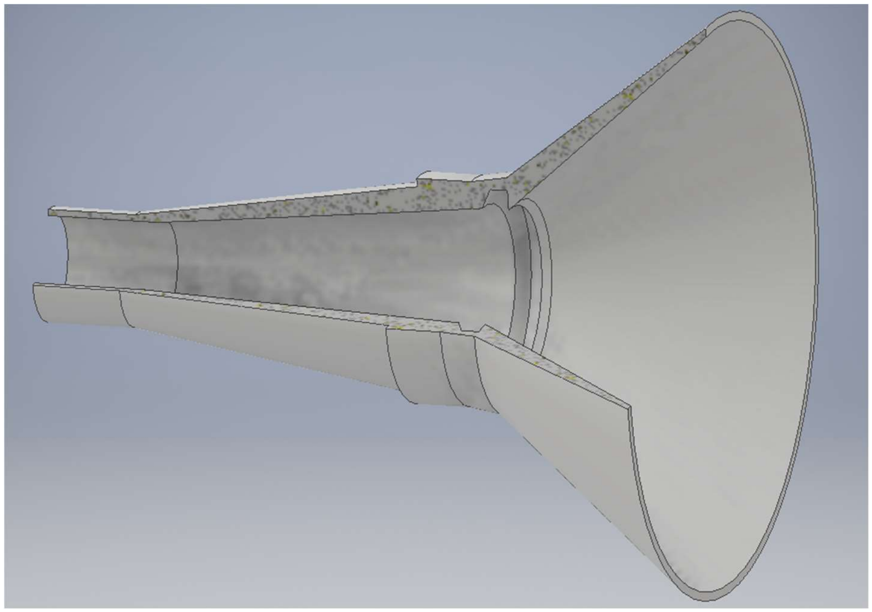


Figure 27: Female component, aka receiver, cross sectional profile

A 4" mounting block was included behind the catchment area, designed to accommodate a 4" exhaust clamp for use with the prototype testing rig.

4.2.4. Prototypes – Version 1

The first rounds of components were mainly intended to test fitment and sealing, and were modified to be a quicker print, reducing the overall volume and dimensions, mostly by eliminating the catching area/funnel section. Unfortunately, despite printing well, the CAD files had been exported and imported incorrectly, and the female component's ID was undersized. As a result of the male component not fitting, no testing could be conducted. Figure 28 below shows the first round of 3D printed prototypes.

Figure 28: Prototypes - round 1

4.2.5. PROTOTYPES – VERSION 2

The second round of prototypes were successful, and able to be used for testing. These components can be seen mounted in the testing rig in figure 29 below. The female component was printed full size, with the inclusion of the large catchment area. Material and therefore printing time were reduced by altering the thicknesses at various points to a minimum of 4.5mm, with varying thicknesses at various stressed/loaded points to be adequately strong for testing.

4.3. METHODOLOGY FOR TESTING

4.3.1. TESTING RIG

Two series of tests will be conducted for this experiment. The first series of tests will evaluate the ability of the couplings and actuators to self-align under various displacement and rotational misalignments. The second series of tests is to determine the sealing ability of the coupling under actuation. A single test rig was constructed for both tests, largely from componentry readily available in the workshop. A thick wooden slab was used as a portable benchtop, with several parts of RHS and an intake clamp forming the mount and bracket for the female side. The male side was clamped via a hose clamp onto a 500mm drawer slide from bunnings, which was mounted to a block of wood pivoting about an angle iron bracket below the block, and on the rear of the base slab. The drawer slides were actuated by a loaned 250mm stroke electric linear actuator, using modified RHS for brackets.

Figure 29: Test rig fully retracted and inline. Female component is white, male is red.

The rig is designed for both mounts/brackets to be able to pivot, enabling simulation of various offline connection scenarios. The testing rig was largely improvised, as several of the clamps and other hardware originally planned for were either unavailable or did not suit their purpose as well as intended. For example, the 60mm exhaust clamp purchased for mounting the male part to the drawer slide was too large due to the c plate fouling on the funnel of the female part when there was more than 30 degrees of misalignment.

The drawer slide and electric actuator were used as they are a scaled down and much simpler version of the actuator system likely to be used to connect the two couplings. The drawer slide is relatively frictionless and ensures straight travel, whilst the linear actuator is useful for a consistent force and range of motion, with simple operation by reversing the polarity of the switched power supply (12V battery).

4.3.2. TESTING FOR SELF-ALIGNMENT

The series of tests conducted to evaluate the self-alignment of the system will be split into three parts:

- Straight: to evaluate the functionality of the test rig and couplings in general
- Angled: to simulate rotational misalignment, robot does not drive in straight
- Offset: to simulate sideways misalignment, robot not stopped directly on spot.

For each test the two apparatus were positioned to the desired angles, with the probe fully retracted, before the probe was extended. The extension ran unhindered until the probe either bottomed out, or risk of damage was likely. The responses of both couplings to interactions/forces were observed and evaluated. Each test was run at least three times, with slight adjustments in attempt to stimulate a more positive or negative response.

4.3.3. TESTING FOR SEALING

To test the sealing capability of the coupling, an adaption to the test rig was included. As seen in figure 30 below, 2” lay flat hose was connected to each coupler halve. The female half simply connected to a bung as a water drain or topping up point, whilst the male end connected to a manifold with compressed air and a pressure gauge plumbed in.

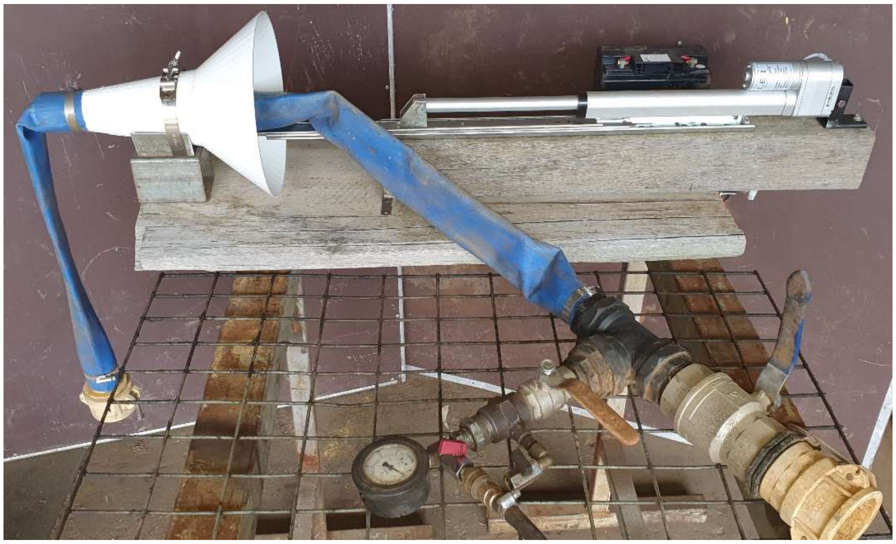


Figure 30: Test rig with additions to pressurise fluid

After the couplers were engaged in line, the system was slightly pressurised to find and rectify major leaks before the system was filled with water. After rectifying more leaks from hose clamps and etc, the system was slowly pressurised until air/water leakage occurred. The leaks location, intensity and cause were observed, and improvements made where possible. This process was repeated several times to determine the maximum pressure at which the coupling can remain sealed.

4.4. Evaluation of results

4.4.1. Testing for self-alignment

Straight

The results for the straight test proved that the couplings were capable of connecting in a relatively perfect scenario. Figure 31 below shows the two couplers when mated under these conditions. The only discrepancies present were the upwards tilt both components experienced when force continued to be applied, due to both being mounted by a single base support. Which may potentially inhibit the sealing effectiveness of the coupling. Also, the secondary seal was not engaged, due to the primary seals o-ring preventing the probe from entering further. This was an intentional feature, as the secondary seal was originally intended as a backup if the primary were to fail/collapse/deteriorate, however throughout all tests it became apparent that this secondary seal and taper should be redesigned to provide more self-aligning and sealing assistance.

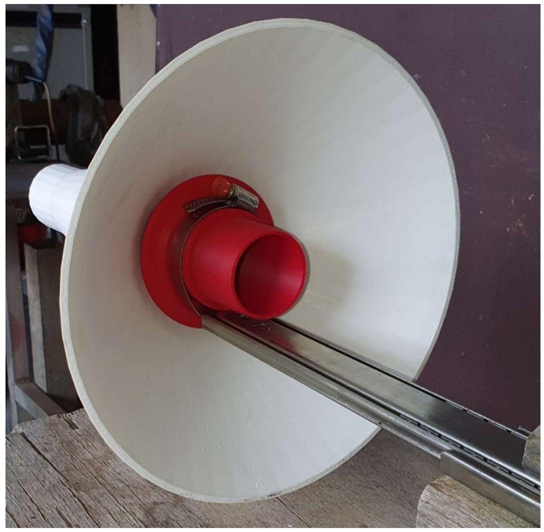


Figure 31: Self-alignment: straight

Angled

When the receiver was angled but the probe remained straight (simulating off rotationally misaligned positioning) the system was mostly capable of self-aligning. As can be seen in figure 32 below, the probe did make it into the seating/sealing position of the receiver, however the components were not completely aligned. The female mounting was adequately rotated around its pivot by the extending male component, for the probe to enter the tapered sealing section. However, once the probe stopped interacting with the catching area the female component no longer rotated as the o-ring began to deform and seal within the tapered section. The frictional and applied forces between the o-ring and the taper eliminated any further rotation.

Figure 32:Self-alignment – Angled – 1st Attempt

Offset

By pivoting both the male and female components around their mounting points, the test rig simulated connecting under linear misalignment (in direction of travel of platform). The distance between the axis of each component was 4”, thus the testing was for an 8” range of misalignment. Figure 33 below displays how the test rig was configured for these tests.

Figure 33:Self-alignment – Offset - Setup

The first attempts were unsuccessful, with the male probe remaining in its location, and the female being pushed around its pivot point until it was almost perpendicular to the male component, with no possibility of connecting throughout the motion. See figure 34 for visual aid.

Figure 34:Self-alignment – Offset - Failed

This was due to the lower resistance of the pivot for the female coupling, mounted via a bolt and washers, to the highly resistive pivot for the probe. For the probe to pivot, sufficient force must be provided to overcome the friction developed between the heavy block of wood and the wooden base slab, both with rough and uneven surfaces. The pivot bolt for the female end was tightened, increasing the friction through force, and a smooth aluminium ruler place under the contact point of the probes large block of wood reducing the coefficient of friction and frictional surface area. Testing was then reconducted.

Figure 35:Self-alignment – Offset – 2nd attempt success

As displayed in figure 35 above, the increase of stiffness/friction of the receiving mount, and reduction for the probe, saw the couplers able to self-align and connect. However, as with the angled tests, the couplers did not completely self-align, increasing the likelihood of the seal developed in the tapered section from being fully effective.

4.4.2. TESTING FOR SEALING

After the initial leaks were taken care of, the system was capable of holding static water indefinitely. However, when the system was pressurised, there were several leaks that could not be rectified. The most major leak originated from where the 2” lay flat hose was connected to the 2” barb on the back of the male component. Under pressure, water leaked from between the hose and the barb, despite two hose clamps being used. There was also a regular air leak from where the lay flat hose was connected to the back end/barb of the female component, despite two hose clamps being used. An intermittent leak from the 2” camlock cap also contributed to pressure loss throughout the system.

As a result, the test was not able to be performed as intended, as the system was unable to hold a stable pressure to determine the breakout pressure of the system. However, the air pressure could be steadily increased to determine the pressure at which the internal seal of the coupling failed. After several tests, with the use of cardboard tell-tales to determine the origin of leaks within/around the coupling, the average pressure at which the internal seal began to leak, noticed by several small droplets running out from within the tapered section, was at 14psi. This was when the couplings were correctly aligned, as when slight misalignments as seen in the angled and offset self-aligning tests the leakage pressure dropped to 9psi.

The maximum pressure the internal seal could withstand was unable to be determined, as the 2” lay flat hose attached to the barb on the female component repeatedly slid off after 14psi. This, along with the water and air that began to seep out of the 3D printed male component along the seam, and the leaking 2” barbs, prohibited a proper range of testing. The hose barb issues were largely due to the lay flat hose itself, along with the barb design. The barb design was kept minimalistic, to aid in achieving a quicker and tidier print. As such, there was no barbing/chamfered ridges to aid in traction, or a lip on the end of the component to assist with sealing.

Also, the barbs were too small in diameter for this application, as 2” Chemflex hose was originally going to be used, however lay flat was used due to its flexibility. Lay flat hose is a very thin, canvas like hose, that is used for pumping lower pressure fluids greater distances, due to the ease of dealing with a compact roll of lay flat over a mess of Chemflex or similar. The very thin material, and slightly larger ID, resulted in small crinkles/ridges when clamped to the components barbs. These, along with the thin hard material not providing any “squash”/deformability resulted in an imperfect seal.

It was observed during testing that the barb on the male component was a weak point, as upon attempts to cease leaks by overtightening hose clamps, micro-cracking sounds could be heard from the 3D printed component. As such, the inclusion of an inner cross brace to strengthen the component under compressive loads will be necessary.

4.4.3. Summary

Overall, the proof of concept was largely successful, however the results highlighted several areas for future improvement. The couplings were successfully able to connect under various misalignments and hold water pressure up until 14psi before drip leakage occurred. The capability of the couplers to self-align, along with the secondary seal design, require reworking as the connection when offset or angled results in a slightly skew connection, reducing the effectiveness of the seal, evidenced by the pressure at which drip leakage occurred dropping to 9psi. The componentry also require proper barbs, as the smooth printed surface did not provide enough traction or sealing with the 2” lay flat hose, as the tapered barbing and sealing lip were not incorporated. An inner cross brace will be included to strengthen the male component, specifically the barb, where evidence of micro-cracking was found.

It was proposed for the inner cross bracing to extend forwards and form an extra tip/spear at the front of the male component, chamfering to a narrow front. Aside from strengthening the component, this would also increase the catchment radius by reducing the radius of the male probe's contact point and provide extra leverage to ensure a finer tolerance of fitment after self-alignment.

CHAPTER 5 – System Integration

5.1. DUST SEALING LID/CAP

The need for a lid/cover to seal the female receiver for both the tank top refill and the alternative method has been well established throughout this report. However, as the tank top refill has the receiving funnel opening vertical the potential for dust and debris to both settle on the cone and subsequently enter the solution tank and onboard fluid system is greater than the alternative methods horizontal receiver. Therefore, the conceptual design will focus primarily on the tank top refill system, although the design will be such that it can simply be modified to suit the alternatives receiver.

5.1.1. RECEIVER MOUNTING

Before the design for the lid can be developed, the mounting for the receiver must be developed to ensure strong and stable mounting in the tank. The seating (lower) section of the receiver will have a 3mm sheet flange mounted 10mm below its upper lip, with a diameter of 300mm. The flange has 6 9mm clearance holes for M8 bolts to be used for mounting. An identical flange split into two halves so it may fit through the 200mm hole of the spray tank are used as spreaders on the inside of the tank to spread the clamping force and stresses from any applied forces to the receiver, reducing the risk of cracking the expensive poly tank. The lower mounting of the min flange plate results in the majority of the lower receiver section residing within the chemical tank. A pained coating or use of stainless material will prevent corrosion, and the lower mounting assist with keeping the design low profile and unobtrusive. Figure 36 below displays the concept model for tank top mounting of the receiver.

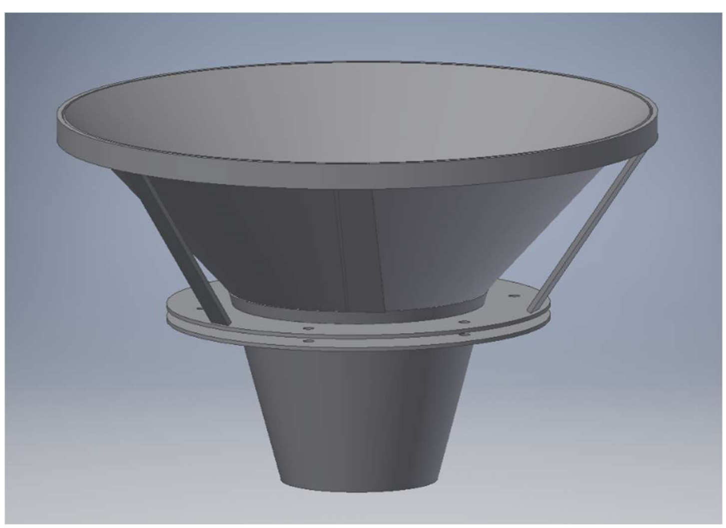


Figure 36: Receiver with flange plates and braced ring

The main flange plate has three 20mm x 3mm flat bar braces welded to the upper surface, which support a 20mm x 3mm flat bar ring around the upper and outermost lip of the receiver. This ring serves as a brace to protect the lip from impacts, and to strengthen the overall structure of the receiver. As the receiver was constructed from 1.2mm MS sheet, the material is significantly lighter and thinner than the 3mm sheet used by Mr Holcombe in his experiment, and extra support enables the material to be adequately strong enough to warrant using the easier to work with and cheaper to source 1.2mm sheet.

5.1.2. LID

The brace ring also serves as a mount for a hinge/pivot for the dust lid. The design for trial 2 in the first experiment saw the overall diameter of the receiver at 460mm. This was due to the smallest available ground open spun silo lid being a 20” diameter, suited for 18” silo openings. Ground open silo lids are most often operated by a steel cable which personnel pull on via a handle within reach at ground level. When the cable is pulled, the silo lid is pivoted open around a hinge mounted to either the silos roof or chute/chimney of the silo opening. The cable is locked via chain links at ground level, holding the lid open. A spring around the axle of the lids hinge provides constant back pressure, which when the cable is released closes the lid and seals silo.

Adapting this concept, a silo lid pivots off a hinge mounted to the brace ring of the receivers mounting system. However, no spring within the pivot is required as unlike cable, actuators are double acting. A bracket is mounted either by screwing/riveting/gluing to the top surface of the lid and extended over the side behind the pivot. An electric actuator with the base mounted in a position tucked under the receiver’s cone and on the upper flange plate extends to meets this bracket when the lid is closed. To open, the actuator retracts, pulling down over the pivot and opening the lid. When closed, the actuator provides a static force to the lid to help seal the tank as the braced ring presses into a rubber seal mounted on the inside of the lid. A mock model of this concept is displayed in figure 37 below.

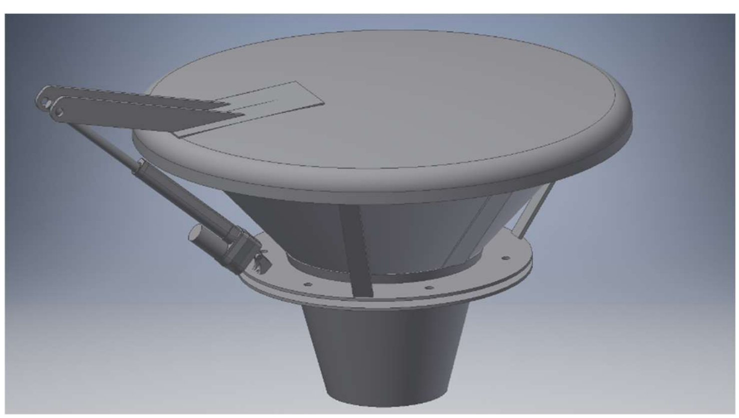


Figure 37: Braced and mounted receiver with mock actuator and lid

An electric actuator was chosen due to several factors, the foremost of which concerned the unavailability of hydraulics, as all auxiliary hydraulic circuits on the SwarmBot 5 platform are already engaged with the pump for spraying and rams for folding the boom. Two circuits are available at the rear; however, these are reserved for 3-point linkage implement applications and are preferred left unengaged.

The lid assembly will be quite light at an estimated maximum weight of 5kg, using the parameters of the mock model the actuator will likely need to provide an estimated 120N of force. As such, smaller electric actuators are more than suitable, as most smaller models are capable of producing at least 750N. Utilising an electric actuator also offers the ability to digitally monitor and precisely control the movements of the actuator and therefore the lid, ensuring the that the system is operating as desired, and no lagging/malfunctioning components are likely to result in a collision or interference etc.

Being onboard the SwarmBot 5 platform, an electric actuator reduces the bulk/complexity of controlling elements, as no hydraulic lines, solenoids, pumps and etc are required. The selection is also keeping in line with the companies plan to electrify the majority of the platform's operations in the mid future. The actuator will also not overload the electrical system, as standard 12V linear actuators draw a maximum of 3A when at their rated static load (typically around 230kg for smaller actuators), and less than 500mA when lightly loaded. The SwarmBot 5 platform crate motor has an 120A alternator fitted, which supplies an 80Ah battery. The typical maximum electrical draw from the several PLCs (programmable logic controllers) and other circuits for solenoid actuation and lights averages 25A, and as such the worst case scenario of 3A will not interfere with other electrical systems.

5.2. ACTUATION AND MOUNTINGS

6.2.1. INITIAL CONCEPTS

The simple mounting system used to test the prototypes in experiment 2 (chapter 4) had several flaws, which contributed to the couplings failing to self-align in certain scenarios and/or buckle when extra force was applied after connecting.

In summary of the findings from the self-alignment testings of the coupler in chapter 4.3.2, the couplers ability to self-align and connect under linear misalignment was greatly improved by a freer moving male probe and actuator. Also, a greater frictional force for the female receiver's pivot mounting greatly increased the effectiveness of connections under both angular and linear misalignments.

The buckling observed was due to the couplers being mounted by a singular clamp on their underside. After the couplers have self-aligned and the male probe has bottomed out in the taper of the female receiver, any additional extension of the electric actuator was to provide extra force directly to the primary seal. This force was intended to apply greater pressure and therefore compression to the soft oversized o-ring, increasing the leakage/breakout pressure of the connection. However, the force instead resulted in couplers rotating upwards/backwards around the singular mounting point, developing an angle between the o-ring and tapered sealing section axis', which decreased the sealing pressure of the connection.

Using a scale that was inserted between the two couplers, the maximum force able to be applied to the connection before serious buckling occurred was 19kg (186N). When the testing probe was held down, and the couplers held in line, the system was able to apply 35kg (343N) of sealing force through to the primary seal. Electric actuators are commonly able to output between 5kN to 15kN depending on models, with specific high force models of a similar size able to output up to 25kN. As such, a new mounting method with fuller support must be developed.

In order to provide a stiff mounting for the female receiver to prevent jack-knifing as seen in figure 34, yet still allow slight pivoting for sealing/self-alignment, a sprung mount concept was decided upon. Originally, the mount was intended to comprise of a 4" or 5" ID coil spring, which would be mounted to the female receiver near the current 4" cylindrical block used for mounting, or further forward. The spring would mount sufficiently in front of the point where the male probes primary seal seats within the female receiver's tapered sealing section. When the probe is withing the tapered sealing section, the force exerted is able to push the back of the receiver around and result in an aligned and strong seal. However, the spring cannot be mounted too far forward, as during the catching stage of connecting the front of the female receiver must be able to move sideways.

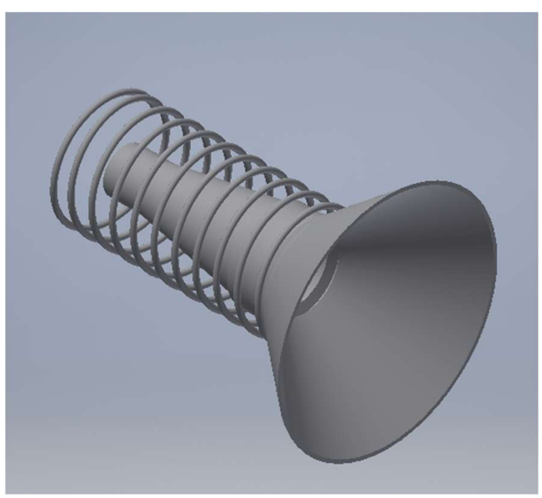


Figure 38: Original spring concept for female component

A smaller diameter coil spring (65mm to 75mm ID) was to be used for the male probe, offering flexibility for the probe to assist with the self-aligning primarily after the catching, as the probe is being forced to seat within the tapered sealing section. Both coil springs also serve the purpose of a compression buffer, allowing the actuator to apply greater forces, with any excess force unused by the primary seal to be absorbed by the springs. This reduction of force transferred into the couplers, along with the ability to realign, results in significantly lowered stress concentrations within the couplers.

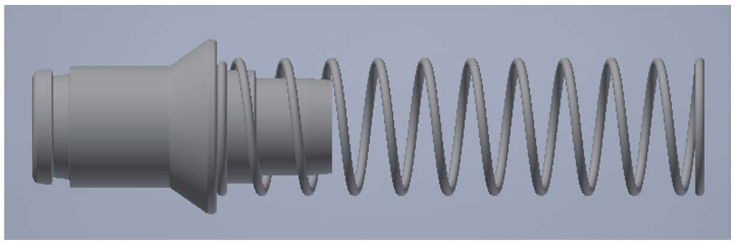


Figure 39: Original spring concept for male component

It proved quite difficult to source large enough ID coil springs, as most of suitable sizing were designed for suspension components and had a spring rate too high for adequate flexion. There were no 4" to 5" coil springs able to be sourced as the closest alternatives were custom spring making and motorbike rear strut springs. As such a new system needed to be developed using the smaller sized off the shelf springs.

6.2.2. FEMALE COMPONENT

Modifying the compression spring approach, a bracket for the female component was developed that incorporates several smaller springs, at lower rates, that results in a similar range of motion.

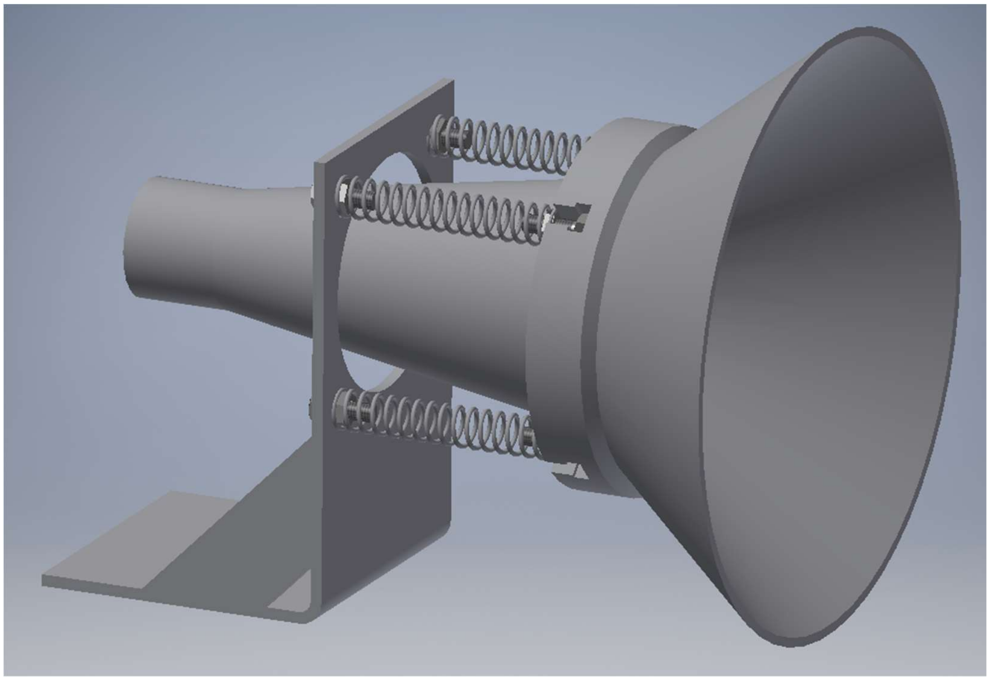


Figure 40: Sprung mounting system for female component

Figure 40 above shows the model of the female sprung mounting system. A 130mm x 5mm mild steel sheet was folded to make a bracket 200mm tall, which had clearance holes for the female receiver and M8 bolts. The bracket was braced with 40mm x 5mm flat plate and designed to bolt onto 4" SHS bars (or larger with a wider plate), that compose the SwarmBot 5's folded boom supports. 4 compression springs of OD of 18mm, 2mm wire diameter, free length of 98mm and spring rate of 3.19N/mm have M8 nuts welded into both ends (RS Components Pty Ltd, n.d.). The 4 springs provide an adequate force to arrest up to 790N of actuation before they reach their minimum working length of 35.9mm, which is more than twice the maximum force recorded from the electric actuator used throughout experiment 2. For a stronger actuation force, the springs can simply be swapped out for higher rated springs.

The springs mount to the female receiver through a slotted bolt recess, which allows the bolts to be dropped into position, before the spring is used as the nut to tighten. The springs and receiver are then bolted to the bracket via another 4 M8x25 bolts. After physical testing it may be recommended to decrease the spring length and increase the spring rate, to increase the stability of the systems dynamics.

6.2.3. MALE COMPONENT AND ACTUATION

For the male coupler, the female receivers mounting concept will not work as the mounting method must be compact and narrow enough to fit within the female receiver on an angle. Chapter 4.3.1 highlights that even the narrow exhaust clamp originally intended for use fouled and was unsuitable. After consideration, it was decided that a sprung mount was still ideal, and further research was conducted into available springs. Century springs stock #73297 has a 86.5mm OD, 8.71 wire thickness, 152.4mm free length, with a maximum load of 1.5kN at 71.1mm minimum working length (Century Spring Corp, 2018). This spring was used to provide a compression buffer and ability to slightly flex/rotate to create a better seal and can be seen modelled in figure 41 below alongside the male probe and female receiver with sprung mounting system.

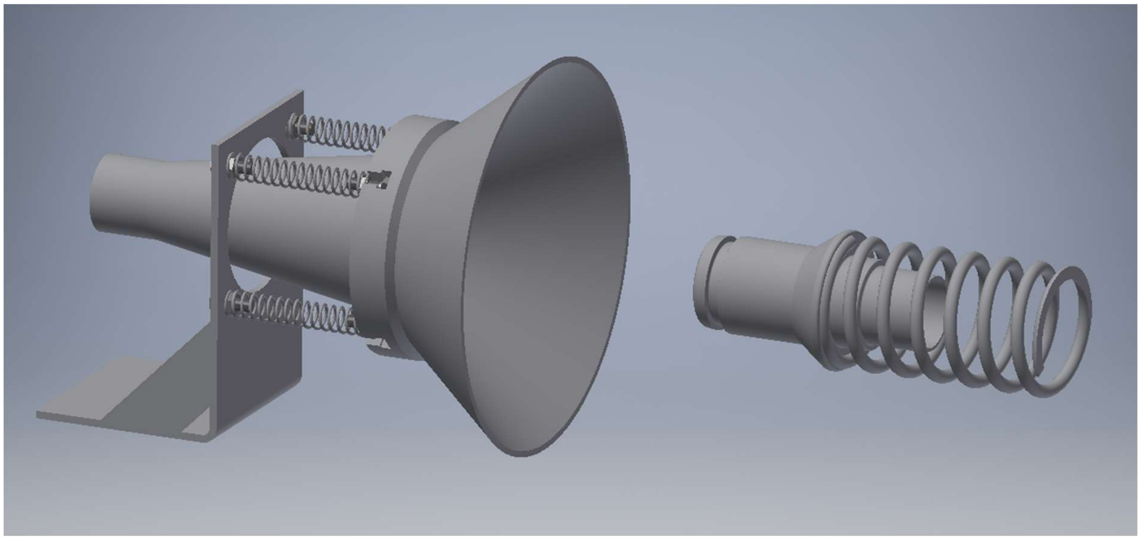


Figure 41: Sprung female mount with male probe and spring

The century spring corporations #73297 compression spring fits flush with the male probes extremities, and the closed and grounded ends provide a firm and even contact with the back of the probe, which is ideal for transferring forces in a linear and even manner. The modelled concept for mounting included a 100mm x 3mm folded steel plate to form a bracket onto which the spring was welded with a clearance hole for 2" lay flat or Chemflex hose which will run through the hole in the bracket and spring, being clamped to the hose barb on the back of the male coupling. This bracket is clamped onto 40mm SHS which 4 M8x65 hex bolts and an 75mm x 3mm plate folded into a bracket which eliminates sliding of the bracket along the SHS. The Chemflex or lay flat hose will be used to loosely hold the male probe within the compression spring when uncoupled, as the probe primarily experiences compressive forces. Any drag experienced by the probe during disconnection will low, and easily overcome by the hose and clamps.

Figure 42: Male probes telescoping and hinged frame - retracted

Figure 42 above displays the male probe, spring and brackets mounted onto a concept model of a pivoting and telescoping frame. The frame is intended to be mounted to the ends of spray refill trailers and boom spray refill stations/tank setups. The hinged brackets provide the free pivoting necessary (chapter 5.2.1) and can easily be mounted via up to 8 M8 clearance holes. The frame telescopes from an 805mm protrusion (mounting surface of hinge bracket to tip of probe) to a 1635mm protrusion as seen in figure 43 below. This can be easily modified by changing the length of actuator and SHS sections, however the current 830mm travel and 1635mm reach is sufficient to reach the female component when mounted on the SHS for the folded boom support on the SwarmBot platform.

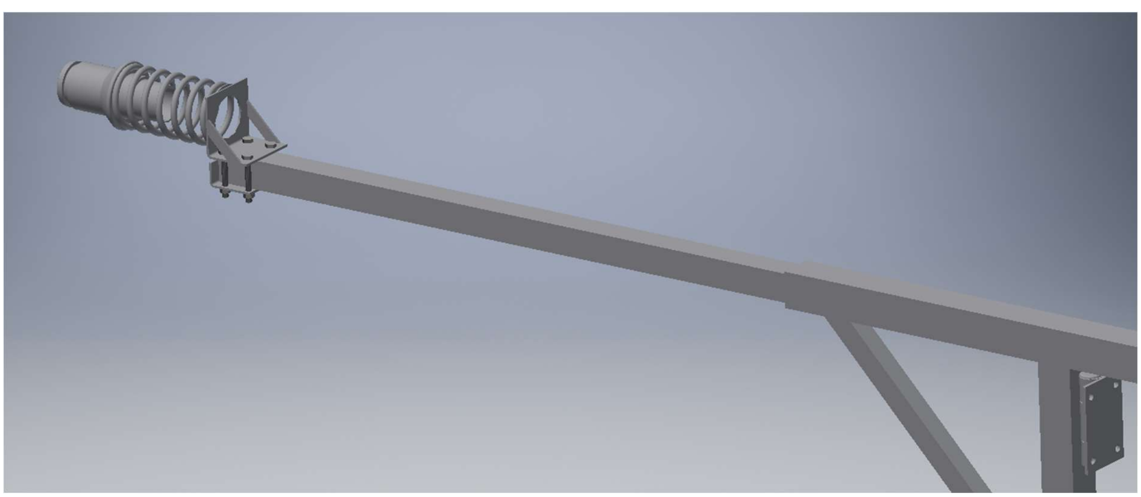


Figure 43: Male probes telescoping and hinged frame - extended

The telescoping frame overhangs the hinge rearwards by 750mm (63 percent of the static frame) to assist with counterbalancing of the system both when extended and retracted, but mostly for the purpose of compacting the overall dimension. By transferring a large portion of the bulk to above/beside/below the refill structure there is significantly less overhang/protrusion into the working and driving area. This is important as protruding components are often driven or walked into and damaged. It is likely that the stroke of the telescoping frame will need to be extended and the static section of the frame shifted further behind the hinge to reduce the retracted protrusion and increase the distance which the platform can be located from the station to reduce the risk of collisions.

6.2.4. ACTUATION

Chapter 2.5.1 summarises literature review on common methods of linear actuation; pneumatic, hydraulic, cable/winch, and electrical. All methods of actuation offer several benefits, however linear electric actuators were chosen. The primary factor being the ease of control and power supply for electric actuators, and SwarmFarm's long term goal of electrifying as many as practical/all operations.

Electric actuation is bidirectional/reversible, whereas cables/winches are not. Electric actuators also provide an easily and highly accurately position and movement reading and control, through the built in revolution counter and pulse width modulation (PWM) in some. Hydraulics and pneumatics, whilst as linear, and faster, are a lot less controllable.

Electric actuators come in numerous configurations, concerning extension speed, stroke length, maximum force output, mounting style and shaft sizing. It is intended for the linear actuator to be housed inside the 50x50mm SHS that constructs the static section of the telescopic frame for the male probe, protecting the component from weather and collisions. However, as electric actuators can be expensive, and a long stroke length is required at significantly less force than the actuators are capable of, a levering/gearing setup will be established. This will allow the use of a shorter/more common sized actuator, reducing cost and the excess force wasted during connecting.

The second most preferred solution involves the same telescoping frame as above, but with the static telescoping section being open on both ends, and the extending section much longer. An electric motor with a reduction box to sprocket output or high speed worm drive will mesh with a "rack", a straight and flat section of gear teeth, which runs along the side of the extending 40mm section of SHS. For actuation, the electric motor revs up and the gear or worm drive meshes with rack pushes the extending section in and out. The benefit of this concept is that an expensive linear actuator does not restrict the length to which the probe can be extended. The limiting factor is the length of the rack and the 40mm SHS, which can be longer than and extend tout through the back of the stationary frame 50mm SHS.

5.3. FLUID SYSTEMS

6.3.1. INITIAL CONCEPT

The concept originally featured the onboard pump drawing the solution through the coupling from a gravity fed tank/bank of shuttles. This approach was simple, without the need for an extra pump and power source, the suction of the fluid was also suspected to assist with the sealing of the coupling. Control of this system was simple, as a single solenoid on the storage tank/shuttle switched between allowing flow, and venting via a check valve to air. Another solenoid on board switched the pumps suction line from drawing from the tank to drawing through the connection. When the desired fill level was reached, the solenoid at the base of the refill storage tank switched to atmosphere, and air was drawn through to purge the system to avoid spillages when disconnecting and residual solution in lines.

However, the pump used on board the SwarmBot 5 platforms is a 9303s centrifugal pump with stainless steel housing, powered by a HM5C hydraulic motor, and is capable of delivering 556 litres per minute at a maximum pressure of 145psi (10 bar). Despite these impressive specifications, as discussed in chapter 2.2.3 centrifugal pumps cannot be run dry (pumping air) for any period of time greater than momentarily, as permanent damage results. centrifugal pumps are also more efficient at pumping than suctioning. As such, a new fluid system must be conceptualised.

6.3.2. PUMPING

Off platform pumps require their own power source and wireless control capabilities, which provides a large issue for selecting a pumping solution for both refill methods as explored in chapters 3 and 4. Petrol powered pumps are an excellent self-powered pump, however are very uncontrolled/elemental. Electric pumps are often quite small, yet a lot easier to control via relays and wireless communication etc. However, standard petrol-powered centrifugal pumps (commonly known as firefighter pumps) have been adapted by a few companies to offer remote starting capabilities. The Davey remote start firefighter MKII (RFS MKII) can be controlled by programmable timing loops and logic via input sensors, wireless remotes, and via SMS messages from phones.

The Davey RFS MKII is offered in a high head dual stage high flow single configuration, outputting up to 800 lpm @ 46m head or 430lpm @ 90m head respectively. The control systems offered by the off the shelf solution of the Davey RFS MKIII would likely integrate well with the SwarmBot 5 platform, which is capable of sending and receiving SMS messages. However, the flow specifications of the pump in both configurations are excessive and would fill the on-board tank in less than three minutes, and likely result in leakages due to the high flow rates and pressures. (Davey Water, n.d.).

Unless the pumps higher flow rate would be utilised for either pretransfer agitation of the solution, and/or mixing through a quick draw such as the SureFire Ag system, then at over $4500 per pump the Davey RFS MKII is not the most ideal/viable solution.

Alternative start kits can be fitted to the general Honda firefighters, and operated via wired or wireless inputs/remotes logic circuits. At a cost of $1600 for a Davey 5165HE (500lpm max, electric start) plus labour for programming a chip to interact with the starting circuit, a custom solution can be developed.

Alternatively, a small generator can be fitted with a POWERGUARD Wireless Start Control module for $800, or an online alternative for $70. The generator could then be used to power a 240VAC or 12/24VDC electric pump. A genset solution would offer several benefits including the ability to run electric actuators and pumps off a the same remotely started power supply, instead of drawing upon banks of batteries and solar panels. In addition, an array of solar panels could be established with a bank of batteries at the refill station, with the auto start of function of many small generators/inverters simply starting the genset to recharge the batteries and meet current draw when voltage levels or current draw crosses a trigger point.

6.3.3. System purge

For the alternative fill method explored in chapter 4, as the coupling is positioned below the tank solution will remain in the piping, even if the pump has run dry. One of the primary design requirements stated that the design must not leak, thus the residual solution must be removed before the couplers can be disconnected. Check valves could be installed in the piping directly next to the couplers (on the hose sides), however whilst this will prevent the lines from emptying and greatly reduce the amount of solution leaked, the fluid between these two points will still leak when disconnected.

The original concept involved suction throughout the transfer piping, with an air inlet at the storage side to allow the onboard pump to purge the lines. However, as this option is no longer viable a purging capability should be included on the fluid system for the alternative filling method. If a medium to large capacity diaphragm pump was used for the fluid transfer, regardless of suction or pressure application (on board or storage located respectively) the ability of the pump to move large quantities of air without damage would enable an easy purge. However diaphragm pumps are typically quite expensive, and 12/24VDC configurations are quite limited in flow rate.

If a genset was used to power either a standard centrifugal transfer pump, a separate firefighter pump, or a 12/24VDC centrifugal pump, the electricity could also be used to run a small air compressor which pressurises a small tank. After refilling just before disconnection, the air is released through the lines in a controlled but fast manner, purging the lines of solution and resulting in a dry break. Or an electrical diaphragm pump may be powered by the genset, and its air moving capabilities utilised.

6.3.4. FLOW MEASURING

The SwarmBot 5 platform has an inbuilt solution tank level monitor, used as input for the computer for decision making and displayable on operators' phones/laptops etc. This sensor has proved appropriately accurate for its intended purposes and should be capable of reading and influencing the control of the solution transfer during refilling. An additional or replacement sender which is more accurate and responsive, and capable of dealing with chemical/agitation foaming may be installed in the future, pending testing results. A flow meter such as an internal paddle wheel meter would be quite beneficial as an alternative/additional meter. Although the ideal location would be directly after the pump, on the storage side of the coupler, the wired communication method of the flow meter would require that the flow meter is installed on the platform, directly after the female receiver.

The ideal solution, however, would be to incorporate the measuring and mixing capabilities of the SureFire Ag quick draw system to measure the flow rate and quantity transferred. However communicating to/with the proprietary system may be difficult due to a closed system design. This will need to be researched before project planning/purchase, as the communication between the quickdraw, SwarmBot, and the pump will be essential.

CHAPTER 6 – Conclusion

6.1. SUMMARY

From an overarching perspective, this project was a success. The primary aim of this project was to develop a robust and reliable mechanical coupling mechanism for agricultural chemical transfer, within the application of an automated docking and refilling module (see chapter 1.2). A summary of the key design requirements from chapter 3.1.2 stated that the solutions must be:

- leakproof,
- simple and robust,
- sealable and contaminant proof,
- modular and able to be easily integrated/diagnosed/repaired/modified etc.

It was also preferred that the solutions where possible be:

- low profile and unobtrusive,
- cost effective/economically viable,
- able to utilise existing hardware where possible.

Experiment 1 (chapter 3) resulted in a successful modification of a previous design for tank top refilling, as the new suspension method and cone geometry resulted in a simple and robust solution, which was low profile, cost effective and leak free. The solution was also able to utilise the existing hardware of the SwarmFarm boom arm currently reused for manually refilling the platforms, by being attached in a modular manner. Testing proved that the solution was capable of correctly connecting in scenarios of much greater misalignment than typically experienced when the platform stops at a way point. Therefore, experiment 1 was a success, and presents a viable solution to for simple tank top refilling of the SwarmBot 5 platforms utilising the cam arm previously setup by Mr Holcombe.

Experiment 2 (chapter 4) resulted in a moderately successful alternative fill solution, based upon an adaptation of the Lewis Mobile Automated Fluid Transfer System as reviewed in chapter 2.4.2. The concept was successful, as the couplers were capable of connecting via their own actuation and interaction in scenarios of misalignment relatively larger than typical of the platform. The pressure test revealed that the connection was capable of withstanding the pressure required to transfer the solution to the top of the tank, however without a satisfactory margin of safety. These unsatisfactory results were largely the result of the simplified design of the hose barbs on the component resulting in inadequate sealing and traction between the hoses and the components.

Unfortunately, testing of a new series of prototypes was unable to be performed within the time limitations surrounding this project, and therefore the evaluation is not completely conclusive. However, the design was technically successful, as it met the experiments aim to prove an alternative concept plausible. The alternative concept is lower profile and less obtrusive than the tank top refilling, and modular approach, especially as most clients will not have the pre-existing boom arm for refilling as on the SwarmFarm property.

6.2. FURTHER WORK

There are a range of opportunities for further work and continuation of the development and testing of the concepts explored throughout this project. Firstly, the reworking of the male and female components for the alternative fill method in experiment 2 need to be finalised and then prototyped and tested. The inclusion of the internal brace to strength the male barb and aid self-aligning, along with the inclusion of proper hose barb designs should allow the connection to withstand much higher fluid pressures, making the concept much more viable for it's likely application with a high flow and medium pressure firefighter pump.

The components/systems conceptualised and developed in chapter 5 are prime candidates for future work, as the concepts must be prototyped and tested for proof of concept and/viability. In particular, the sprung mounting systems developed for the alternative fill method in chapter 4. It is hypothesised that the sprung mount systems will result in a greater self-alignment capability, both in terms of catching and seating/sealing. These need to be tested alongside the hinged and telescoping male probe frame, to test the viability of the system as a whole and to further the development of the modular mounting system. With the platform parked in position, it will be necessary to determine the travel of the telescoping frame required, and thus the style and design of the actuation.

Another essential component of the system that should be further developed is the dust and debris sealing lid/cover, which was conceptualised alongside the tank mounting required to suit the tank top filling method in chapter 5.1. Without the ability to seal the system and the tank from the outside environment the entire system is unviable, and as such the concept presented should be further developed and prototyped. If the alternative refill method is chosen for either installation or further development, the fluid system purging is an element that should also be further investigated. The ability to purge the lines of solution is essential as lines should not be left full of solution whilst not in use, due to the potential for leakage or unknowing disconnections that result in personnel and environmental exposure.

As the demand for SwarmFarms SwarmBot 5 platforms has increased, it has been decided to create a project group to pursue the development, finalisation and inmplementation of an automated refill solution. In the time since the literature review in chapter 2 was conducted, several new couplings have come to light. These couplings are highly professional and specialised yet off the shelf connections that may present readily viable solutions for SwarmFarm. These should be investigated and evaluated in terms of applicability, viability and availaibilty. The connections recently discovered are the FIA SAF approved refuelling system used in some F1 racing teams, and the 360 sprint liquid nitrogen refill on the move system offered by the 360 Yield Centre.

CHAPTER 7 – References

1000L SHUTTLE / CONTAINER - FOOD GRADE [Photograph]. (2020). Paramount Browns. https://www.paramountbrowns.com.au/products/1000l-shuttle-container-food-grade/

Agrifac. (2017). World record spraying. Retrieved May 26, 2020, from https://www.agrifac.com/world-record-spraying/

ALSCO. (2017). Banjo valves and fittings. Banjo Valves and Fittings - Alsco Industrial Products, Inc. https://www.banjovalves.com/dry-mate-polypropylene-dry-disconnect.aspx

American Friends of Tel Aviv University. (2015, July 22). First evidence of farming in Mideast 23,000 years ago: Evidence of earliest small-scale agricultural cultivation. ScienceDaily. Retrieved May 26, 2020 from www.sciencedaily.com/releases/2015/07/150722144709.htm

Apple Rubber. (n.d.). Classification - Seal types & gland designs SAE AS-568. Rubber Seals, Sealing Devices & O-Ring Seal Design. https://www.applerubber.com/seal-design-guide/seal-types-and-gland-design/static-seal-types.cfm

Arag Camlock Coupling Male Thread F [Photograph]. (n.d.). Spray Shop Australia. https://sprayshopaustralia.com.au/product/arag-camlock-coupling-male-thread-f/

BANJO DRY-MATE Polypropylene Dry Disconnect [Photograph]. (2017). ALSCO. https://www.banjovalves.com/dry-mate-polypropylene-dry-disconnect.aspx

Banlaw products. (n.d.). Integrated Fuel Services and Solutions. https://integratedfuel.com.au/products/banlaw-products/

Bulk fluid transfer coupling. (n.d.). Banlaw. https://www.banlaw.com/refuelling/bulk-fluid-transfer/

Burando Hill. (n.d.). Chemical Handling [Photograph]. https://www.burandohill.com.au/liquid

Carbis Loadtec Group. (2019). API Couplers [Photograph]. https://www.carbisloadtec.com/product/api-couplers/

Carbis Loadtec Group. (2019). Drylok dry-disconnet couplings [Photograph]. ("Drylok dry-disconnect couplings," 2019)https://www.carbisloadtec.com/product/drylok-dry-disconnect-couplings/

Carbis Loadtec Group. (2019, October 22). API couplers. https://www.carbisloadtec.com/product/api-couplers/

Century Spring Corp. (2018). 73297 - Compression Spring. https://www.centuryspring.com/catalog/compression-regular?page=product&cid=compression-regular&id=73297CS

Copely. (2020, June 9). Flow rate calculator. https://www.copely.com/tools/flow-rate-calculator/

Core Electronics. (n.d.). Concentric LACT10P-12V-20 linear actuator with feedback: 10. https://core-electronics.com.au/concentric-lact10p-12v-20-linear-actuator-with-feedback-10-stroke-12v-0-5-s.html

Daly, K. (2018, July 12). Airbus performs world’s first automatic air-to-air refuelling contact with large aircraft receiver. Airbus. https://www.airbus.com/newsroom/press-releases/en/2018/07/Airbus-performs-worlds-first-automatic-air-to-air-refuelling-contact-with-large-aircraft-receiver.html

Davey Water. (n.d.). Remote Start Firefighter MkII. https://www.daveywater.com/au/product/remote-start-firefighter

Dietz, J. (2012, May 30). Understanding autosteer in 2012. Top Crop Manager. https://www.topcropmanager.com/understanding-autosteer-in-2012-11491/

Dixon Valve US. (n.d.). API coupler with bonded nose seal. https://www.dixonvalve.com/product/5300

Dry break Fitting - Diesel refuelling nozzles - Banlaw. (n.d.). Banlaw. https://www.banlaw.com/refuelling/dry-break-nozzles/

Drylok dry-disconnect couplings. (2019, October 22). Carbis Loadtec Group. https://www.carbisloadtec.com/product/drylok-dry-disconnect-couplings/

Duiker, S. W. (2005, February 12). Avoiding soil compaction. Penn State Extension. https://extension.psu.edu/avoiding-soil-compaction

FAO, World Bank, & American Economic Association. (n.d.). Top 5 ways agriculture impacts the global economy. CropLife International | CropLife International. https://croplife.org/wp-content/uploads/2015/10/PSP_October_Infographic-Top5.pdf

Farm facts. (2020, January 29). National Farmers' Federation. Retrieved May 25, 2020, from https://nff.org.au/media-centre/farm-facts/

Flush face range. (n.d.). Banlaw. https://www.banlaw.com/fluid-transfer/flush-face-range/

Fulwood, J. (2019, April 10). Weed detection technology offers new approach. Ground Cover. https://groundcover.grdc.com.au/story/6009959/no-place-to-hide-for-in-crop-weeds/

Global Agriculture. (n.d.). Industrial agriculture and small-scale farming. https://www.globalagriculture.org/report-topics/industrial-agriculture-and-small-scale-farming.html

Groeneveld, R. (2020, March 19). SwarmFarm goes global with agricultural robots. Future farming. https://www.futurefarming.com/Machinery/Articles/2020/3/SwarmFarm-goes-global-with-agricultural-robots-552240E/

Holcombe, W. T. (2018). SwarmFarm Dock and Refill [Unpublished doctoral dissertation]. The University of Newcastle Australia.

Integrated Fuel Services and Solutions. (n.d.). Dry Break Fuel Nozzle & Check Valve Reciever [Photograph]. Banjo Products. ("Banlaw products," n.d.)

Just Water Pumps. (n.d.). Davey 5165HE Honda electric start firefighter pump. https://justwaterpumps.com.au/davey-5165he-honda-gx200-electric-start-firefighter-pump-flow-700-lpm/

Kale, B. (2014, May 1). This is the boom system of refueling. The fighter jet is an F-22 [Photograph]. Popular Science. https://www.popsci.com/story/technology/aircraft-automatic-air-refueling/

LEWA GmbH. (2018). Reciprocating positivedisplacement pumps: Technical basics and applications. https://www.lewa.com/fileadmin/5_competence/2_whitepapers/Whitepaper_Reciprocating_positive_displacement_pumps.pdf

Lewis Australia. (n.d.). Mobile Automated Fluid Transfer System [Photograph]. Mobile Automated Fluid Transfer System. https://www.lewis.com.au/project/automated-fluid-transfer-system/

Lewis Australia. (n.d.). Mobile fluid transfer system. https://www.lewis.com.au/project/automated-fluid-transfer-system/

Lowder, S. K., Skoet, J., & Raney, T. (2016). The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Development, 87, 16-29. https://doi.org/10.1016/j.worlddev.2015.10.041

Mackenzie, C. (2020, May 4). Refueling fighter Jets mid-flight is complex, but new tech from Airbus could simplify the process. Popular Science. https://www.popsci.com/story/technology/aircraft-automatic-air-refueling/

Neales, S. (2020, January 18). How a farm in remote Queensland became a high tech AI hub. Australian Financial Review. https://www.afr.com/technology/how-a-farm-in-remote-queensland-became-a-high-tech-ai-hub-20200116-p53s5f

Nufarm, & Monsanto. (2011, March 25). Roundup® Herbicide by Monsanto: Directions for use. https://www.herbiguide.com.auLabelsGLY36_31393-54214.PDF

Poly Camlock Type B - Male BSP Thread [Photograph]. (2020). Irrigation Box. https://www.irrigationbox.com.au/poly-camlock-type-b-male-bsp-thread

Poly vs steel vs fibreglass vs concrete water tanks. (2019, March 6). Tank Shop. https://www.tankshop.com.au/articles/poly-vs-steel-vs-fibreglass-vs-concrete-water-tanks/

Polyethylene water tanks | Rainwater tanks direct | Water tanks blog. (2018, June 19). RainWater Tanks Direct. https://rainwatertanksdirect.com.au/blogs/about-polyethylene-water-tanks/

Pump Fundamentals. (2019). Centrifugal pump system tips, do's and dont's. https://www.pumpfundamentals.com/centrifugal-pump-tips.htm

Rain Again Tanks. (n.d.). Industrial Tanks [Photograph]. https://www.rainagaintanks.com.au/newpage

Ritchie, H. (2017, October 3). How much of the world's land would we need in order to feed the global population with the average diet of a given country? Our World in Data. Retrieved May 25, 2020, from https://ourworldindata.org/agricultural-land-by-global-diets

Rosales, M. A. (2016). An F/A-18 Hornet uses a "probe-and-drogue" system for refueling in 2016 [Photograph]. Popular Science. https://www.popsci.com/story/technology/aircraft-automatic-air-refueling/

RS Components Pty Ltd. (n.d.). RS PRO steel alloy compression spring, 98mm X 18mm, 3.19N/Mm. https://au.rs-online.com/web/p/compression-springs/0121270/

Scotts Automation + Robotics. (2016, May 12). Mining Technology - Robofuel - Automated Robotic Refuelling [Video]. YouTube. https://www.youtube.com/watch?time_continue=27&v=heCwHb-rgCk&feature=emb_logo

Scotts Automation + Robotics. (n.d.). Productivity gains with Robofuel: Automated Refuelling. SCOTT - Automation + Robotics » Robofuel. https://www.scottautomation.com/assets/Resources/Robofuel-Brochure-English.pdf

Selecting the right pump. (2019, August 28). Mid-South Ag. Equipment. https://shop.midsouthag.com/blogs/tips-tricks/selecting-the-right-pump

Sprigg, S. (2019, April 18). Why rotational moulding of poly water tanks is a big deal. Welcome - Coerco Agriculture. https://agriculture.coerco.com.au/agriculture-blog/why-rotational-moulding-of-poly-water-tanks-is-a-big-deal

Sprigg, S. (2019, April 18). Why rotational moulding of poly water tanks is a big deal. Welcome - Coerco Agriculture. https://agriculture.coerco.com.au/agriculture-blog/why-rotational-moulding-of-poly-water-tanks-is-a-big-deal

Steel vs concrete vs fibreglass vs poly tanks. (2018, August 30). npiwpadmin. https://www.nationalpolyindustries.com.au/2018/06/15/steel-vs-concrete-vs-fibreglass-vs-poly-tanks/

SureFire Ag Systems. (n.d.). QuickDraw Spray Tender System. https://www.surefireag.com/product/quickdraw

Tankulator - Tank materials > price Comparision. (n.d.). Tankulator. https://tankulator.ata.org.au/tank-materials-price-comparision.php

CHAPTER 8 – Appendices

10.1. APPENDIX ONE – PROJECT SPECIFICATIONS

ENG4111/ENG4112 Research Project

PROJECT SPECIFICATION

FOR:	Matthew Burge
TITLE:	SwarmFarm Robotics Dock and Refilling Station Module
MAJOR:	Mechanical Engineering
SUPERVISORS:	Dr Craig Lobsey William Holcombe, SwarmFarm Robotics
COMMUNICATION:	Fortnightly zoom conferences with Dr Lobsey to begin with, then weekly as things progress. Emails throughout the weeks as needed. Communication with SwarmFarm via Mr Holcombe via phone calls and emails as needed. Project discussion stage marked on schedule.
ENROLMENT:	ENG4111 – ONC S1, 2020 ENG4112 – ONC S2, 2020
PROJECT AIM:	To continue the research and development of a coupling and associated actuators and control systems, developing a module that enables SwarmFarm's SwarmBots to autonomously dock and refill with chemical.
PROGRAMME:	**VERSION 3 – 25th March 2020**

1. Analyse previous dissertation on topic and research/tests conducted by SwarmFarm. Identify areas of weakness in original system and coupling design.

2. Discuss with SwarmFarm and establish requirements relating to location and style of refill method, and accuracy of the positioning of the robots at a refill point.

3. Review and evaluate potential fluid couplings suitable for chemical and autonomous application.

4. Review and evaluate potential solutions for robotic refilling (system).

5. Identify a suitable coupling and automation approach that satisfies requirements (e.g.refill style / positioning accuracy, environmental protection e.g. dust). Develop a conceptual design for onboard and external systems for refilling the robot.

6. Develop preliminary design and models of a robotic filling system.

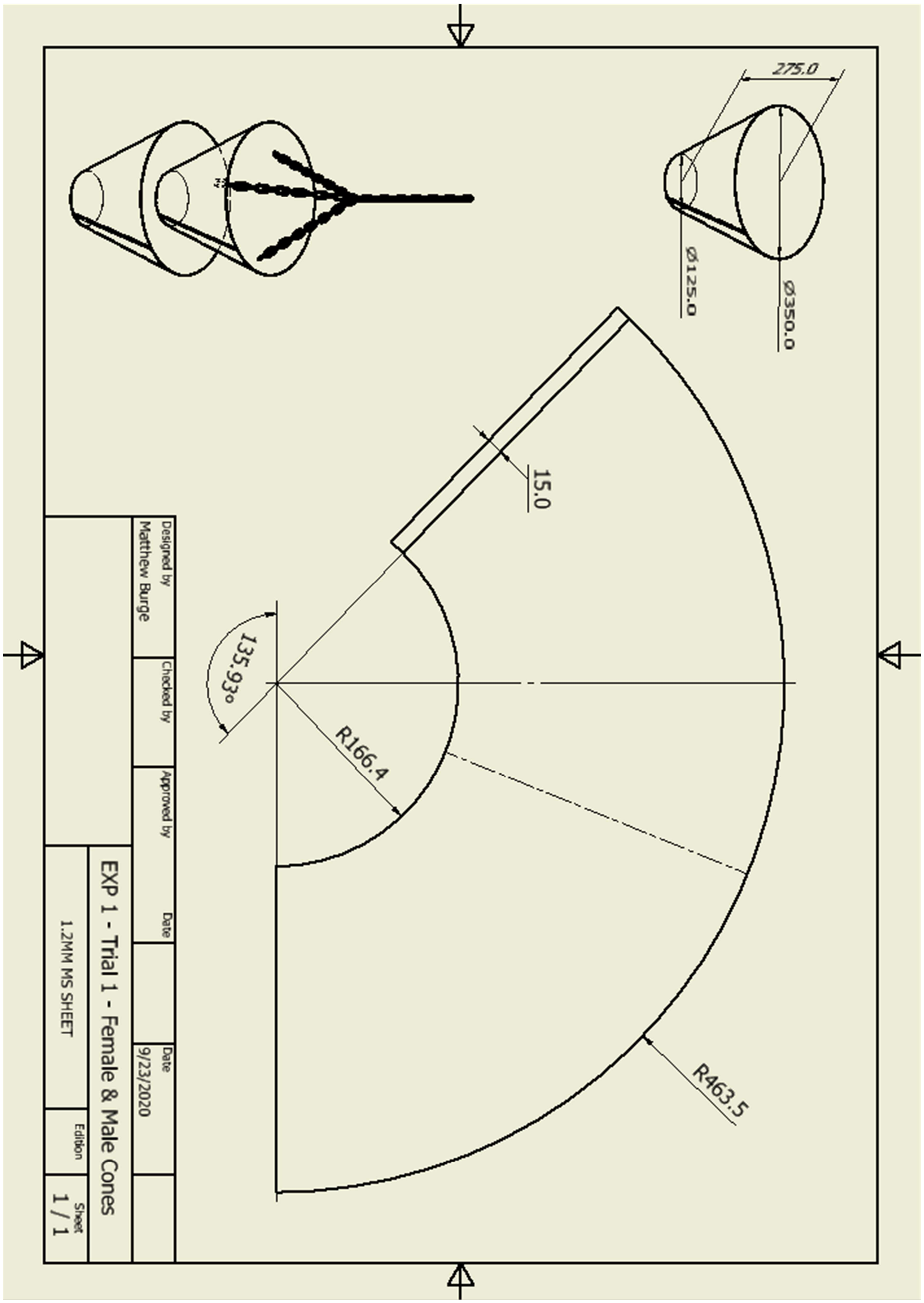
7. Evaluate the performance of the design against requirements using modelling/simulations or prototyping as appropriate.

If time and resources permit:

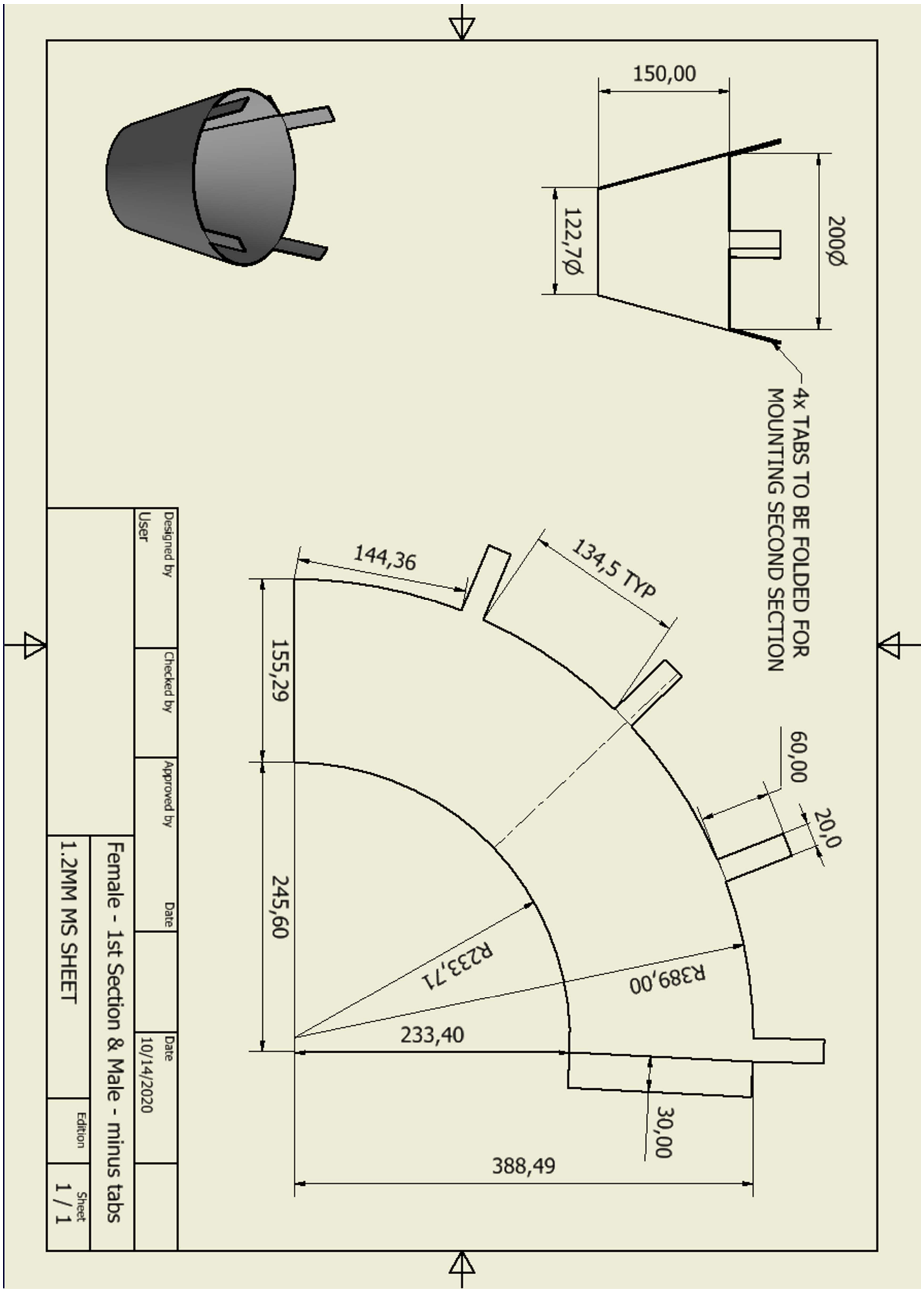
8. Acquire and test several of the shortlisted couplers, along with prototypes of alternative designs. Select best design based upon criteria set by self and client (SwarmFarm).

9. Build and test prototypes of the components of the robotic system for proof of concept functionality

10.2. APPENDIX TWO – TRIAL 1 CONE FLAT PATTERN



10.3. APPENDIX THREE - TRIAL 2 MALE CONE & 1ST FEMALE SECTION FLAT PATTERN



10.4. Appendix four – Trial 2 2nd female section flat pattern