Group Teal of PBL 12
Teal Team Six
Hawken Engineering Building
Saint Lucia, QLD, 4067

May 28th, 2021

The Director of the DFES
The Department of Fire and Emergency Services
Parliament House
Parliament Dr, Canberra ACT 2600

Dear Sir or Madame,

Attached is a copy of the report commissioned on the 11 of May 2021 relating to the development of an unmanned fire fighting vehicle to be used in the event of an aircraft emergency at Brisbane airport. The main findings of the report are:

- The best design to use is a 180-degree pan and tilt nozzle driven by a manual 4-wheel drive chassis.
- The ideal material to use for the construction of the chassis is aluminium.

Manual controls can be expected to be more consistent in comparison to automation based on the low budget preventing the group from acquiring high quality sensors and computer controls. The reliability of the fire vehicle will be crucial in saving lives, as it ensures that people will get help without the risk of computer failure.

Aluminium ensures the fire fighting vehicle will be durable yet lightweight allowing the vehicle to manoeuvre efficiently as well as have a large load bearing capacity. Furthermore, aluminium has a high heat resistance which allows it to get into proximity with the fire, shortening the distance the water must travel thus maximising efficiency.

Teal Team 6 would like to offer their gratitude to the Department of Fire and Emergency Services for allowing our company the opportunity to design an unmanned fire fighting vehicle (UFV). We personally ensure the design and execution of the fire fighting vehicle will achieve the requirements outlined within the project brief. If you are uncertain or have questions regarding the design, please contact the undersigned.

Yours sincerely,

Group Teal of PBL 12
Mitchell Dykes
Ethan Chai
Hana Abdelhameed
Charlotte Watts
Jay Hunter
Riley White

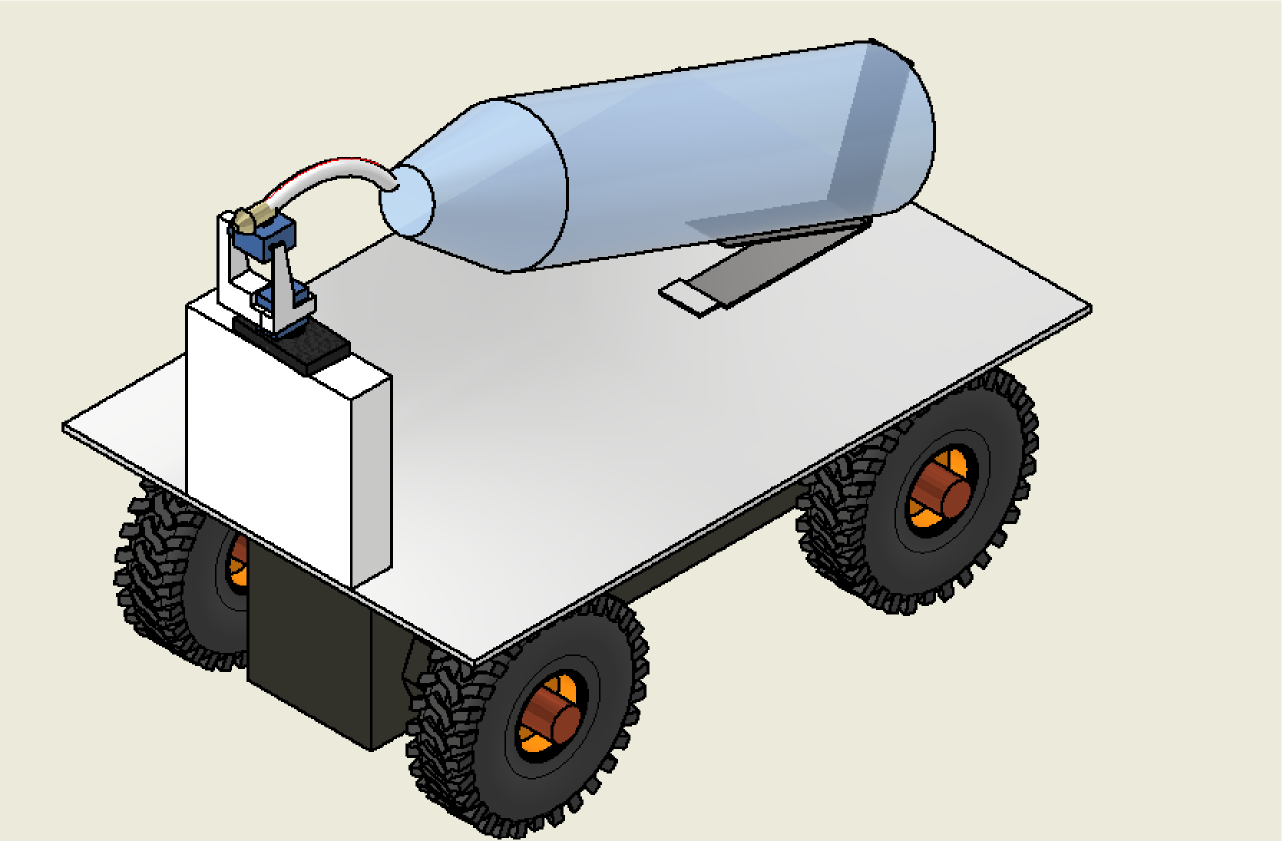


Figure 1: Model of the Unmanned Fire Fighting Vehicle

Unmanned Fire Fighting Vehicle

University of Queensland EAIT Faculty
ENGG1100 PBL 12
Team Teal Six
Due Date: 28/05/21

Group Members:
Mitchell DYKES - 4696710
Ethan CHAI - 46992475
Hana ABDELHAMEED - 4640464
Charlotte WATTS - 46983781
Jay HUNTER - 45776182
Riley WHITE - 46991142

Executive Summary

The quality of firefighting resources is a vital safety measure for airports. They need to protect aircraft, infrastructure, and human lives. Over the last decade, the increasing technological advancements of aircraft equipment such as turbines, avionics and battery storage has increased the complexity of protecting people and assets from danger. Consequently, the need for faster, more efficient firefighting equipment has never been more important. Teal Team Six were commissioned to design an unmanned firefighting vehicle (UFV) for the remote extinguishing multiple fires following an airport emergency.

In this report, a design for an unmanned firefighting vehicle is presented to reduce the injury and casualty of Fire Officers in the event of an emergency. Efficiency of both response to incidents and the removal of hazards is a second key goal of UFVs. These design considerations are in line with the goals of the Australian Aviation Rescue Fire Firefighting Service (ARFF) and the design presented is to be evaluated and considered primarily by this stakeholder. Design constraints given by the ARFF are as follows:

1. The UFV must be able to drive forward and backward at a variable rate, whereby it is easily controlled either through autonomous or manual operation. (Drive Subsystem)

2. The UFV must have a fluid subsystem entailing the storage of water, pressurisation of water through a pump, which is then directed by a nozzle to aim and shoot water at a variable velocity and in effect cool down the heat sources. (Fluid Delivery Subsystem)

3. The UFV must have a method to operate the drive subsystem and the fluid delivery subsystem to an extent which satisfies the criteria and is either fully automated or elements of manual control (Control Subsystem).

4. The design of the UFV must be able to support the various subsystems including the drive subsystem, the control subsystem, and the fluid delivery subsystem. (Structure Subsystem) (Aminossadati 2021).

The constraints restrict the overall dimensions of the UFV to be 300x200x300mm. The UFV must also weigh less than 3kg, including 1 litre of water, and cost less than $150AUD. The lightweight nature of the UFV enables it to manoeuvre quickly thus decreasing response time. The lower production cost allows for a high supply of UFVs in the event of a major incident requiring multiple units, or where multiple units requiring repair or replacement.

The final design and construction of the presented prototype UFV contain numerous recommendations for future improvements. These improvements relate to more complex environments, compared to the testing arena, a full-scale UFV will be operating in. Insights into the heat resistance of each subsystem will be able to determine points of weakness. The control system will utilise Wi-Fi connectivity compared to the concept's Bluetooth. Incorporating all components including screws and washers should be considered. Investigations into improving the pan and tilt kit will improve the accuracy of the water stream

Table of Contents

Table of Tables

Table of Figures

1.0 Introduction

1.1 Abstract

Potential dangers to firefighting personnel to cause injury or death amid extreme emergencies are ever present from heat exhaustion, falling debris, explosions, gas leakage or smoke inhalation. In 2020, a total of 96 firefighters lost their lives whilst being on call in the US (Carrey, 2021). With the number one cause being overexertion leading to sudden cardiac death (National Fire Protection Association, 2021). Substituting firefighters with unmanned firefighting vehicles (UFV) removes the potential for overexertion, thus establishing long term solutions to minimising fatalities. This report will detail specifications and subsequent applications of a remote operated robot to extinguish fires without direct human intervention. UFV's allow for greater benefits to personal safety, the capability to transport firefighting equipment closer to dangerous zones without subjecting personnel to harm as well as being able to be rapidly deployed. By establishing a systematic overview of the firefighting vehicle's structure, control system, drive system and fluid delivery, the ground vehicle will be able to efficiently put out fires.

1.2 Stakeholder needs

The Australian Aviation Rescue Fire Fighting Services (ARFF) is responsible for responding and managing real or possible aircraft emergencies at 27 locations around Australia. The ARFF has excess of 1000 support and operational personnel which are able to respond in less than 3 minutes of an initial report (Aminossadati 2021). The stakeholder prioritises the rapid deployment of a large quantity of firefighting equipment. Thus, the UFV will be lightweight yet powerful enough to carry twice its weight in water. The ARFF also requires the design to be affordable by establishing innovative solutions to reduce costs, ensuring UFVs can be efficiently mass produced on scale.

1.3 Design objectives and criteria

The primary objective of the task is to design an unmanned firefighting vehicle to be used in an airport emergency event.

Table 1: Objectives and Criteria of the Report

Criteria	Objective	Technical Consequence
Lightweight	Needs to be able to be maneuverer quickly with 1 litre of water, which will be most of the weight.	The materials for construction are required to be light whilst also being able to support a high payload.
Affordable	The UFV needs to be affordable yet utilise high quality parts to ensure it will work effectively.	The UFV will require innovative solutions to maintain low costs. I.E. Using a water bottle as a storage container for the water.
Rapid deployment	To ensure the quickest most efficient response time. The UFV is required to be fast and agile.	The design should be lightweight, and the drive system must be able to propel the vehicle rapidly both forward and back.
Large water capacity	The UFV must put out 6 fires at multiple locations from various distances.	The tank storing the water must be sealed to stop water leakage and hold the 1 litre of water.
Energy efficient	Batteries cannot exceed a 13-volt rating.	Each system must use little energy.

1.4 Contents of the Report

Section	Aim
Introduction	A general introduction to the report. Outlining the objectives, aims, scope, assumptions, and the contents of the report
Technical Understanding of the Subsystems	This section provides a technical understanding of the various subsystems including the fluid delivery, drive, structure, and control subsystems. The section encapsulates the various nomenclature, calculations and reasoning necessary to provide a conclusion about the respective components.
Design Approach	A detailed explanation of the process of completing the UFV and its array of subsystems. It entails the various complications during the design process and any deviations from the expected result of components used
Design Analysis	Provides a justification of the materials, mechanisms, and components within the respective subsystems of the UFV. Subsequently, the justification provides insight into the reasoning and various design choices that resulted in the finalised subsystem.
Reflection	A reflection of the overall process and methodology during the entire period of the production of the UFV, whereby the complications and successes are documented and justified.
Conclusions and Recommendations	Concludes the results and findings of the project and recommends any future adjustments or remodelling of the manufactured UFV system.

1.5 Project aims

There are several project-aims that relate to the social, environmental, economic, and technical aspects of the design. These can be seen below in *Table 2*.

Table 2: Project Aims

	Aim
Social	The social aim is to design an unmanned firefighting vehicle which is able to be rapidly deployed and efficiently extinguish fires. The UFV will save lives, reuniting passengers with families in the event of an aircraft emergency.
Environmental	The vehicle design aims to be environmentally sustainable. This is achieved by reusing recyclables and sustainable materials as well as being powered by a battery in convention to diesel powered trucks.
Economical	The design aims to reduce economic costs on the vehicle's construction. This is achieved by utilising innovative solutions and establishing a design that does not waste materials. Each component of the UFV will be evaluated to ensure its functions directly improves the overall efficiency. Limited functional components are substituted with more affordable replacements.
Technical	The UFV design will be technically sound, therefore it will be able to efficiently carry the weight required without struggling or collapsing. This is achieved by utilising lightweight materials, spreading the load over the axles, and removing unnecessary components. Furthermore, the UFV will also undergo vigorous testing to ensure the design is able to hold 3kg.

1.6 Timing with Gantt

The Gannt chart contained in *Appendix 6* shows the optimal times each subsystem was to be finalised and tested. The final weeks of the Gannt Chart were not followed in development of the system due to a multitude of delays. Due to these delays, as a team we decided to incorporate a drive system from a remote-control car in our own design. This decision, while ensuring we could complete the project, caused further delays as the overall structure and placement of subsystem elements needed to be overhauled. These delays prevented the preferred amount of testing of the UFV. Despite this, the UFV was finalised and presented. A resolution to prevent this issue in future projects is presented in the reflection section of this report.

1.7 Constraints

The Australian Aviation Rescue Fire Fighting Services (ARFF) is commissioning the construction of an unmanned firefighting vehicle to be used at various airports around Australia. The final design presented addresses the aspects considered in scope for the ARFF's needs.

Table 3: Scope Outline

In scope	Out of scope
Sourcing materials	Transportation of the UFV to the disaster location, such as the optimal route.
Budget	Sourcing workers to maintain and potentially help pilot the UFV
Design and material testing	Storage of UFV
Detailed design for the full-scale model	Repairing the UFV because of a problem that is not related to a faulty design or construction. Such as if the arena breaks
Appropriate instructions for the deployment of the UFV	Delivery to client
Adhering to the design dimensions and requirements. Such as being less than 300mm x 200mm x 300mm.	Analyse into the various options and the best outcome for the components of the scaled-up UFV
UFV components	Finalised pricing of the manufactured, scaled-up UFV
UFV sub systems	
Repairing any damage due to faulty design or construction	

1.8 Assumptions

Serval assumptions were developed and utilised for the design and development of the prototype UFV. These assumptions can be seen in *Table 4* below.

Table 4: Assumptions

Assumption	Explanation	Justification	Effect of Justification
Outside temperature	The heat sources will not be affected by the weather or temperature outside. Weather conditions are optimal. (i.e., the temperature of the fires will remain consistently at 150 degrees)	Assumption allows for the conclusion that any deductions in the temperature of the heat sources are directly due to the UFVs ability to put out fires.	Within the scope of our project, this assumption allows for an easy and effective way to assess the specificity of the UFV However, not considering environmental factors and how they can impact the effectiveness of the firefighting vehicle's ability may cause issues when scaling up. This needs to be considered in the Scale-up considerations
Water remains at same temperature	The water is at ambient temperature (i.e., approximately 25 degrees Celsius).	Constant temperature allows for an easy analysis into the change of the heat source's temperature.	Any change in the temperature of the heat source is due to the UFVs ability to put out the fire rather than the change in temperature of the water
Testing arena is accurate	That the machine will accurately signal when the fire is put out at 100 degrees Celsius.	Allows for the accurate calculation of the quantity of water used when extinguishing fires.	The tanks will hold the correct quantity of water to complete the required tasks and limit the chances of wasting water.
Accurate design specifications	The appropriate specifications for each part of the UFV are accurate.	Assumption allows for ease in calculations	Upon assuming this, the data can be analysed with ease as these specifications are in place.
Assume that the UFV can only carry 1 litre of water	When creating the tank and fluid delivery system we assumed that the maximum water load is 1 litre.	Constraints on the design of UFV were used and assumed to be the only requirements. Therefore, we are unaware as to how well the current model will perform with greater water storage.	The clients may require greater flexibility in terms of water storage. This will mean another analysis into which pump, fluid structure and delivery system will have to be undertaken; there is no knowledge currently into how a greater water storage size will affect the pump's ability or the flow rate of the water.
Thermal conductivity is 155 W/m.k	The heated puck is assumed to have a theoretical value of 155 W/m.k for thermal conductivity	The thermal conductivity of the heater source has not been tested or calculated. Hence, this value is assumed to be correct for all 6 of the heat sources	Any thermal dynamic calculations that are calculated based on this assumption are predictions assuming this value is accurate for thermal conductivity.
Heat source is consistently maintained at 150 degrees Celsius	All six of the heat sources are at a constant temperature of 150 degrees Celsius for the entire six minutes	Heated sources are electrically controlled to be set at this specific temperature	All temperature changes to the heat source are as a result of the water reducing it and not any variations in the heater source itself

2.0 Technical Understanding of the Subsystems

To ensure a unified UFV design was developed, the multiple subsystems incorporating the holistic prototype were investigated and designed before the final assembly. The system is divided into the four main subsystems identified by the Functional Layout shown in *Appendix 1*, and then further into components. After deliberation, Team Teal collaborated to produce the functional decomposition tree shown in *Figure 2*.

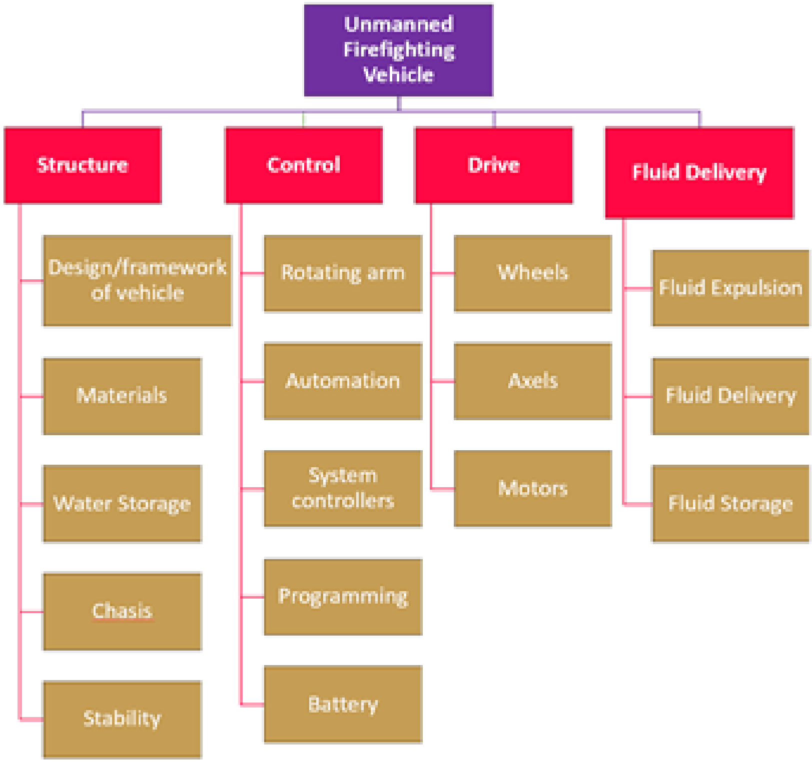


Figure 2: Component-level Functional Decomposition Tree

2.1 Drive

An in-depth analysis into the most optimal options for the wheels, axles and motor were undertaken. This prior research demonstrated the subsystem requirements that needed to be met to reach the outlined design specifications. The option to 3D-print these specific parts was chosen as the most beneficial. The initial alternatives considered for the main driving force component of the drive subsystem were a plethora of different motor options entailing the use of either a DC, brushless DC, AC, stepper motor, or a servo motor. As such, the DC motor was the most appropriate solution with regards to the design and objective constraints provided by the stakeholders. This was due to it being relatively lightweight, cost effective and sufficient in propelling a maximum 3.5kg system. Assuming the max weight would be 3.5kg, the minimum torque at the wheel required would be around 11Nm in which the DC motor would be ample enough force to propel the UFV (White, 2021). Through a piecewise-matrix comparison, 3D printed gears were the optimal material when considering steel, 3D-filiment, and premade gears. This option was chosen as its capacity to change the teeth and overall size of the gears and thus its adaptability and ability to gear it towards the required torque and RPM at the wheels is greatly enhanced.

2.2 Structure

The structural subsystem of the unmanned firefighting vehicle is divided into two components. *Figure 3* below, shows the functional layout and decomposition of the structural subsystem.

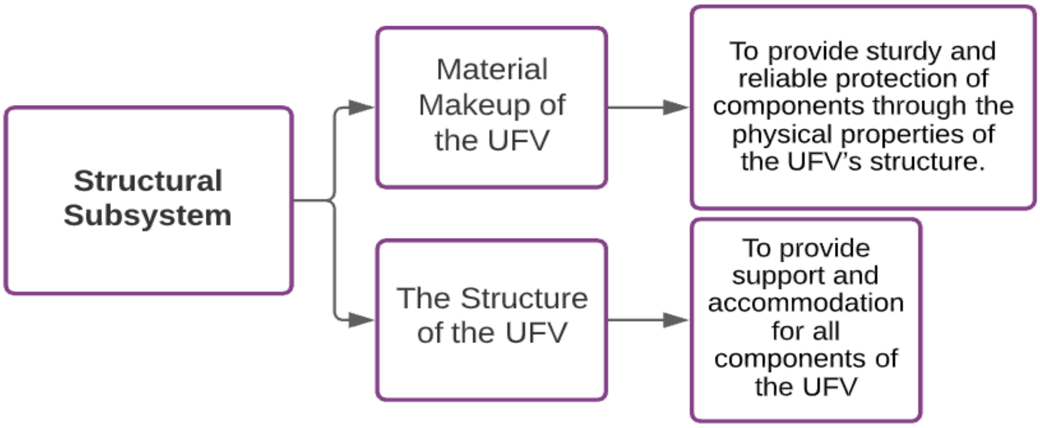


Figure 3: Functional Layout and Decomposition of the Structural Subsystem

2.2.1 Chassis Design of the UFV

The chassis of a vehicle must be strong enough to accommodate and protect the components of that vehicle (Jha et al., 2015). Acknowledging this and the project scope, an analysis was done on the varied chassis designs and two possible designs were found: the ladder chassis and the monocoque chassis designs. The ladder frame chassis design by which two long rails are connected by multiple smaller rails (Muthyala, 2019), excel in both durability, manufacturability, and low cost. However, it increases weight and provides weak torsional rigidity. The second design, the monocoque chassis, is designed to be both the structural framework and hull of the car (Muthyala, 2019). Its advantages are its stability due to its low centre of mass, durability, and high torsional rigidity. However, it is expensive and extremely heavy (Rangam, 2020). A decision-making matrix and sensitivity analysis by Chai (2021) comparing the two chassis designs, shown in *Appendix 4*, against the conditions of size, durability, weight, cost, and manufacturability was conducted and the ladder frame chassis proved to be the better choice.

2.2.2 Material makeup of the UFV

According to Jha (2015), the vehicle chassis needs to be strong and light. After conducting some research, four different materials were found and analysed. These are aluminium, plastic, magnesium, and steel. Aluminium and magnesium are both lightweight metals. Magnesium however is 33% lighter but low in mechanical strength (Pooyan, 2015). Though aluminium is heavier, it is superior to magnesium in terms of durability and tensile strength (Ismail, 2013). For the material polyethylene or plastic, it is a relatively common material used for building the chassis of remote-controlled vehicles. It has low cost, high tensile strength, and is extremely light (SpecialChem, n.d.). For the material steel, it provides the greatest strength but also the most weight (Muthyala, 2019). Due to the mass constraints of the UFV and low requirements of durability of the chassis, steel was disregarded. A decision-making matrix and sensitivity analysis by Chai (2021) compared these four materials against the conditions of cost, weight, durability, and flexibility, and found that plastic was considered the best material. However, it was suggested that aluminium may be the better choice due to its superior strength and lightness as the plastic's strength may not be suitable for the UFV's chassis and project scope.

2.3 Fluid Delivery

The fluid delivery system was divided into three subcomponents that were identified on the bases of functionality. The diagram in *Figure 4* depicts the subcomponents of this subsystem. Together in conjunction, these three components create the fluid subsystem.

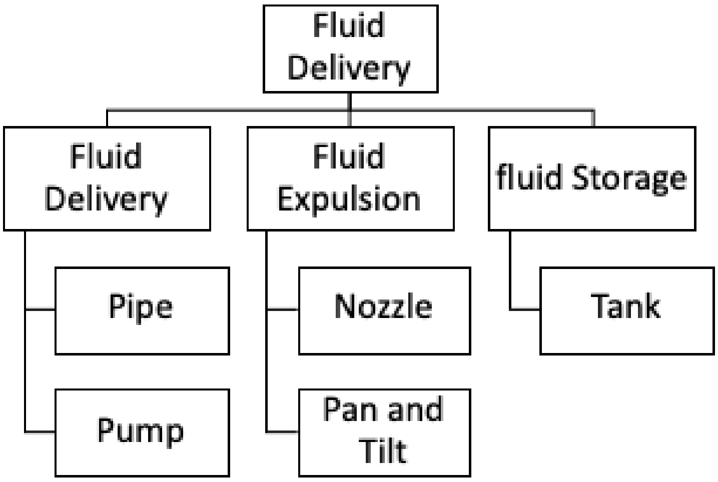


Figure 4: Defined Subcomponents of the Fluid Delivery Subsystem

2.3.1 Fluid Expulsion: Nozzle

Analysis into the different nozzle heads displayed that the spinning tooth nozzle was the best option for firefighting. This nozzle contains stainless steel teeth lining the inner circumference of the nozzle head. "[These] are built to withstand harsh fire ground conditions rendering it resistant to change" (Abdelhameed, 2021). This allows for the added benefit that if there is any damage to the nozzle, the spray pattern would not be affected. Although this nozzle head is a great option for firefighting, it has many properties that are not desirable in terms of the scope of the UFV. Firstly, it is made entirely of stainless steel which is a heavy metal. Considering the 3kg weight constraint this nozzle would not be feasible. Moreover, the spinning tooth nozzle is large, increasing the complexity in developing a system that supported this nozzle. Therefore, considering the scope of this project the hollow nose nozzle was the best option as it met the requirements needed without breaching weight and cost specifications.

2.3.2 Fluid Delivery: Pump

After conducting initial research, two possible pump types and two possible functions were determined: centrifugal or positive displacement, and submersible or non-submersible (Smith, 2021). Two viable options for the UFV were then considered: Option A was a submersible, centrifugal water pump and Option B a non-submersible, peristaltic, positive-displacement water pump. After deliberation with engineering literature and principles, Option A, the submersible centrifugal pump, was chosen.

Prior engineering literature emphasized the importance of their pump having "minimal power consumption" as well as "high effectiveness" (Aliff et. al., 2016). Given their pump was 6V, this was determined the most desirable voltage. A similar project to this made use of a centrifugal pump because of its constant flow rate instead of the pulsing flow rate produced from positive displacement pumps (Rakib & Sarkar, 2016). The reliability of Option A was thus improved. The low cost and weight of Option A was more desirable over its more expensive and heavier counterpart, Option B. Finally, the flow rate displayed by Option B was only 0.15L/min, below the minimum calculated flow rate required of 0.33L/min (Watts, 2021). Thus, the submersible centrifugal water pump in Option A was determined as the more desirable pump.

2.3.3 Fluid Storage: Tank

Two primary options were considered for the tank. Option A consisted of using foam board to create a cubic tank positioned upon the chassis of choice. Option B was a litre PET water bottle that was modified to allow for connection of the pump wires to the electrical circuits as well as inclusion of a port for ease of filling the tank with water. Preliminary evaluation of these options revealed that both produced similar results regarding the desired design criteria; however, Option B was chosen as most satisfactory due to its light weight and ease of accessibility (Watts, 2021). Although Option A performed better when considering the environmental sustainability design criteria according to engineering literature, the weighting of this factor was deemed lower than that of reliability and weight (PETRA, 2015). As such, Option B was chosen due to it being deemed more reliable than the foam board tank and displayed a weight of 20g compared to Option A's 280g.

2.4 Control System and Power Delivery

The initial design of the control system was one cohesive electrically self-contained unit. Development of the system conveyed numerous faults with this, outlined in the design approach and design analysis. As such, the recommendations made in the final concept report were ignored in the design as they were no longer applicable to the requirements needed for a safe and homogenous system.

3.0 Design Approach

As to develop a fluid delivery subsystem that worked cohesively, components were chosen to optimise the capacity of water, the weight, the trajectory, and the pressure. In theory, choosing components that maximise these properties should create the best design for the project. However, when optimising one property, another may be affected negatively. Therefore, compromises need to be made for the benefit of the system. Coming up with a holistic design was not easy as each member of the group had already chosen components irrespective of one another. Bringing these individual parts together was thus challenging. The piping was bought to fit the chosen pump; however, the pipe was too thick for the nozzle head. Due to the large piping, the rotation abilities of the pan and tilt for the nozzle was affected. Our range of motion was limited, which affected the UFVs efficiency in aiming at the targets.

One of the main issues faced when creating the fluid subsystem was the formation of the tank. After analysing the two different options set, a unanimous decision to use a water bottle was decided. To develop the water bottle into a functional tank for the UFV, there had to be a way for the tank to be filled up without compromising the integrity of the tank. Therefore, the top part was cut to allow for detachability. This allowed for the water to be poured in, the top of the bottle to be secured back into place and therefore the tank to be secure in terms of water leakage and storage. A hole was created in the bottom portion of the water bottle to allow for the wiring to connect from the pump to the electrical boards. Since the pump chosen is submerged in water, but the wiring cannot come in contact with fluids, the hole and wiring was sealed with a hot glue gun.

After these modifications were complete, it was noticed that the tank proved inefficient in holding the required 1L of water. Thus, a 1.5L plastic bottle was used instead, and modified as such. This version proved much more effective in containing the required quantity of water; however, further problems arose with the tank's effectiveness. Leakages occurred at multiple stages during the final weeks of development, causing major concerns for the control subsystem and led to the inability to properly test the UFV on the rigs due to water damage. After minor alterations were made to the tank to properly seal it with hot glue and duct tape, it was able to efficiently function. The final design of the tank is further explained in Section 4.4 and shown in *Appendix 2*.

Furthermore, the control system was redesigned three separate times due to failure or safety concerns. The final design of the control system considers each main component of the control system as its own subsystem. These subsystems are isolated from one-another to prevent unnecessary short circuiting and allow for more simple upgrades and replacements of that subsystem. Though this increased the cost and complexity of the control system, the major increases in safety of the system were immense. As an example, if the second design were implemented, the use of the motor would cause the batteries to explode during operation and possibly kill the Arduino UNO in the process.

4.0 Design Analysis

4.1 Overview

As a team we came together and collectively collaborated on creating a fully functional system. Each member contributed knowledge that they had accumulated for their subsystem and assisted in the production of a cohesive prototype.

4.2 Structure

The purpose of the structural subsystem was to accommodate and protect the components of all other subsystems. Therefore, durability, stability and sturdiness of the vehicle was prioritised, as well as the objectives and constraints of the project.

Different chassis designs like the monocoque and ladder frame chassis were considered as a viable design choice of the unmanned firefighting vehicle. However, concerns were raised regarding the complexity and difficulty in manufacturing or modifying these designs. If successfully manufactured, its integrity and effectiveness would be up for debate. While the ladder frame chassis was considered the most ideal, like the monocoque chassis, its potential usefulness for the performance test in addition to its increased costs, weight and strenuous manufacturability, other designs were explored. Therefore, the platform chassis was implemented as the final chassis design. It provides a flat even surface which allows easy accommodation of components, in addition to its simplistic design for easy manufacturability and adjustability. Although it provides less structural support and strength when compared to the ladder frame chassis, the project scope doesn't require high amounts of durability as the vehicle is tested in a controlled environment where external damage of the vehicle is of lower priority and stability of greater priority. Especially when considering the gaps introduced from the ladder chassis would create difficulties when placing the relevant components onto it, possibly reducing overall stability of the vehicle.

The chassis size was also modified in accordance with the changes made with the tank and other additional components added. The initial 160mm by 250mm length and width respectively, was extended to 160mm to 300mm. This was done to accommodate the components comfortably and easily in which the previous measurements failed to do so.

While the plastic material provided the best result according to the decision-making matrix by Chai (2021), aluminium was chosen instead. This was because while polyethylene provided the least amount of cost and weight, its other attributes like durability and flexibility was poor. In comparison to aluminium which excelled both durability and flexibility, and coming second to low mass, aluminium was considered the better choice.

4.3 Drive

The drive subsystem criterion consisted of it being along a linear axis; it was also required that the subsystem is lightweight; was able to propel the UFV with 1kg of water; and must have fit in with the overall budget of the UFV. Time constraints and other extenuating circumstances caused the team being unable to complete the 3D printing. Instead, the base and wheels were derived from a child's toy car and alterations were made in order to align with the objectives of the UFV. This included the linear requirement of the drive subsystem which was achieved through modifying the original drive system to suit the UFV's design constraints. Furthermore, the subsystem originally had a mechanism, whereby it allowed for the change of axis of the UFV and was not required by the stakeholder's outlined objectives and thus was removed from the system to remain along the same axis. Additionally, the wheels were sourced from the child's toy car and were the most cost effective in regards to a drivetrain for the UFV. The motor used was a 12V DC motor which surpassed the required torque to push the UFV system, however the motor could burn out over time due to the stress placed on the brushes inside of the motor and as the current increases, the speed and torque also increases along with the risk of failure due to burn out. Therefore, the stakeholder's criteria and requirements were met through the various implemented components within the drive subsystem.

4.4 Fluid Delivery

After designing and redesigning the fluid delivery subsystem multiple times to ensure maximised efficiency, water capacity, weight, trajectory and pressure, the final fluid delivery system was created. This final design was still comprised of the plastic water bottle for the tank, the hollow hose nozzle and the horizontal submersible centrifugal pump initially chosen; however, some adjustments were made to optimise the performance of this subsystem.

The tank was tested to carry a minimum of 1 litre of water; however, it may potentially be able to carry beyond this amount, reaching a maximum water storage of 1.2 litres. This poses the added benefit to the client as they will not be limited to the one litre constraint in instances of fire emergencies. As for the technicalities and specifications of the pump itself, it was theoretically able to produce a maximum flow rate of 120L/min; however, when measured in preliminary testing the pump was producing a flow rate of roughly 25L/min. According to calculations conducted previously, the minimum required flow rate is 0.34L/min, meaning it can be concluded that, assuming the water is fired accurately and in a timely fashion, the fires will be extinguished within the required timeframe (Watts, 2021). The pump is predicted to use between 3 and 6 volts of power, drawn from the batteries included in the control subsystem.

As such, via consistent reviewing and adjusting the components throughout the development of this subsystem, the needs of the client and stakeholders were met and exceeded, with the final system able to perform all required tasks effectively and efficiently. The completed models of the fluid delivery subsystem can be seen in Appendix 2.

4.5 Control System and Power Delivery

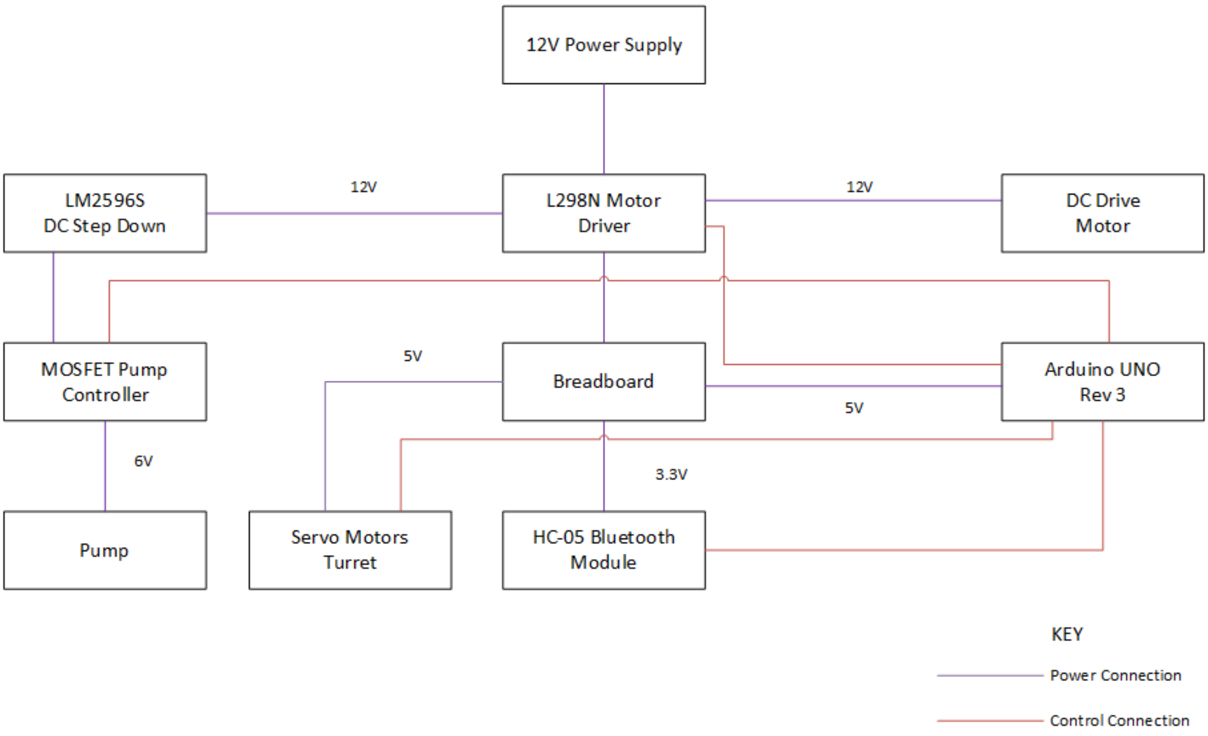


Figure 5: Diagram of Power and Control Connections

The control system is designed to be controlled either wirelessly through Bluetooth or wired through a USB Type-A cable. The system takes 12V total from 8 AA batteries connected in series. Power is consistently delivered to the HC-05 and the Arduino UNO, the other subsystems receive power through a *two-factor* system. This system prevents short circuiting from water spilling by keeping each subsystem isolated from each other. This is achieved through utilising the features of the Arduino UNO and L298N Motor Driver. The Motor driver does not deliver power without receiving a signal from the Arduino. The Arduino also sends a signal to the sub-system in use. If either of these connections are damaged, nothing happens. This isolation design also allows for more efficient replacements or upgrades of circuit elements and the testing of them. The code developed to operate the UFV is located in *Appendix 5*.

The system can be tested without the use of the 12V power supply through the following steps:

1. Remove wire from Arduino UNO's Vin port and place it in the 5V port.
2. Connect the Arduino UNO to a computer.
3. Send command through the Arduino IDE's Serial Monitor

5V may not be strong enough to fully run a certain sub-system, but an LED will indicate a successful connection of both voltage and command signal. Each system has their own. This was developed to mitigate risk of injury or further system damage when diagnosing issues caused by either damage or improper wiring of the system.

4.6 Technical Design Drawings

Technical design drawings for the UFV were all composed in Inventor. *Figure 6* displays a diagram of the completed prototype UFV. For detailed diagrams of other components, see *Appendix 2*.

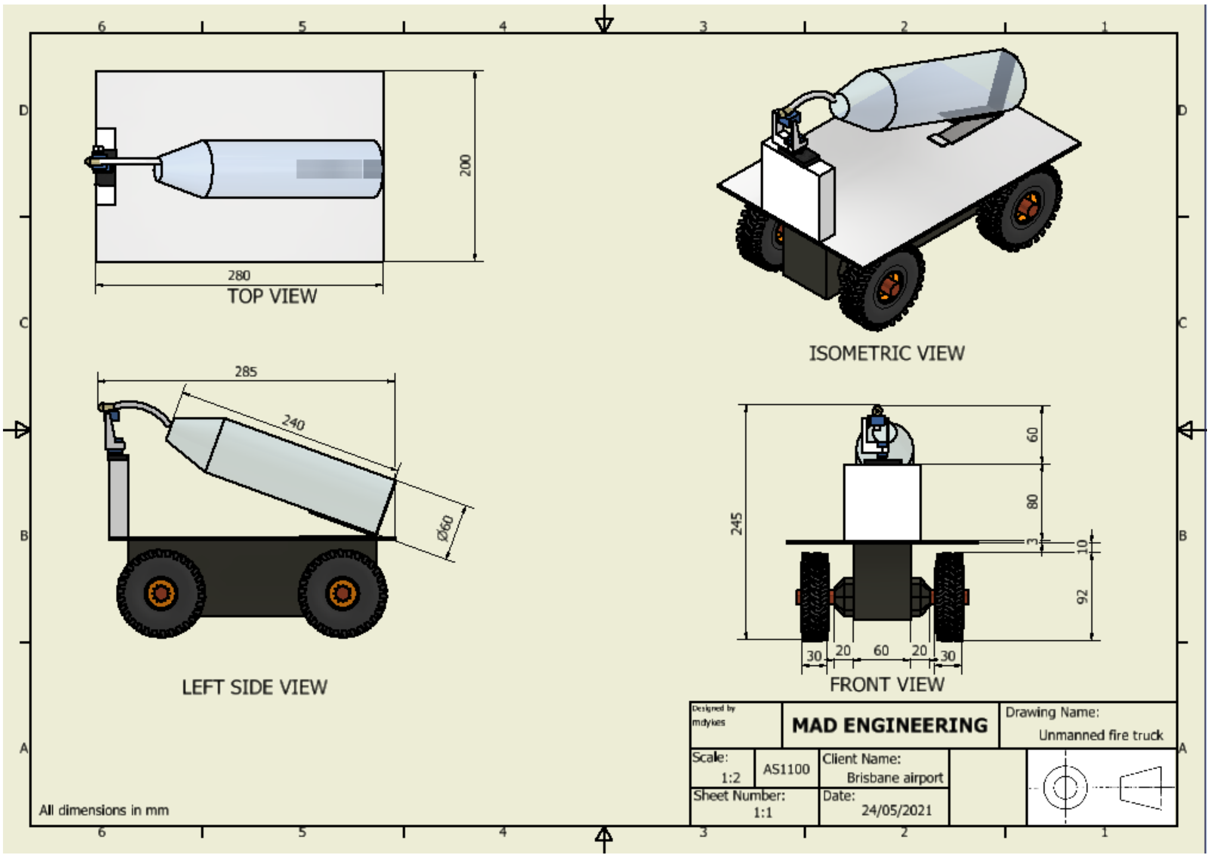


Figure 6: Inventor Models of the Completed Unmanned Firefighting Vehicle

4.7 Life Cycle Analysis

The Life Cycle Assessment regarding the sustainability of this Unmanned Firefighting Vehicle is shown below in *Table 5*.

Table 5: Life Cycle Assessment

Materials and Inputs	
Raw materials required for the UFV	• Aluminium (for chassis) • High impact nylon and polycarbonate (RC car) • Rubber (wheels) • PET plastic (water tank) • PVC plastic (piping) • HDPE plastic (pump)
Indirect Inputs for the UFV	Transportation of materials, material processing to make plastic, moulding the plastic to make the pump, piping and tank by melting. Manufacturing the aluminium sheet. Synthesis of the rubber material, moulding into the tyre shape.
The positive and negative sustainability impacts of the materials required to create the UFV	Positive: Reusing materials where possible, using an eco-friendly method to melt down plastic, use of an environmentally friendly metal such as aluminium. Negative: Utilising machines that expel polluting wastes such as toxic fumes from melting down the plastic.
Use	
Any potential sustainability impacts (positive or negative) during the operational phase of the UFV's lifespan	Breakdown of the plastics used, such as the PET plastic tank. Erosion of the rubber wheels during use.
End-of-Life	
Identified end-of-life scenarios for the UFV ranked from most likely to least likely to occur.	1. Melted and developed into other materials or objects. 2. Melted into a UFV again. 3. Litter – put in landfill.

4.8 Failure Mode and Effect Analysis

The Failure modes and effects analysis will allow us to define, identify, prioritise and then eliminate known or potential failures within the scope of the unmanned Firefighting vehicle. The UFV has many components within 4 larger subsystems. Due to the nature of the risk associated with each individual component the resolution of the FMEA is very specific, focusing on a component level. The focus must also be defined for our FMEA. Our focus is on a combination of different areas that hold equal weighting of importance to our project. Safety is of high importance, as is functionality. The aim of the project is to create a UFV that works according to the specified aim safely.

Table 6: Failure Mode and Effect Analysis table

Hazard	Failure Mode	Causes	Consequences	Risk Priority Rating				Mitigation	Risk Priority Rating			
				Sev	Prob	Det	RPN		Sev	Prob	Det	RPN
Tanks	Tank not made securely so water leaks from openings	Poor manufacturing of the tank	Short circuits electrical boards if water gets into contact with it	4	2	1	8	Create tank out of non-permeable material so as to ensure no water leakage. Using centre of mass principles create a physically stable structure	4	1	1	4
	Tank not secured to chassis. Instability leads it to tipping over and falling	Poor choice of glue or other binding strategy										
	Tank tips over and pump is no longer submerged leading to the system operation failing	Instability of tank	Pump Stops									
Stability of Chassis	Material not strong enough to withhold the mass	Aluminium chassis too thin to be able to withstand the mass	Structure collapse	3	2	1	6	Increase thickness of chassis	3	1	1	3
Pipes	Piping unfastens itself from connecting components	Rapid movement of UFV causes piping to move	Water flow no longer continuous and hence it does not reach the nozzle. Cannot put of fires	2	3	2	12	Add extra material to secure piping	2	2	2	6
Battery	Wiring of battery	Not attached correctly	No current	2	1	2	4	Test with DC voltage to check if wired correctly	1	1	1	1
Material not able to withstand heat	Melting of metal	Materials sensitive to heat	System stops operating	4	2	2	16	Create a 'lid' like structure that goes over the main body of the UFV protecting the inner components from any external risks. Also adds aesthetic appeal	2	1	3	6
	Plastic melting	Piping too close to the heat source target										
	Electrical boards overheating	No proper insulation to protect systems from external heat sources and internal overheating										

Weights are defined in *Appendix 1*.

Analysis of the FMEA table indicates that the last hazard, the ability of the material to withstand the heat, poses the greatest risk to the system in theory. However, in the scope of our project the materials chosen are of lower flammability. Moreover, the heated targets are highly concentrated in area and hence the UFV cannot heat up to an extent that may damage the vehicle. This risk may pose a greater impact on the scaled-up version of the firefighting vehicle.

Therefore, the greatest risk imposed on the UFV is the water from the tank coming into contact with the electrical circuits. Mitigation techniques must be in place to prevent this from occurring.

4.9 Scale-up Considerations

The drive system would need to be entirely redesigned to avoid copyright infringement, be capable of stabilising and moving a larger weight, and provide the ability to turn. This would provide the ability to protect the control system more safely from damage in the design.

As for the pump component of the fluid delivery system, a larger and sturdier pump would need to be investigated to allow for the larger quantity of water and increased flow rate required to adequately extinguish fires in a scaled-up vehicle. The pump would still be required to be centrifugal as to maintain a constant flow rate and work most efficiently at the required pressure. After preliminary research, a Rosenbauer normal-pressure centrifugal pump would prove suitable for a scaled-up UFV. The efficiency and low-pressure surges evident in this pump would ease strains on the nozzle whilst effectively performing the required flow rates of around 750L/min and can reach 11,000L/min if required (Rosenbauer International AG, 2021).

The control system would require a Raspberry Pi 4 2GB, with SX1272 LoRa Shield and a Raspberry Pi Camera Board V2. This would allow for the UFV to be controlled long-range from the airport control tower and allow the operator the ability to see what the UFV sees. These additions would not increase the voltage requirements of the system but would decrease the battery lifespan.

5.0 Reflection

As the development of the drive system was continually delayed and because of time constraints, the drive system for the UFV became a deconstruction of a commercial remote-control car for children. This delay and decision had numerous negative effects on the testing and capabilities of the final UFV design. The motor utilized is a small 12V motor, designed to quickly move the light plastic shell casing the product originally came with. The torque of the motor is not strong enough to move the UFV when its total mass exceeds 3.5kg. As the total mass of the UFV with 1L of water contained is 2.5kg, it is possible to drive the unit. Despite it being capable of doing this, the lifespan of the motor is drastically reduced. As this lifespan is currently untested, the total lifespan is unknown but would be under 60hrs of use.

Another issue that comes from this choice and others during development was the lack of time the control design had to be tested and fine-tuned for the UFV's control system. The UFV is split into two halves, the bottom and the top. The top consists of the tank, the turret, and the MOSFET all attached to an aluminium base. The bottom consists of the RC drive system with the designed control system replacing the commercial, attached to the top of it. A battery pack attached to the bottom of the RC drive system. And an Arduino UNO attached towards the back of the UFV on the bottom of the aluminium sheet with the sheet and the RC drive system connected through drill holes. The control engineer was required to develop the bottom half of the system alone.

Though the control system had been developed prior to this, fitting it into a base that was not designed for it required time and planning. After a week of work, the bottom and base were finished, and the fluid delivery team could build the top half. By the time this was all complete, there were errors in the Bluetooth system that could not be amended in the remaining time. The backup USB-A design allows for the UFV to still be controlled for the demo. Further issues from this followed.

The tank design was ineffective in containing water causing leakage on the control system. This led to a two-day delay of testing. During this time, the team fixed the holes in the tank. On the second attempt, water was poured too quickly into the funnel to the tank causing a second spillage a day before the UFV was due for handing in. After a night to dry, the UFV, when tested, short circuits following the use of the pump. Without the time to retest everything, the UFV was 'finalized' with this major error.

Upon submission of the UFV, the tested vehicle was fully functional. The vehicle was able to move forwards and backwards, the pump would start up and propel water from the tank through the pipe and nozzle. Our only concern prior to Demo Day was whether the circuit had enough time to dry. Our team predicted a maximum threshold of 50% failure at worst. It was due to our previous testing that we were shocked to find out that when directed to shoot water on Demo Day, nothing came out. Our prior mitigation plan for unpredicted outcomes on Demo Day, seen in *Appendix 7*, did not assume a malfunction as significant as this one. After realising that the vehicle was no longer operating in this way, our team decided to risk the one-minute penalty and figure out if we could solve the issue. Initially, the thought process was that something had occurred to the wiring. A quick examination of the wires demonstrated that nothing had occurred to them, changing the vehicles functionality. We tried the vehicle again in the arena. Although there was no fault in the control system water the fluid delivery was no longer working. The pump would start up, which was indicated by a light sensor. It is because of this we deduced that all the systems were working properly, but the pump and pipe dislodged in storage. No other explanation can be warranted in this situation.

Due to the high stress our team was put under, we were unaware of the time. Our two-minute penalty meant that we exceeded our time limit. If we were to repeat this again, something we would have done differently is ended much earlier on. This experience demonstrated that unforeseeable circumstances occur and as a result we must be prepared to deal with these situations more effectively.

From our experience, it is clear a design is required to move water away from the circuitry in the event there is a leakage. The methods of storage and distribution need to be refined to ensure the UFV remains intact. Better communication is also required so that one team member is not left alone to work on half the build. This could include better documentation on how individual subsystems work so that all members are capable of understanding subsystems that are not their own. Team member also need to develop the confidence to build and test designs. Developing subsystem designs that fail is normal and part of the development process.

6.0 Conclusions and Recommendations

The results of testing the final UFV design have created the following recommendations:

1. Develop a system of draining water off the body of the UFV.
2. Redevelop the drive system to better support larger weights.
3. Redevelopment of the tank for ease of access to the pump and to carry a full 1L.
4. Upgrade the control system to allow for further control distances.
5. A better storage system for the UFV for shipping and warehousing purposes.

Recommendation 1:

The testing phase of development conveyed the glaring issue of removing water from the chassis. The initial leak from the tank, mistakes made filling the tank, and removing excess water from the tank all caused significant amounts of water to spill onto the chassis. This caused electrical failures when affected areas were activated. The two-factor system only works if an effected area is not utilised. The most optimal solution to prevent electrical failure due to water spillage is a drainage system on the chassis. This system would channel water off the body and better cover exposed electrical sections of the control system. This solution is novel and is recommended to be implemented immediately.

Recommendation 2:

Infringements on intellectual property aside, a full redesign and development of the drive system is required to better support the UFV's weight and increase longevity of the drive motor. It is recommended that this is implemented immediately.

Recommendation 3:

From the incident from storage, and the risk of water leakage during movement, it is clear the tank requires a redesign. This design must allow for the UFV to move at its top speed with a full tank without risking water spillage. It should also allow for a better ease of access to the pump and pipe contained within for replacement and maintenance.

Recommendation 4:

As the UFV will be controlled from large distances, it is recommended that the Arduino Uno is replace by a Raspberry Pi 4. This change will allow for the upgrade from Bluetooth to long-range Wi-Fi connectivity.

Recommendation 5:

The storage incident has made clear the need for a design to be developed that would better protect the UFV when shipped and not in use to prevent damage to the system.

Conclusion:

The founding design requirements for the UFV has been based upon material usage, associated costs, basis for sustainability, the ability to scale up and technical concepts. The utilisation of 3D computer modelling alongside an in-depth analysis of stakeholder requirements allowed for the initial acquisition of items which were able to be scaled up according to a full-size model. Supporting calculations with the 3D model depicts the cost efficiency of the design as well as its high load bearing capability. Further testing is required for the larger model to be completely aware of the performance.

Despite the final showcase of Team Teal Six’s UFV design being an undisputable failure, the information gathered from the development of the system and its final showcase allowed the team to consider recommendations other teams may not have considered. The UFV has been designed and developed with the intent on being upscaled, mass-produced and then distributed to airports across Australia for Australian Aviation Rescue Fire Fighting Services. The storage of the UFV for distribution was an unconsidered but vital system itself. The UFV needs to be operable from delivery. No matter how well developed a design may be, it is useless to stakeholders if it unreliable due to shipping damage.

The other recommendations, once developed and tested, would immensely improve the design of the UFV itself. Excluded the incident, the UFV would only be functional for the demonstration. As stated, the lifespan of the drive motor is likely short, and water is a persistent concern of failure. The demonstration does not require the UFV to direct itself left or right, only forward and back. A scaled-up version of this would require the ability to turn to be of any use in an emergency. Connectivity across long ranges also requires further investigation with the considerations of interference to and from already existing sensor and communications systems airports utilise.

References

Abdelhameed, H. (2021). ENGG1100 Concept Report.

Banggood. (2019). Peristaltic Dosing Head Pump. Retrieved from https://www.banggood.com/DC-6V-Water-Pump-Peristaltic-Dosing-Head-Pump-DIY-Dosing-Pump-p-1505755.html?cur_warehouse=CN&ID=532943&rmmds=search

UQ EAIT Department. (2021). Project Brief. In Project 2021: Unmanned Firefighting Vehicle: University of Queensland.

Khan Academy. (2015). What is Volume Flow Rate? Retrieved from https://www.khanacademy.org/science/physics/fluids/fluid-dynamics/a/what-is-volume-flow-rate

Aliff, M., Yusof, M., Sani, N., & Zainal, A. (2019). Development of Fire Fighting Robot (QRob). International Journal of Advanced Computer Science and Applications, 10(1). Retrieved from https://thesai.org/Downloads/Volume10No1/Paper_18-Development_of_Fire_Fighting_Robot.pdf

Machifit. (2018). Machifit JT80SL Water Pump. Retrieved from https://au.banggood.com/Machifit-JT80SL-DC-3-6V-Water-Pump-120LH-Ultra-quiet-Micro-Horizontal-Submersible-Mini-Water-Pump-p-1348608.html?utm_source=googleshopping&utm_medium=cpc_organic&gmcCountry=AU&utm_content=minha&utm_campaign=minha-au-en-pc&currency=AUD&cur_warehouse=CN&createTmp=1&utm_source=googleshopping&utm_medium=cpc_bgcs&utm_content=frank&utm_campaign=ssc-aug-all-1129&ad_id=400330096020&gclid=Cj0KCQiA-aGCBhCwARIsAHDl5x9vQTMkwmqnoi0rtp-oOXJ4SoBTZk75UtK64PtEd_BM2UJgTmv-8n8aAswcEALw_wcB

New Directions Australia Pty Ltd. (2020). Clear 1L PET Boston Round Bottle. Retrieved from https://www.newdirections.com.au/Clear-1L-PET-Boston-Round-Bottle

PETRA. (2015). Sustainability. Retrieved from http://www.petresin.org/sustainability-recyclability.asp

Rakib, T., & Sarkar, R. (2016). Design and fabrication of an autonomous fire fighting robot with multisensor fire detection using PID controller. Retrieved from https://dx.doi.org/10.1109/iciev.2016.7760132

Rosenbauer International AG. (2021). Truck-mounted pumps. Retrieved from https://www.rosenbauer.com/en/au/rosenbauer-world/products/fire-fighting-systems/truck-mounted-pumps

Smith, M. (2021). Useful information on centrifugal pumps. Retrieved from https://www.michael-smith-engineers.co.uk/resources/useful-info/centrifugal-pumps

Watts, C. (2021). ENGG1100 Concept Report.

Jha, K., et al. (2015). DESIGN AND FABRICATION OF RADIO-CONTROLLED CAR.

Muthyala, M. (2019). Design and Crash Analysis of Ladder Chassis.

Rangam, Kartik. (2020). *Types of Car Chassis Explained |From Ladder to Monocoque! https://gomechanic.in/blog/types-of-car-chassis/*

Chai, E. (2021). *Concept Report: Unmanned Firefighting Vehicle*.

SpecialChem. (N.d.) *What is Polypropylene and What It's Used for?* https://omnexus.specialchem.com/selection-guide/polypropylene-pp-plastic

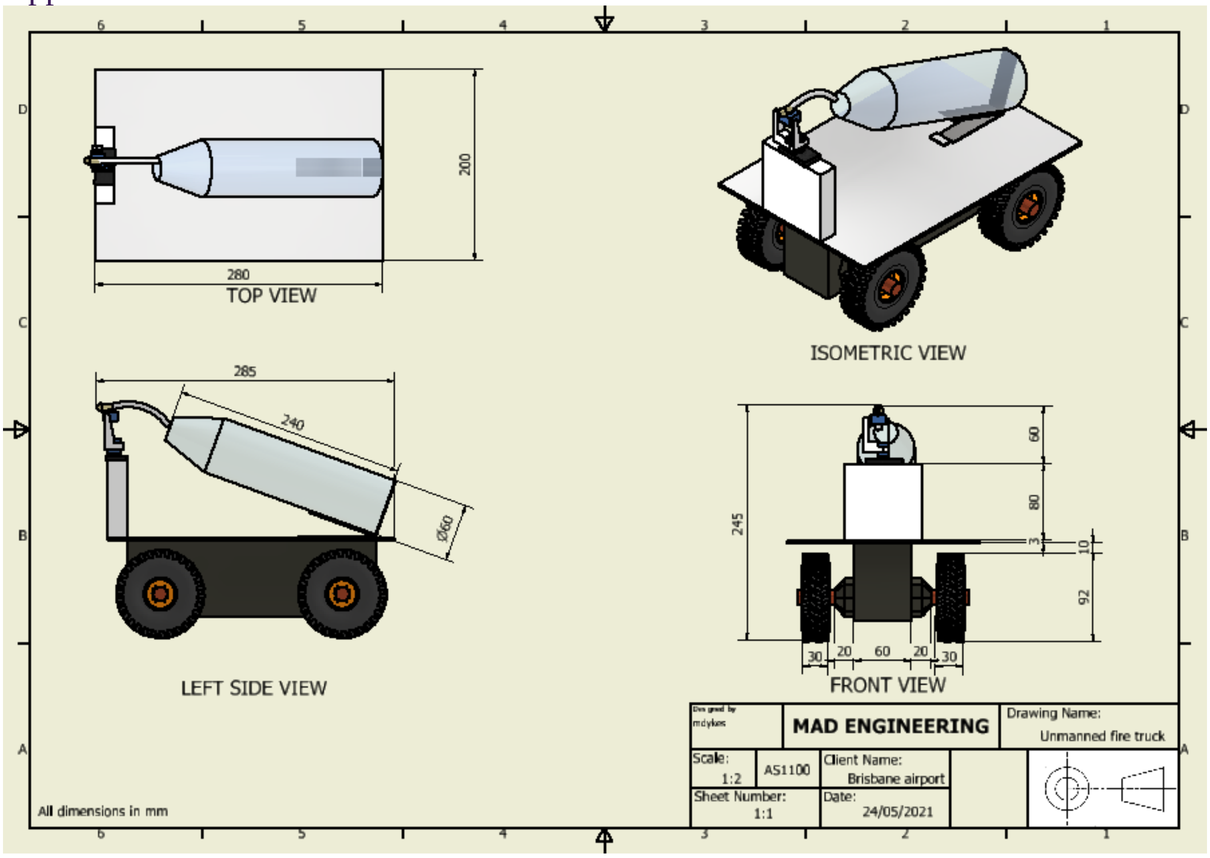
Nayyeri, Pooyan. (2015). *Materials for Automotive Body and Chassis Structure*. https://www.linkedin.com/pulse/materials-automotive-body-chassis-structure-pooyan-nayyeri

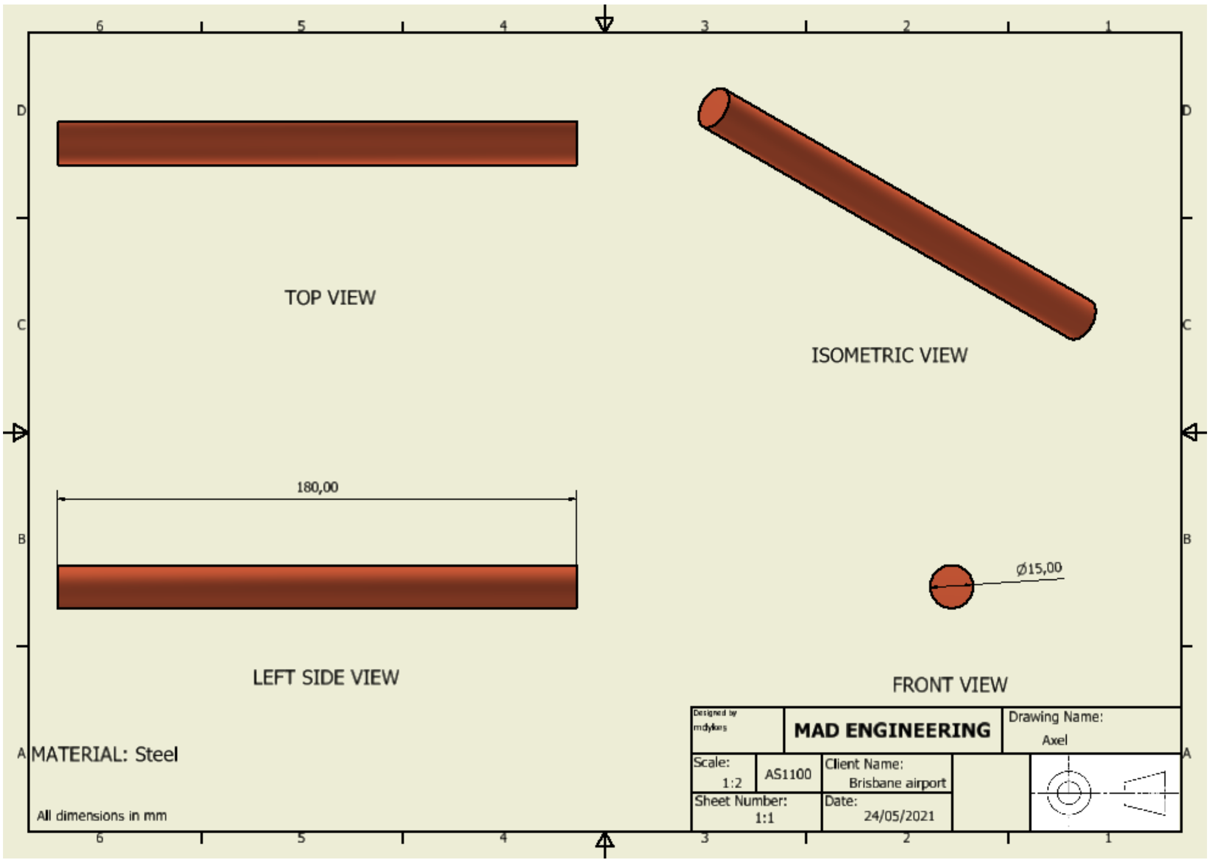
Appendices

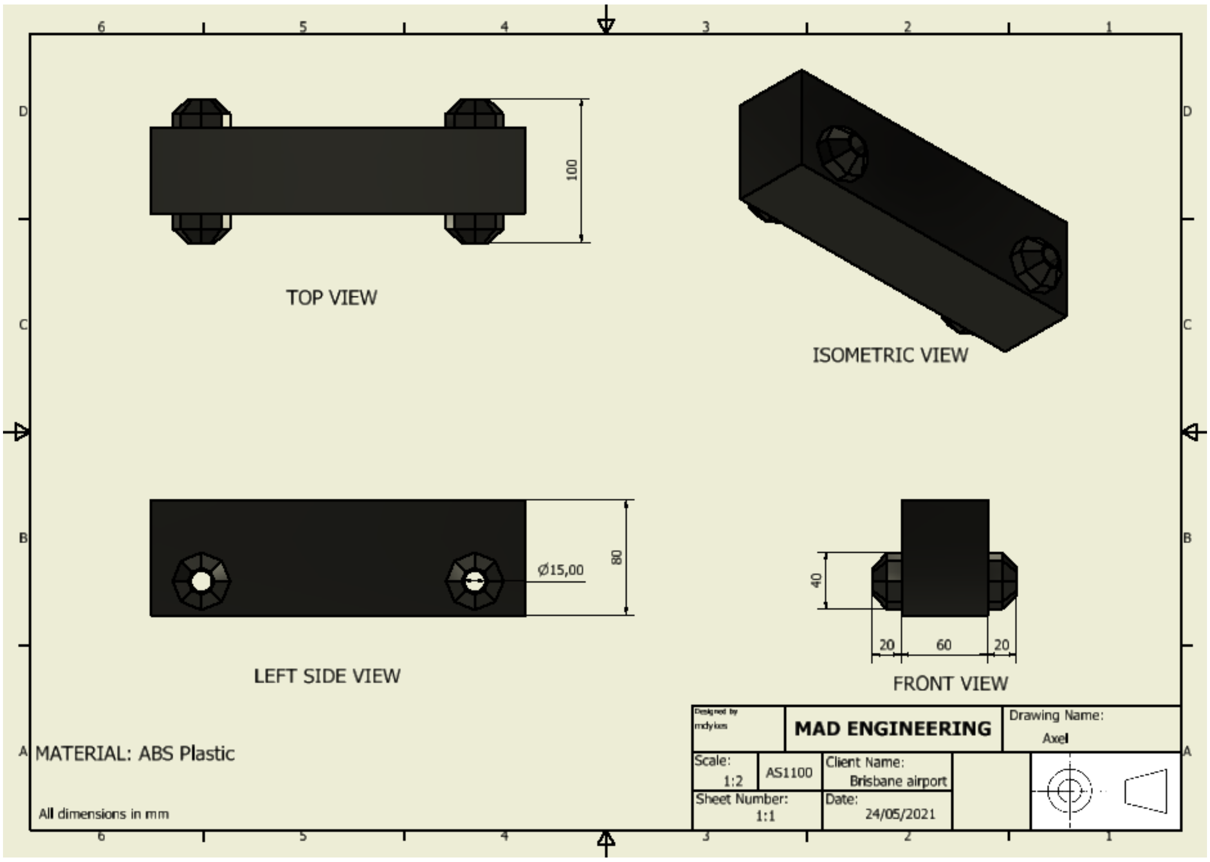
Appendix 1 – FMEA Weightings

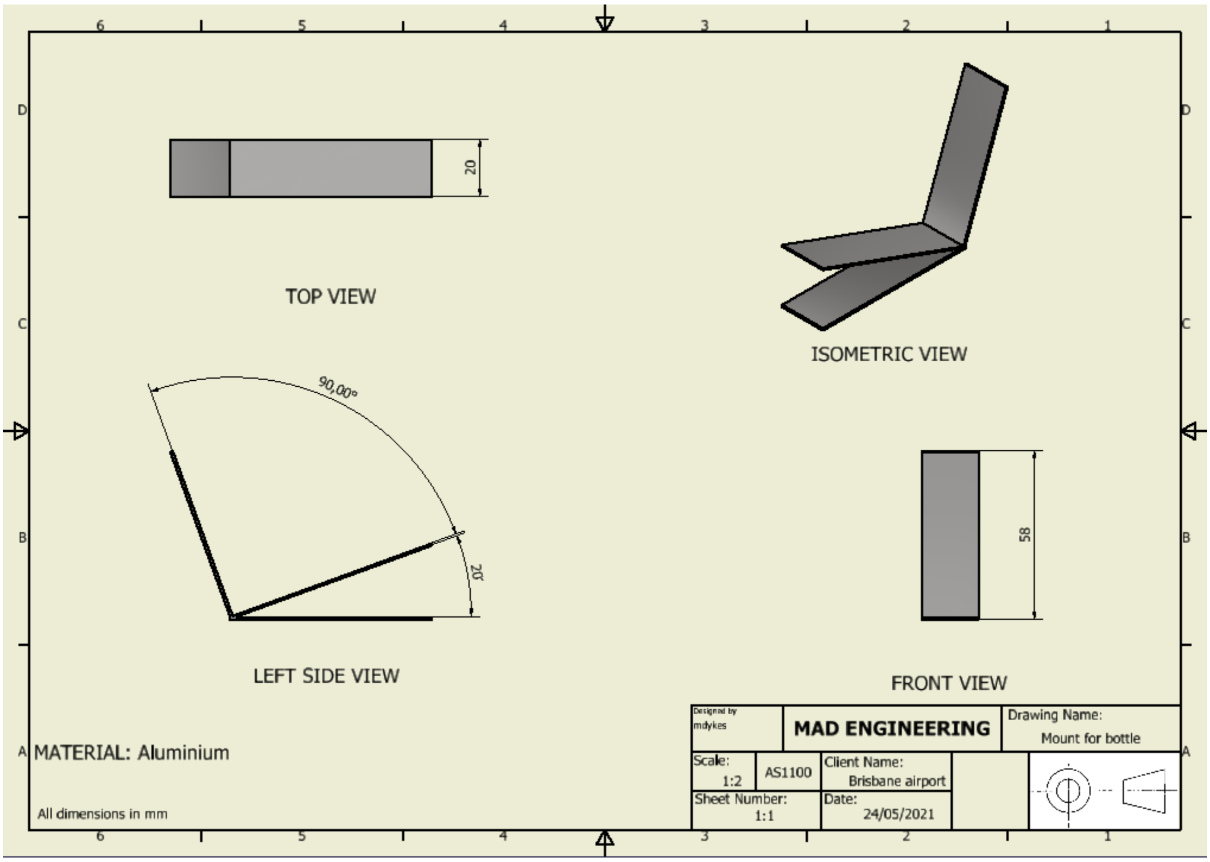
	Weightings		Definition
Severity	4	Catastrophic	Extremely severe consequences to both the system and individuals around it. (95% - 100% system failure)
	3	Critical	System is no longer functioning accordingly to the aim (efficiency of output is reduced by 40%)
	2	Marginal	Risk of severity is not that high. (efficiency of output is reduced by 20%)
	1	Negligible	No threat detected (minimum 5% impact of total output and functionality)
Probability	4	Expected	Will most likely occur immediately
	3	Occasional	75% chance of occurrence
	2	Remote	>50% chance of occurrence
	1	Improbable	>10% chance of occurrence
Detection	4	Impossible	Impossible to detect
	3	Possible	<50% chance of detection
	2	Likely	<75% chance of detection
	1	Certain	100% chance of detection

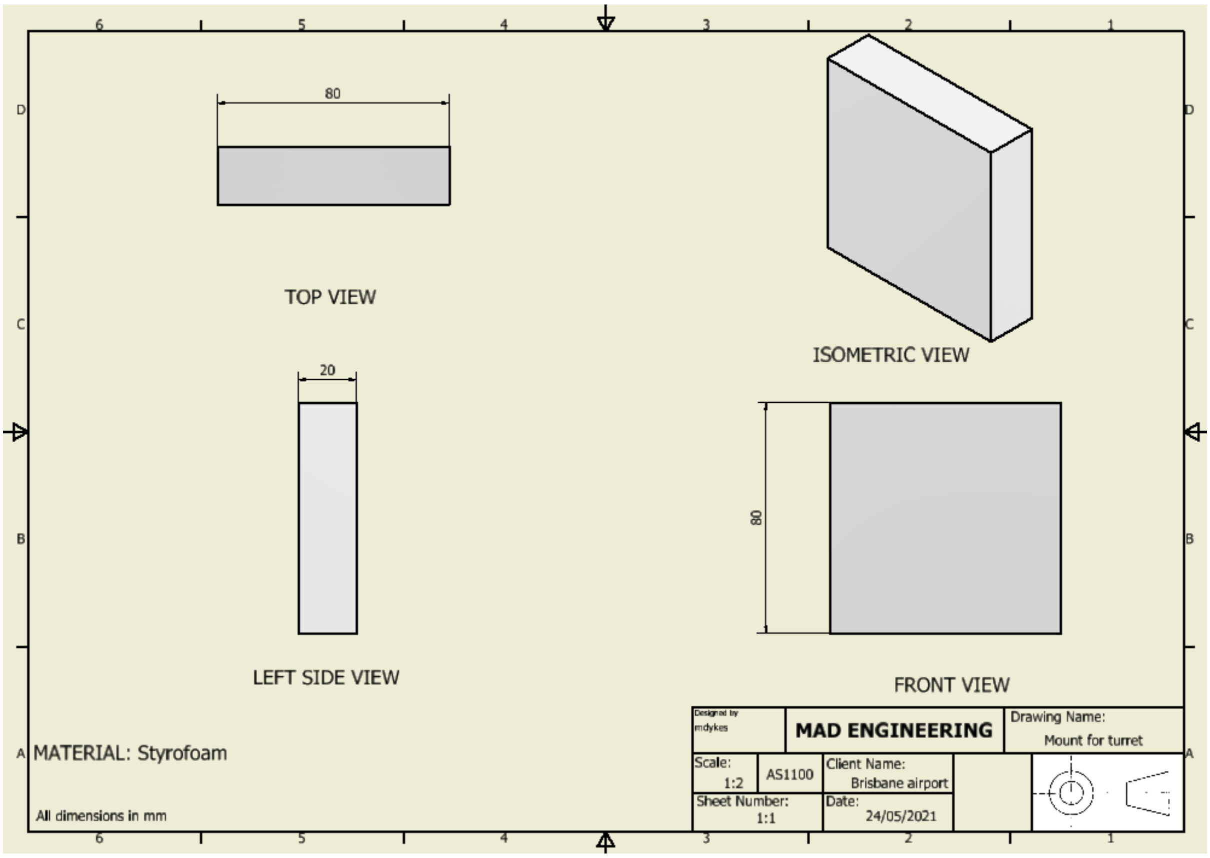
Appendix 2 – Inventor Models

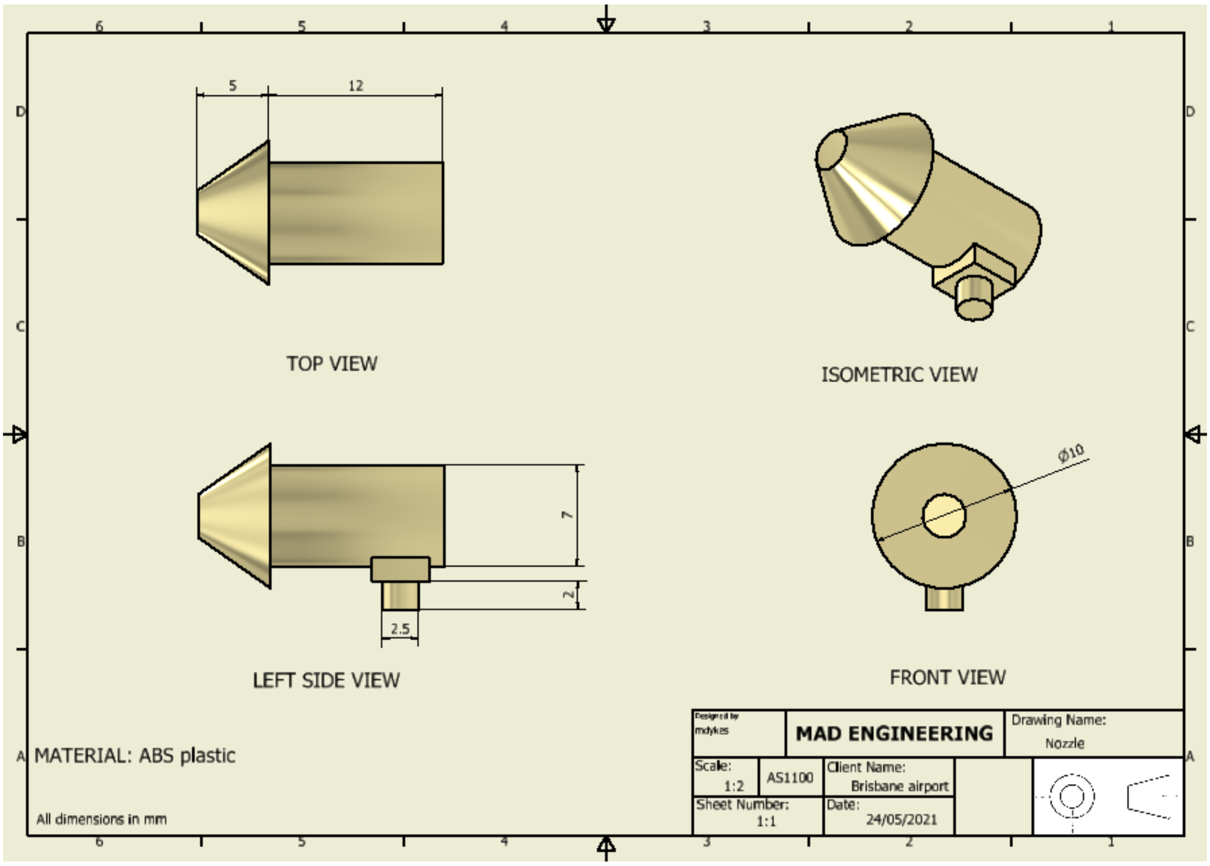


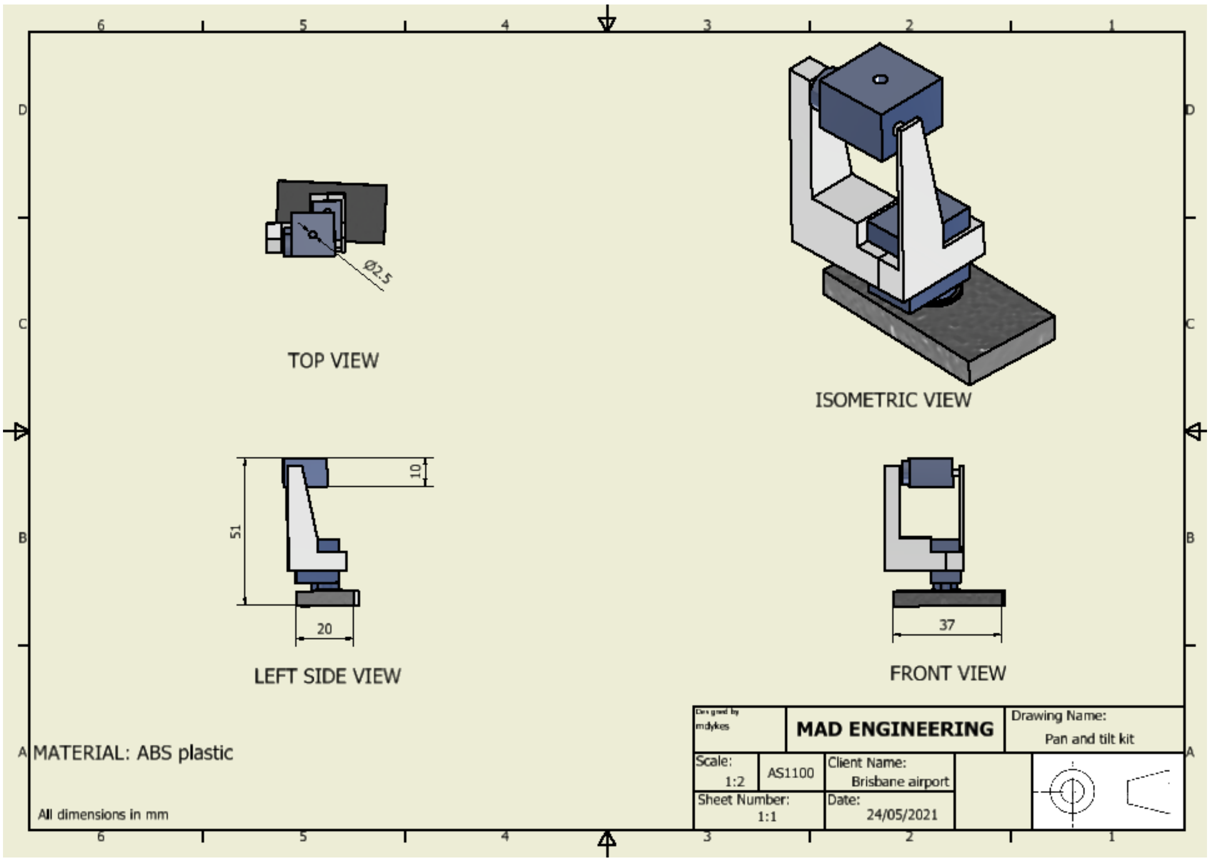


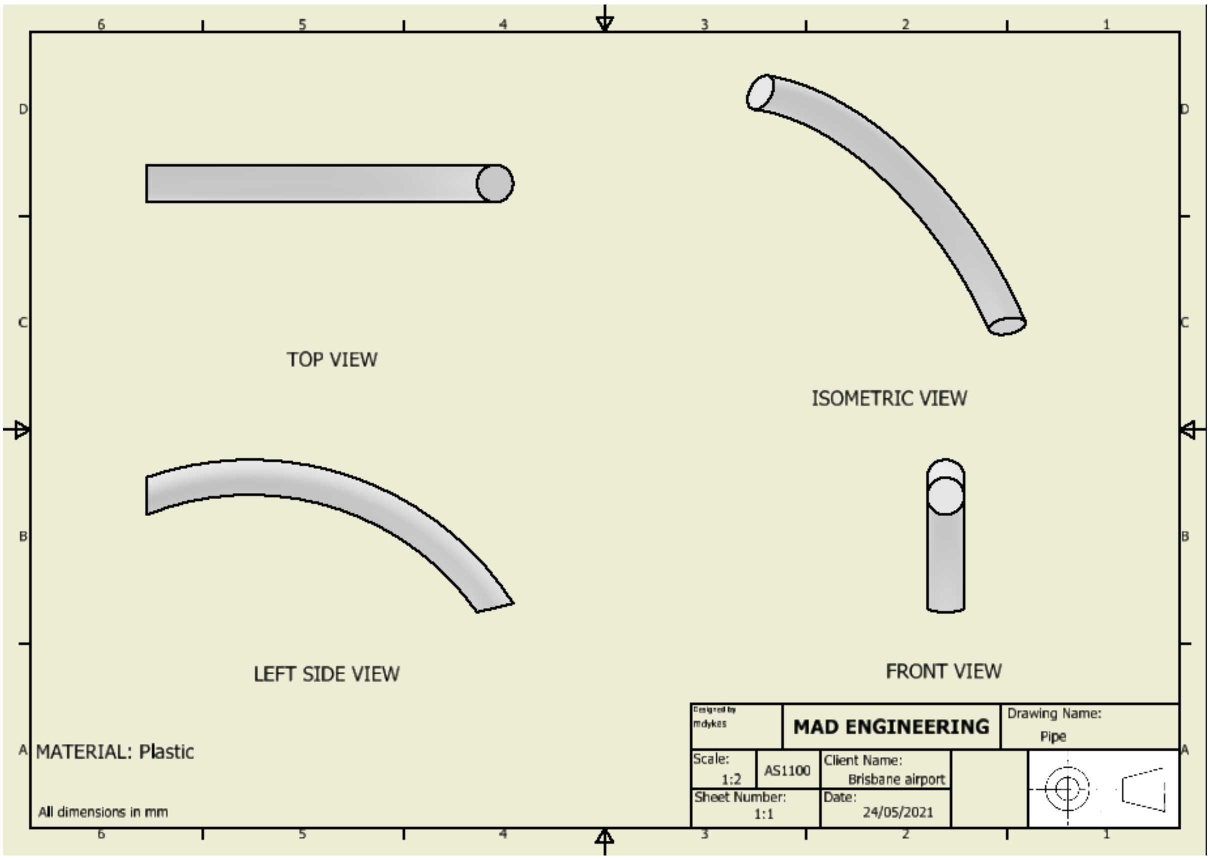

100
TOP VIEW
ISOMETRIC VIEW
Ø15,00
80
LEFT SIDE VIEW
40
20
60
20
FRONT VIEW
MATERIAL: ABS Plastic
All dimensions in mm
Designed by
mdykes
MAD ENGINEERING
Drawing Name:
Axel
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021

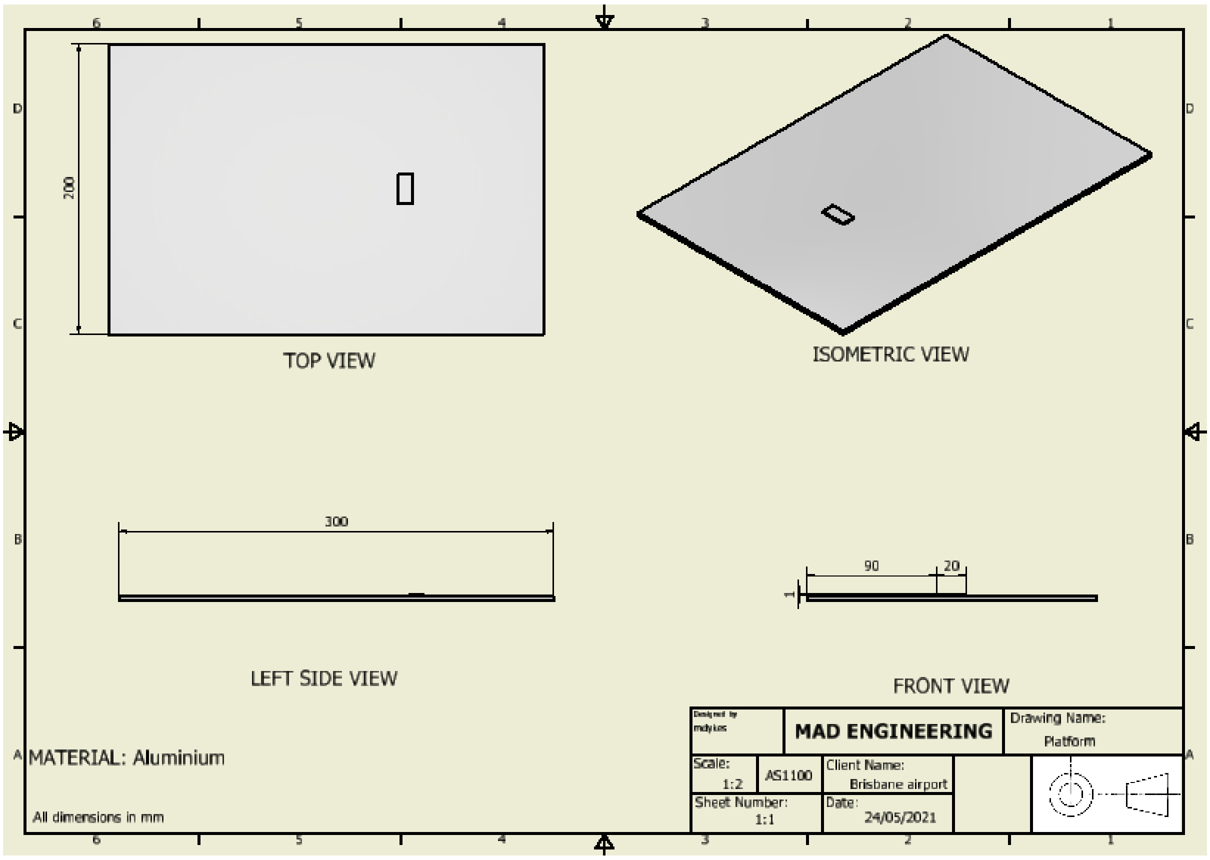

20
TOP VIEW
ISOMETRIC VIEW
90,00°
20
LEFT SIDE VIEW
58
FRONT VIEW
MATERIAL: Aluminium
All dimensions in mm
Designed by
mdykes
MAD ENGINEERING
Drawing Name:
Mount for bottle
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021


80
TOP VIEW
ISOMETRIC VIEW
20
80
LEFT SIDE VIEW
FRONT VIEW
MATERIAL: Styrofoam
All dimensions in mm
Designed by
mdykes
MAD ENGINEERING
Drawing Name:
Mount for turret
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021

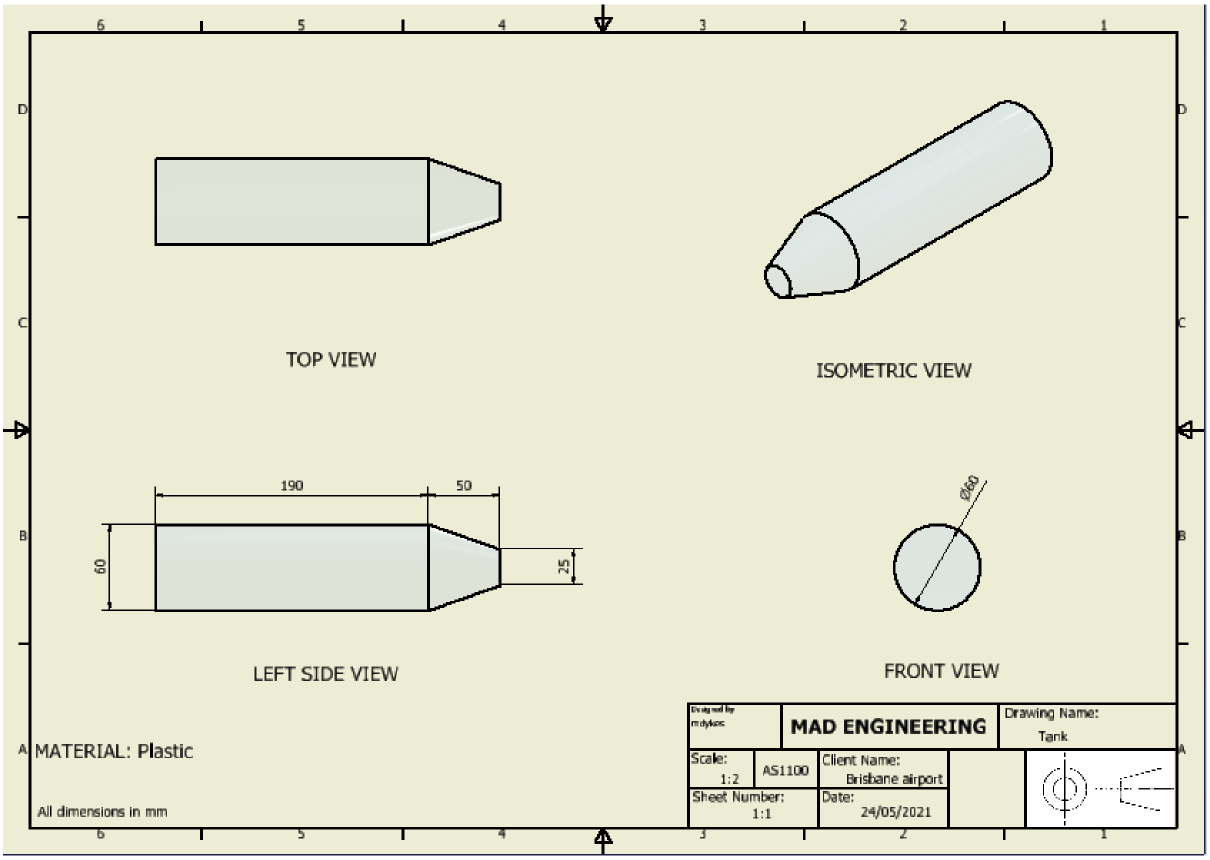

5
12
TOP VIEW
ISOMETRIC VIEW
Ø10
7
2
2.5
LEFT SIDE VIEW
FRONT VIEW
MATERIAL: ABS plastic
All dimensions in mm
Designed by
mdykes
MAD ENGINEERING
Drawing Name:
Nozzle
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021


TOP VIEW
Ø2.5
ISOMETRIC VIEW
LEFT SIDE VIEW
10
51
20
FRONT VIEW
37
MATERIAL: ABS plastic
All dimensions in mm
MAD ENGINEERING
Drawing Name:
Pan and tilt kit
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021

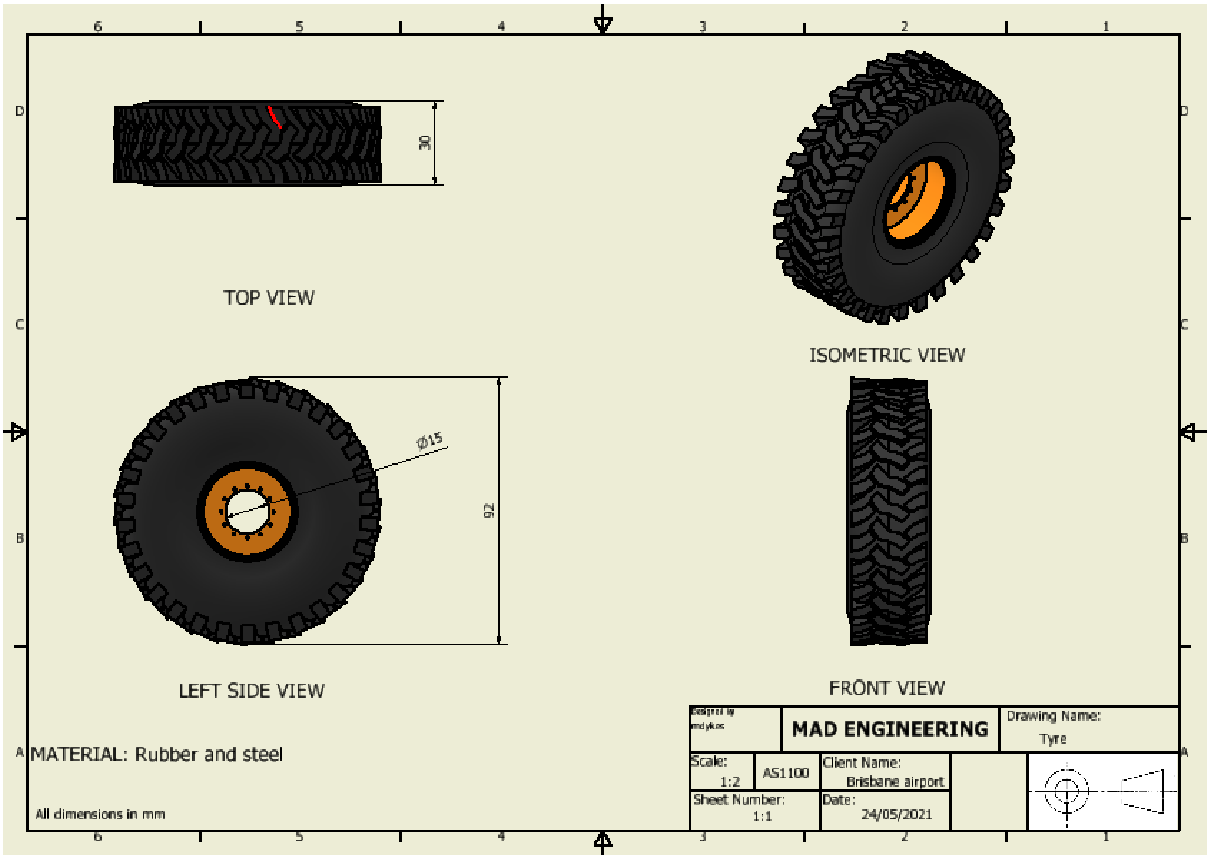

TOP VIEW
ISOMETRIC VIEW
LEFT SIDE VIEW
FRONT VIEW
MATERIAL: Plastic
All dimensions in mm
MAD ENGINEERING
Drawing Name:
Pipe
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021



TOP VIEW
200
ISOMETRIC VIEW
300
LEFT SIDE VIEW
90
20
1
FRONT VIEW
MATERIAL: Aluminium
All dimensions in mm
MAD ENGINEERING
Drawing Name:
Platform
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021



TOP VIEW
ISOMETRIC VIEW
190
50
60
25
LEFT SIDE VIEW
Ø60
FRONT VIEW
MATERIAL: Plastic
All dimensions in mm
MAD ENGINEERING
Drawing Name:
Tank
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021



TOP VIEW
30
ISOMETRIC VIEW
Ø15
92
LEFT SIDE VIEW
FRONT VIEW
MATERIAL: Rubber and steel
All dimensions in mm
MAD ENGINEERING
Drawing Name:
Tyre
Scale:
1:2
AS1100
Client Name:
Brisbane airport
Sheet Number:
1:1
Date:
24/05/2021

Appendix 3: Finalised Components and Pricing

Component	Final Choice	Dimensions (mm)	Mass (MAX is 3000g)	Cost	Fabrication Cost
Material for Chassis	Aluminium	160 x 250 x 3	Density of aluminium is 2.7 g/cm^3 = 324g	$26.44	$13.22
Control Mechanism	Arduino UNO REV 3	67 x 52 x 28	-	$13.90	$13.90
Pump	Machifit JT80SL DC 3-6V 120L/H Brushless Submersible Mini Water Pump	56 x 24 x 33	30 grams	$10.26	$10.26
Wheels	Dismantled RC Car		1kg	$29	$29
Nozzle Head	Nozzle Head	-		$2.95	$2.95
Pipes	Pope Clear vinyl tubing 5mm x 5mm	Diameter: 5mm		$5	$5
Servo motor rotation	9g Servo Motor	35 x 50 x 45	45 grams	$15	$15
Power system (Batteries)	8 AA Batteries from 10 pack		253g±5g	$10	$4
Power System	8 AA Series Battery pack			$5.27	$5.27
L298N	L293N	43 x 43 x 27	30g	$2.61	$2.61
LM2596S Step-Down Converter	LM2596S Step-Down Converter	48 x 23 x 14	80g	$2	$2
Mini Breadboard	Mini Breadboard	45 x 34.5 x 8.5		$9.86	$1.97
Breadboard Wire				$15	$2
USB A to USB Cable 1.5m				$3.99	$3.99
Female to Male USB Type A 5m extension cable				$9.45	$9.45

1.5L Lipton Tea Bottle				$19.99	$3.33
Hot Glue Stick	6 used from 24 pack			$9.85	$2.46
Super Glue	Super Glue			$3.99	$3.99
Duct Tape	Duct Tape			$9.99	$9.99
Velcro	Velcro			$14.95	$3.74
			Total Mass; 1853.25g	Total Cost: $219.50	Total Cost: $144.13

Appendix 4: Decision Making Matrix and Sensitivity Analysis

Decision making matrix and sensitivity analysis values for the chassis solutions. Data received from Chai (2021).

Chassis Solutions	Decision Making Matrix Value	Sensitivity Analysis
Ladder Chassis	1.66	1.67
Monocoque Chassis	1.13	1.16

Decision Making matrix and sensitivity analysis values for the material choices. Data received from Chai (2021).

Chassis Solutions	Decision Making Matrix Value	Sensitivity Analysis
Polyethylene	2.19	2.15
Aluminium Alloy 6061	1.87	1.89
Aluminium Alloy 7075	2.07	2.11
Magnesium AZ31b	1.73	1.75
A36 Steel	1.41	1.45

Appendix 5: Control Code

```
#include <Arduino.h>
#include <SoftwareSerial.h>
#include <Servo.h>

char command;
// Pump setup
#define P1 12 // Pump Power Pin One
#define P4 4 // Pump Power Pin Two
#define P2 11 // Pump Speed
#define P3 13 // Pump Speed

// Drive setup
#define IN1 7 // Drive Pin 1
#define IN2 8 // Drive Pin 2
int SPEED = 140; // Constant speed of the motor

// Turret setup
#define T1P 6 // X-Axis Turret
#define T2P 5 // Y-Axis Turret
int TTurn = 5; // Degree increment for the turre
int TXaxis = 90; // X-axis
int TYaxis = 0; // Y-axis
Servo T1;
Servo T2;

void setup() {
    T1.attach(T1P);
    T2.attach(T2P);
    T1.write(TXaxis);
    T2.write(TYaxis);

    pinMode(P1, OUTPUT);
    pinMode(P2, OUTPUT);
    pinMode(P3, OUTPUT);
    pinMode(P4, OUTPUT);
    pinMode(IN1, OUTPUT);
    pinMode(IN2, OUTPUT);
    SoftwareSerial mySerial(3, 2);  // RX, TX
    Serial.begin(9600);
}

void turret_left() {
    TXaxis -= TTurn;
    T1.write(TXaxis);
}

void turret_right() {
    TXaxis += TTurn;
    T1.write(TXaxis);
}

void turret_up() {
    TYaxis += TTurn;
    T2.write(TYaxis);
}

void turret_down() {
    TYaxis -= TTurn;
    T2.write(TYaxis);
}
void drive_backwards() {
    analogWrite(IN1, SPEED);
    analogWrite(IN2, 0);
    delay(400);
    analogWrite(IN1, 0);
    analogWrite(IN2, 0);
}

void drive_forward() {
    Serial.println(command);
    analogWrite(IN1, 0);
    analogWrite(IN2, SPEED);
    delay(400);
```

```
void drive_forward() {
    Serial.println(command);
    analogWrite(IN1, 0);
    analogWrite(IN2, SPEED);
    delay(400);
    analogWrite(IN1, 0);
    analogWrite(IN2, 0);
}

void turret_fire() {
    digitalWrite(P1, LOW);
    digitalWrite(P2, HIGH);
    digitalWrite(P3, LOW);
    digitalWrite(P4, HIGH);
    delay(5000);
    digitalWrite(P1, LOW);
    digitalWrite(P2, LOW);
    digitalWrite(P3, LOW);
    digitalWrite(P4, LOW);
}

void stop() {
    digitalWrite(P1, LOW);
    digitalWrite(P2, LOW);
    digitalWrite(P3, LOW);
    digitalWrite(P4, LOW);
    analogWrite(IN1, 0);
    analogWrite(IN2, 0);
}

void loop() {
    if(Serial.available() > 0) {
        command = Serial.read();
        Serial.println(command);
        switch(command) {
            case 'L': turret_left(); break;
            case 'R': turret_right(); break;
            case 'U': turret_up(); break;
            case 'D': turret_down(); break;
            case 'F': drive_forward(); break;
            case 'B': drive_backwards(); break;
            case 'P': turret_fire(); break;
            case 'S': stop(); break;

        delay(50);
        }
    }
}
```

Appendix 6: Gannt Chart

Fireman Sam (Unmanned Firefighting Vehicle)

Team Teal

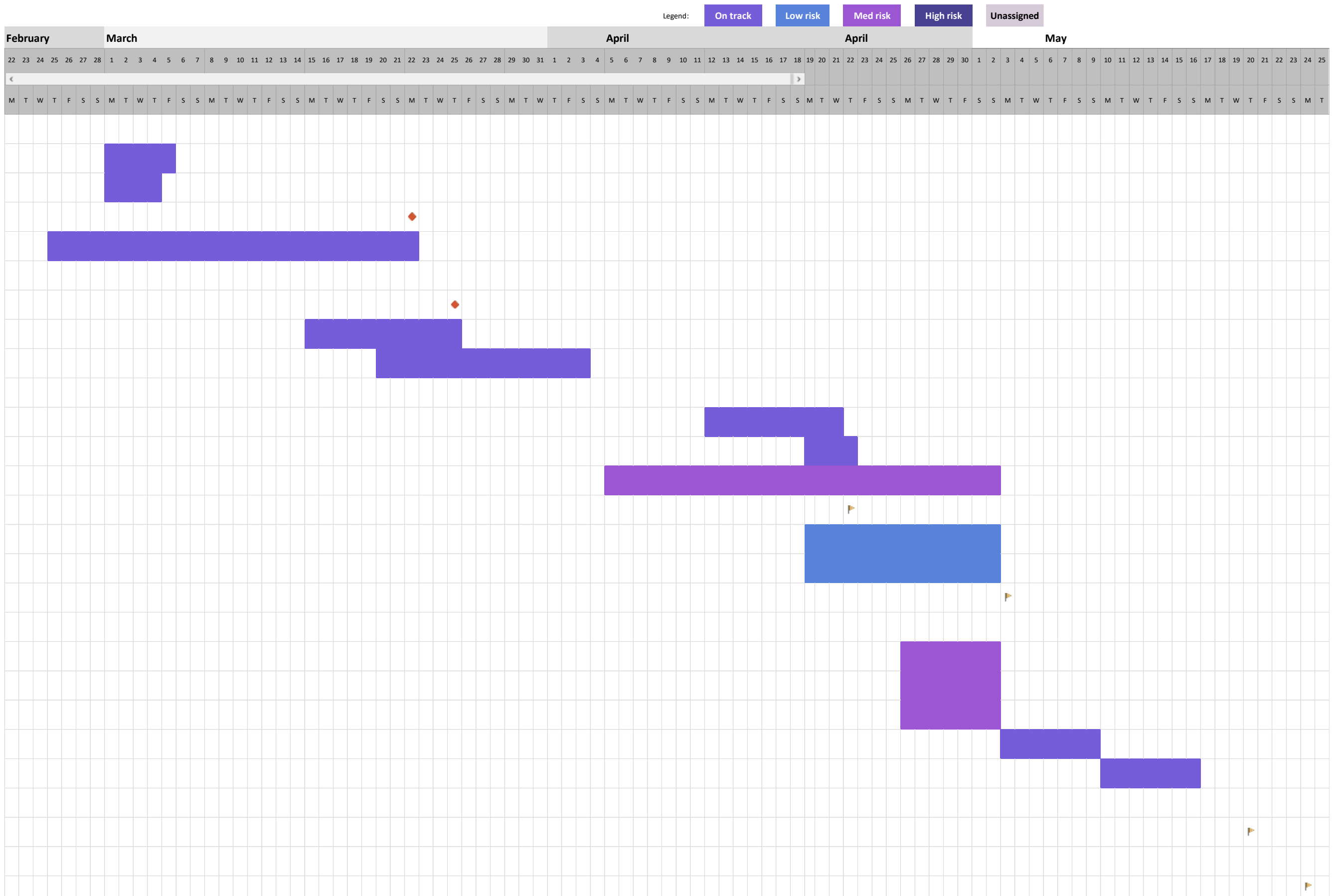
Team Lead: Hana Abdelhameed

Team Members: Hana Adbelhameed, Ethan Chai, Charlotte Watts, Mitchelle Dykes, Riley White, Jay Hunter

Project Start Date: 15/02/2021

Scrolling Increment: 7

Milestone description	Category	Assigned to	Progress	Start	Days
Design					
Create & Sign Team Charter	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	1/03/2021	5
Establish Sub Team Roles	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	1/03/2021	4
Concept Report	Goal	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	22/03/2021	1
Complete Concept Report	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	25/02/2021	26
Devevlopment					
Agree on Final UFV Final Design	Goal	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	25/03/2021	1
Discuss UFV Final Design	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	100%	15/03/2021	11
Develop 3D Model of UFV	On Track	Mitchell	100%	20/03/2021	15
Construction					
Bild Chassy	On Track	Hana & Ethan	100%	12/04/2021	10
Build Tank with Pump	On Track	Hana & Charlotte	100%	19/04/2021	4
Build Control & Power System	Med Risk	Jay	70%	5/04/2021	28
Design Presentation	Milestone	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay		22/04/2021	1
Build Drive System	Low Risk	Riley	25%	19/04/2021	14
Build Turret	Low Risk	Mitchell	25%	19/04/2021	14
Complete Construction	Milestone	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay		3/05/2021	1
Testing					
Test Controlling Each Component Seperatly	Med Risk	Jay	0%	26/04/2021	7
Test Controlling Multiple Components	Med Risk	Jay	0%	26/04/2021	7
Test for Edge Cases	Med Risk	Jay	0%	26/04/2021	7
Trial Run in Arena 1	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	0%	3/05/2021	7
Trial Run in Arena 2	On Track	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	0%	10/05/2021	7
Show Time					
Take out the fires and the judges hearts at the demo	Milestone	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	0%	20/05/2021	1
Final Report					
Complete and Hand-in Final Report	Milestone	Hana, Ethan, Charlotte, Mitchelle, Riley, Jay	0%	24/05/2021	1



Appendix 7: Demo Day Mitigation Techniques and Failure Modes Analysis

Failure Mode	Approach to Failure	Likelihood of Occurrence
UFV is taking too long to extinguish fire.	If the 6 minutes are almost complete, bring the UFV back to the starting point instead of attempting to put out all 6 fires.	50%
Vehicle stops moving due to fault in drive system	Take the 1-minute penalty associated with getting a staff member to manually move the vehicle.	20%
Electrical circuits not completely dry from previous spillage	Alter technique to compensate for this short circuiting of the pump.	80%