# ENG 4002 Research Project

## Solving the Leaky Tank Mystery

Progress Report

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# I. Acknowledgments

The group would like to extend our sincere appreciation to a set of people who have all played a significant role in the duration of this project. An individual paramount to this project, who is deserving of significant gratitude is the project supervisor Derek Abbott. Derek has supported the group with valuable advice and guidance on how to best approach and complete this project. We would also like to acknowledge Scott Letton, a member of the technical resource team who has provided beneficial advice and insight on how best to transfer our design ideas and objectives into a testable prototype.

# II. Declaration of Authenticity

The work, writing and figures found within this report are the intellectual property of the group. The only exceptions are information gathered from exterior sources of which have all been cited and referenced.

# III. Contribution Statement

The contribution statement includes a breakdown of the specific roles each individual group member has had throughout the duration of the project. The contribution statement for each of the group members illustrated below within table 1.

*Table A.1: A detailed breakdown of the roles and contributions made by each group member.*

| Group Member | Role |
|---|---|
| Eric Tsoukatos (a1827083) | Conceptualisation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualisation, Writing – original draft, Writing – review & editing. |
| Michael Stefani (a1825278) | Conceptualisation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualisation, Writing – original draft, Writing – review & editing. |

As can be seen above within the contributions table, there has been a uniform split of roles between the group members, this is largely due to the small amount of group members. Additionally, it is because the majority of objectives and milestones to complete, each require a similar set of responsibilities.

# IV. Executive summary

There exists much academic debate over a question that seems to be a simple physics-based puzzle: if a frictionless rail car filled with water develops a perfect vertical leak in an off-centre position as illustrated in figure A.1, will the car move forward? Or backward? This unknown effect is difficult to observe amongst other real-world phenomena, hence making it challenging to develop effective experimental techniques to settle this debate. However, investigating the theory behind what seems to be a trivial matter offers a chance for a greater understanding of all forces and concepts involved. Developing high sensitivity experiments for testing minute effects is also a broadly applicable skill for investigating the fine details of many physical models. This project involves developing several alternative COMSOL multi-physics simulations, focusing on validating existing theoretical models and determining the magnitude of the effect. From there, a comprehensive set of experiments across a range of the most significant design parameters isolated in simulation, such as tank height, position of the leak and size of leak, will be performed to validate the results generated from the simulated models.

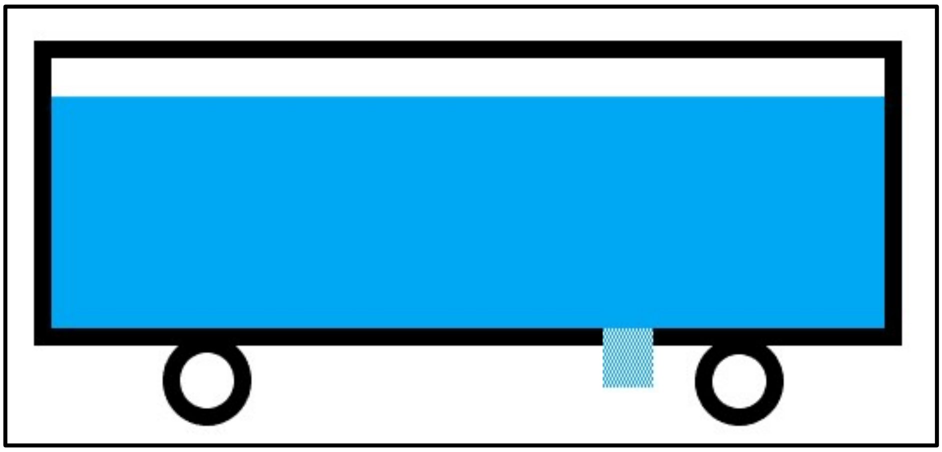

*Figure A.1: A diagram of a tank car which has sustained an off-centre leak.*

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# 1. Introduction

The leaky tank car mystery is a physics-based problem concerned with determining the motion of a tank car filled with water. Therefore, if this tank car is frictionless, and a leak is sustained in an off-centre position, what will the motion of this tank car be? Hence, this project focuses on exploring the parameters of the tank that affect the motion and how they correlate to a practical scenario.

## 1.1. Background

The leaky tank car mystery is a physics-based problem concerned with determining the motion of a tank car filled with water. The tank car begins at rest yet may begin to move once water begins draining from the tank through an off-centre hole. The leaky tank car mystery has been the subject of many investigations in the past. As such, numerous documents and papers have been written about this topic, however, what makes this mystery unique is that many of the experimental findings and results are not uniform across all papers.

## 1.2. Motivation

The leaky tank car problem has been approached and attempted in a number of ways by many researchers spanning over several decades. Despite all of this pre-existing research, attempts to determine the outcome of the leaky tank car have been largely limited to theoretical methods, with some believing that practical methods are not possible (McDonald 1991). This is what has driven the motivation for the project, to verify the solutions of theoretical analysis by simulating the problem with COMSOL and obtaining practical results through experiments.

## 1.3. Aims and Scope

The aim of this project is to be able to accurately determine and solve the mystery of the motion and behaviour of the leaky tank car, specifically how will the car behave when water begins draining from the body.

The project scope includes physics simulation software such as COMSOL and ANSYS which will be utilised to predict the flow and motion of liquids. Additionally, physical designs of the experiment will be created in order to gain experimental results to analyse. Given the simple design and small amount of apparatus required for the leaky tank car mystery, the group will also make creative and effective changes where necessary to yield more desirable results.

## 1.4. Objectives

Through the project numerous objectives must be evaluated and explored. These objectives are used to guide the project to achieve the aim. The objectives for this project are:

**OB1**: Develop two simulation models that can determine the magnitude and direction of motion of the tank based on a range of parameters. One model will be created and analysed in COMSOL, while the other will be completed in ANSYS. This involves models with physical parameters that can be easily adjusted, to investigate how each parameter affects displacement, and determine the parameter with the greatest effect on motion. Results from both simulation packages can then be used to compare against each other, as well as the theoretical calculations to validate results.

**OB2**: Validate the simulated results with a physical experimentation. From the parameters identified in **OB1**, two physical models can be constructed to investigate the effect of a single parameter. By constructing a tank with the same parameters as the simulated model, the results should be replicated, and validate the simulated results.

Through completing these project objectives, the theoretical results can be corroborated by alternative methods, validating the results of both methods.

## 1.5. Document Overview

The following report includes a wide variety of sections each used to convey information necessary to the completion of the project. The beginning of the document, includes important parts such as the executive summary, used to summarise the document and its purpose. Additionally, the contribution statement, is used to identify the contributions to this progress report from each group member. Following this is the introduction, equipped with a number of subsections that detail the context of the experiment such as background information, motivation behind the project, aims and objectives. From this, the literature review and theory portion of the document is introduced. The purpose of these sections is to conduct research on past reports and findings on similar projects allowing the group to gain a sound understanding of what occurs during the project and why this happens. Likewise, the methods part, again builds on from its predecessors, as now equipped with the required knowledge, a variety of methods used and to be used to complete the project can be determined. The technical chapters include a description of the current and future planning of how to best achieve the objectives set. Following this is the completion plan, a section used to identify the remaining tasks to complete and what future developments of this project may include. Thus, this leads to final sections of the document, a summary used to conclude the documents a provide a synopsis of what is detailed throughout the document and a set of references, from which the group has extracted knowledge from.

## 2. Literature Review

The leaky tank problem or a minor variation of this topic has been the subject of numerous investigations in the past. Therefore, to grasp a better understanding of this topic, the laws associated, and what the expected results are, numerous literature reviews were conducted. One report titled the 'Motion of a leaky tank car' explored the theoretical motion that a tank car shaped as rectangular prism would experience if a square orifice was opened at one end of this tank car (McDonald 1991). To find out the motion of this tank car, a series of equations based on velocity and momentum were derived, these have been detailed and explored in the theory section (McDonald 1991). Theoretically, it is determined in relation to the law of conservation of momentum, as water is initially released, the tank car will gain some aspect of motion in one direction resultant of the momentum of water being pushed from the sides of the tank and out of the open orifice. However, since this flow rate decreases as a function of time, the forces applied by the tank walls are decreased resulting in a velocity reduction. As the velocity reaches its minimum, the momentum from the water flowing out of the tank is reabsorbed, thus reversing the direction of velocity of the tank car (McDonald 1991). The findings from this report state that a tank of length 20 m with cross section 25 $m^2$ and orifice opening sized 0.01 $m^2$ would theoretically result in the tank being moved at velocity of 0.06 m/s. Although a velocity was determined, it is likely that the force provided by this velocity would not overcome the magnitude of frictional forces between the tanker car and the ground it rests upon (McDonald 1991).

A similar study that corroborates the findings published in McDonald's report, explores the motion of a rail car filled with solid particles rather than a liquid. In this report it is determined that much alike the aforementioned study, the tank car will begin travelling in one specific direction for a period of time, before stopping and reversing its direction (Ekman 2019). Within this study, the theoretical water in the tanker is replaced with a set of balls that are alike the water, released through an off-centre opening (Ekman 2019). Further corroboration is included in an early document dating back to 1910 which analyses a tank of water with an efflux pipe resting on a frictionless plane (Wilson 1910). Again, the conclusion made is that the tank will begin moving in the direction opposite to the horizontal water flow, however there will be a point where this motion is reversed, and the tank will move back in the opposite direction (Wilson 1910).

The physical concepts present in this problem can also be applied to similar scenarios. As the leaky tank is essentially an object with constantly changing mass, so a similar effect would be expected in a coal car that is being filled from empty (MIT OpenCourseWare 2016). Through investigating initial and final momentum of the car, it is determined that the final velocity is a simple function dependent on the time taken to fill the car, as well as the initial parameters of the problem. However, for an emptying freight car, the momentum of the expelled particles must also be considered, and so the velocity of the tank at a given time is a more complex equation, however it is still a function of the change in mass (MIT OpenCourseWare 2016). Another analysis of a zig-zag shaped tank of emptying water determines the motion through multiple methods including conservation of momentum and energy. Through both analysis methods, it is determined that the motion will eventually reverse, and it is discovered that this reversed motion occurs when the rightmost section of the pipe is completely drained, such that the height of the water $\approx 0$, however it is unknown how the water will behave at this point so the motion cannot be solved analytically (McDonald 2018).

A study published titled 'Force, Momentum Change, and Motion', explores the laws of motion at play and the formulae used to derive the motion of systems with a changing mass (Tiersten 1968). The findings made in this study are mostly applicable and can aid in better understanding the problem. One of the points of discussion from this study is that the equations of motion vary based on the type of system, as such some systems will be defined by force as a product of mass and acceleration, whereas others are defined by the momentum present within the system. However, it is stated that for the general case, a tank with a fixed volume and the possibility of admission/expulsion of particles, the equation of motion is based on the sum of momentum and momentum flux (Tiersten 1968), further analysis of this will be included in the theory subsection.

# 3. Methods

In preparation to complete this honours project, a number of different methods were theorised and detailed in order to best fulfill any objectives set. Therefore, throughout this section the adherence to these methods and how they were able to aid in the completion of necessary milestones will be detailed.

## 3.1. Initial Research

During the beginning of the year when the delegated project topics were distributed, each student in the group began preliminary research to gain a base understanding of the leaky tank problem, what it is and why does it occur. Following this, a set of literature reviews were conducted on documents and reports that had previously explored the leaky tank problem. This further research aided in strengthening our knowledge and understanding of the topic. The documents to review were found through a combination of searches on both Google and Google Scholar, in addition to being supplied by the group supervisor. The literature reviews illustrated within the section above, were each completed on a different set of reports. This was a necessary feature of the research since it provided an important perspective to be able to observe the differences between these reports, irrespective of the fact that they were exploring the same principle.

## 3.2. Design Conceptualisation

Following the literature review, the group had completed necessary research to understand a basic synopsis of the forces and concepts involved with the leaky tank problem. Therefore, from this understanding grew an initial conceptualisation of what experimental prototypes and features would be required to solve the leaky tank problem. This included ideas such as using a model tank car positioned on an air table or set of rails or hanging a tank of water in the air. After analysing the positives and negatives of these ideas, the group came to the conclusion that the prototype that should theoretically attain the most desired results is one that is suspended in the air from a support frame. This decision was made based on the idea that it will eliminate the variable of friction given that the tank will be suspended in the air, rather than sliding across a beam or table.

Since a basic understanding of how to design the experimental prototype had been developed, it was necessary to further add features to aid in the optimisation of the design. The primary feature requiring further tinkering was the outlet of the water. Given that the flow of water through this orifice is what generates the movement of the water tank, a uniform, constant release mechanism is required. In order to gain the most desired results, we must not manually apply any forces to the water tank, as such a remote mechanism to release water is needed. Therefore, possible mechanisms or techniques to release the water from the tank were researched until a component known as a smart water valve was identified. This component allows an inlet of water to be controlled remotely, ensuring that the orifice opening for water release is constant in each experimental trial.

In order to build this prototype as seen in figure 3.1, an engineering plan is to be given to the technical resource team. However, a set of geometric dimensions are first required for the size of the prototype. Therefore, to understand what dimensions will best optimise the experiment, COMSOL is to be used. COMSOL is a multiphysics simulation software which can be used to simulate real-world designs (COMSOL 2024). Therefore, if the desired system to be built by the technical resource team is first simulated using COMSOL, the optimal dimensions can be determined and provided to the technical team allowing them to build an experimental rig and tank which can be utilised and tested. Additionally, further testing can also be completed using a different software Ansys. Alike COMSOL, Ansys is a software that specialises in engineering simulations and 3D design (Ansys 2024), as such a similar method can be applied to this software. This method includes designing a virtual copy of the expected model and running simulations to optimise any desired features such as the geometrical design of the water tank. This software will act as an efficient tool given that the simulations ran are based on user input and investigates the behaviour between fluid, dynamic and static elements (Aggarwal n.d).

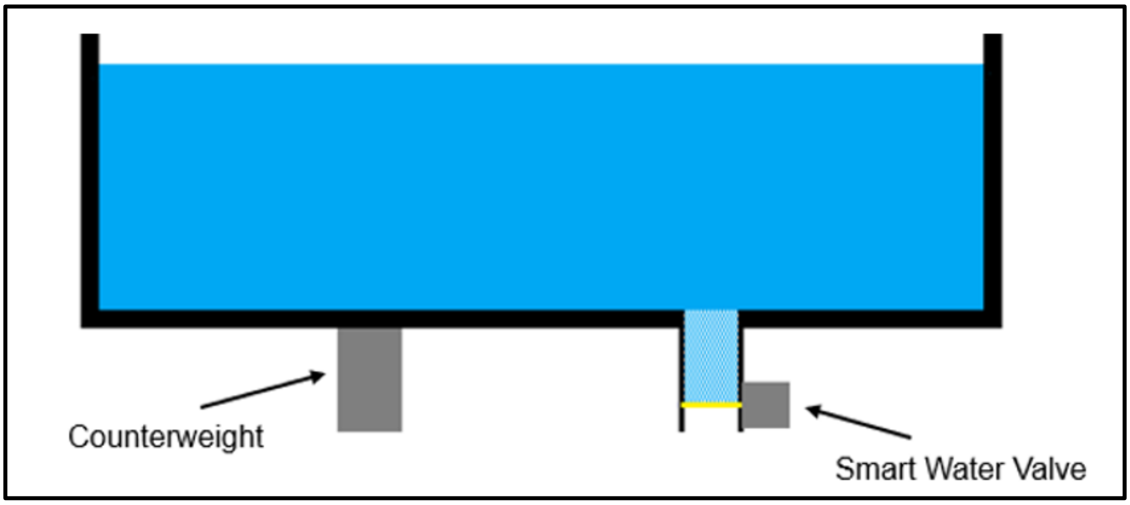


*Figure 3.1: A diagram of the conceptualised tank to be designed exhibiting a smart water valve and counterweight to maintain a uniform weight distribution.*

## 3.3. Testing and Experimenting

Once equipped with the specifically designed experimental rig and water tank, experimentation and trials can begin. The water tank will be filled with water to a measured amount and will be suspended using fishing wire from the support frame. A remote-controlled smart water inlet can be opened and closed allowing water to rush out from a now open orifice in the tank. In accordance with the law of conservation of momentum, the rushing of water out of the inlet should result in the tank being pushed to the side. The displacement of the tank can then be measured using a laser sensor. Mirrors can also be utilised to magnify the displacement of the tank. More trials can then occur using different amounts of water or different suspension heights to collect a greater array of data to investigate.

# 4. Theory

Some knowledge of various concepts relating to the momentum of the tank and flow of the fluid exiting the tank is required to understand the design considerations that must be carefully chosen. The basis of these principles and how they relate to the context of the problem are discussed in further detail.

## 4.1. Conservation of Momentum

Momentum is a property of an object relating to its mass and velocity, as a way to quantify the motion of the object. The conservation of momentum states that for a system that is not acted on by any external forces, the momentum is conserved in all directions (Hall 2021). In the context of this problem, the system consists of the tank, and the fluid exiting the tank. As the horizontal motion of the tank is the only direction that we are concerned with, since the vertical motion can be neglected due to the fact that gravity acts on the tank and fluid in the vertical direction. Therefore, the horizontal momentum of the tank and fluid must always be conserved. This can be defined as $p_{initial} = p(t)$, where $p_{initial}$ represents the initial momentum of the system prior to the flow of liquid, while $p(t)$ denotes the instantaneous momentum of the system at any given time, $t$.

For cases where the mass of an object is changing, the relationship between momentum and the forces acting on the fluid in the tank can instead be written as (Tiersten 1968),

$$F = p + \Phi$$

Where F represents the force acting on the fluid in the tank, $p$ represents the momentum of the entire system of the tank and fluid, while $\Phi$ is the momentum flux of the fluid leaving the tank.

From derivations based on the principles and equations of the conservation of momentum, the initial velocity of the tank is found to be (McDonald 1991),

$$V_{initial} = -\frac{2L}{t_{empty}} \times \frac{\mu}{1+\mu}$$

Where $L$ is the distance of the hole from the centre of the tank, $t_{empty}$ is the time it takes for the tank to empty, and $\mu$ is the ratio of total water mass to the mass of the tank, $\mu = \frac{M_0}{m}$. Therefore by increasing the mass of the water in the system, the ratio $\mu$ is increased, and the time it takes for the tank to empty also increases, resulting in a smaller initial velocity applied to the tank.

The acceleration, velocity, and displacement at any given time, $t$, can also be described by equations found from derivations of the conservation of momentum for the tank system (Esposito & Olimpo 2022).

$$a(t) = \frac{L}{{t_{empty}}^2} \frac{\mu}{1+\mu\left(1-\frac{t}{t_{empty}}\right)^2}$$

$$v(t) = -\frac{L}{t_{empty}}\frac{\mu}{1+\mu}\left[1 - \frac{1+\mu}{\sqrt{\mu}}\left(\arctan\sqrt{\mu} - \arctan\sqrt{\mu}\left(1 - \frac{t}{t_{empty}}\right)\right)\right]$$

$$x(t) = -L\left[\frac{\mu}{1+\mu}\frac{t}{t_{empty}} - \frac{1}{2}\left(\log\frac{1+\mu}{1+\mu\left(1-\frac{t}{t_{empty}}\right)^2} - 2\sqrt{\mu}\left(1-\frac{t}{t_{empty}}\right)\left(\arctan\mu - \arctan\sqrt{\mu}\left(1-\frac{t}{t_{empty}}\right)\right)\right)\right]$$

From these equations, it can be seen that when the hole is in the centre of the tank, $L = 0$, resulting in $x(t) = v(t) = a(t) = 0$. This means that the tank only moves due to the unsymmetrical nature of the system, resulting in reaction forces on the tank in order for momentum to be conserved.

Also, the final velocity of the tank can be determined for when $t = t_{empty}$. Applying this condition to the above equations results in the following equations that describe the motion of the tank.

$$a(t_{empty}) = \frac{L}{{t_{empty}}^2}\mu$$

$$v(t_{empty}) = -\frac{L}{t_{empty}}\left(\frac{\mu}{1+\mu} - \sqrt{\mu}\arctan\sqrt{\mu}\right)$$

$$x(t_{empty}) = L\left(\frac{1}{2}\log(1+\mu) - \frac{\mu}{1+\mu}\right)$$

Once again, the motion of the tank is heavily dependent on the mass ratio $\mu$, and the location of the hole from the centre of the tank, $L$. While other parameters such as hole diameter, size of tank, and type of fluid are not explicitly mentioned in these equations, they all effect the emptying time, $t_{empty}$, and mass ratio $\mu$.

## 4.2. Laminar Flow

The flow exiting the tank must be as stable as possible to prevent inconsistencies between multiple tests. This can be achieved by designing the orifice of the hole in a way that ensures laminar flow is achieved. The turbulence of fluid flow is determined by the Reynolds number, which is calculated from the equation $Re = \frac{VD}{v}$, where $V$ is the velocity of the fluid, $D$ is the internal diameter of the pipe that the fluid is travelling through, and $v$ is the kinematic viscosity of the fluid (Menon 2015). For flow to be laminar, this calculated Reynolds number must be less than 2000, which can be achieved by decreasing the rate of flow or internal diameter of the pipe, or even a combination of the two. Achieving laminar flow increases the repeatability of the experiments, as turbulent flow would act as an uncontrolled variable, affecting the movement of the tank. The smoothness of the internal surfaces of the exit pipe and tap must also be considered, as any roughness can drastically increase the turbulence of fluid flow. Therefore, this is an additional factor that must be considered.

# 5. Technical Chapters

Now that the concepts relating to this topic are well understood, progress can be made towards the objectives, with the goal of working to the aim of the project. Progress is made by dividing each objective into more achievable sub-tasks, with the goal of creating more manageable steps to complete the objective. For this project, much of the initial planning for how to achieve these objectives can be achieved in parallel with each other, however **OB1** must be achieved before the experiment can begin. This is because the physical parameters used in **OB2** are based on the results of **OB1**.

Progress made to completing each objective is discussed in the following sections.

## 5.1. Objective 1 – Simulation Analysis

Physics simulation software programs such as COMSOL and ANSYS, are a powerful tool that can simulate complex physics problems. To obtain meaningful results, it is necessary for the simulation to be as close to reality as possible. This means that the dimensions of the leaky tank model must be accurate, and any assumptions or simplifications made must be reasonable. The advantage of using these simulation programs over other theoretical methods is that the effect of each design parameter can be investigated much easier. To investigate how a design parameter affects the tank, the value can simply be adjusted to a different value, and the results can then be compared with the initial parameter.

### 5.1.1 Design Parameters

The motion of the tank is dependent on several of design parameters. Some of these parameters relate to the size of the tank, while others relate to the size and location of the hole. These parameters and how they affect the motion are displayed in Table 5.1.

*Table 5.1: List of all design parameters, with a description of how they relate to the tank.*

| Design Parameter | Description of Parameter |
|---|---|
| **Length of Tank** | The geometric dimension of the length of the tank |
| **Width of Tank** | The geometric dimension of the width of the tank |
| **Liquid Level Height** | The vertical distance from the hole to the surface level of the liquid |
| **Type of Liquid** | The type of liquid to be used to fill the tank |
| **Location of Hole** | The distance of the hole, from the centre of the tank |
| **Diameter of Hole Orifice** | The diameter of the hole at the entry |

Each of these parameters will be investigated through a COMSOL analysis, in order to determine to what extent does each parameter affect the motion of the tank.

### 5.1.2 Leaky Tank Model

The leaky tank is modelled with several parameters that can be simply adjusted. Each parameter is given an initial value prior to analysis to determine the motion for these initial parameters. Each parameter can then be adjusted in order to determine the set of values for the parameters which maximise the displacement of the tank. It is important to find the conditions that maximise displacement in order to increase the ability to detect motion during the following physical experiment to be conducted.

## 5.2. Objective 2 –Experimental Validation

Experimental procedures are utilised to connect the simulated results of COMSOL analysis to the practical and tangible outcomes of realistic scenarios. These experimental results also act to validate the COMSOL results, ensuring that the model and all assumptions made in COMSOL are reasonable. For the experiments conducted, it is necessary to consider all relevant details.

### 5.2.1 Experimental Planning

The experiment must be designed and planned with careful consideration of everything that could have an impact on the results. By consulting with the technical resource team, input is provided by experts with vast knowledge of how best to construct the tank from the plans. From the initial meeting with the technical team, they were able to offer suggestions on alternative ways to construct the tank, which would provide either more accurate results, or come at a lower cost. One of the suggestions was to suspend the tank by a longer length of material, so that the tank is able to sway more easily. They also indicated that based on the initial ideas, the setup should be simple to build, and be able to yield a set of measurable results.

From incorporating the suggestions of the technical team to the initial design, the updated plan is to hang a rectangular tank from a structure that enables the tank to be suspended off the ground. The structure features an X-shaped beam which allows for the tank to be attached to through string at each top corner of the tank. This beam provides additional support and rigidity to the structure, and allows for the connections between the structure and tank to be perfectly vertical. By keeping the connections vertical, the tank is more susceptible to movement, resulting in less resistance to motion.

### 5.2.2 Materials and Equipment

There are a number of components necessary to use for the experiment. For each component it is important to consider the preferred properties to be able to accurately compare the options for each component. Some properties that must be considered are the cost, strength of the component, as well as any specific properties required of the component. The cost is extremely important as this project is assigned a budget, and thus it is vital to stay below the budget in order to fulfill the aims of the project completely. The strength of the components are a necessary consideration, since the tank must be able to support its weight when filled with water, which may be quite significant depending on the size of the tank. Therefore, if any component was to fail structurally, then it would have catastrophic consequences on the experiment, due to the delays caused by the failure of a component. Some components also have unique requirements, such as the remote release plug must be able to open and close the plug remotely, to prevent human error from interfering with results by introducing inconsistent forces to the tank if the plug was to be opened by hand.

Based on these considerations, the best possible options are listed for each component in Table 5.2.

*Table 5.2: List of all components required, and the possible options.*

| Component | Option 1 | Option 2 | Option 3 |
|---|---|---|---|
| **Material of tank** | Acrylic sheet | Perspex | Polycarbonate sheet |
| **Remote release plug** | Smart water valve | Irrigation tap with pneumatic device | Actuated mechanism to release plug |
| **Hanging material** | Thread | Fishing line | Twine |
| **Measurement device** | Laser sensor | Mirror and laser | Measuring tape |
| **Method of connection** | Holes drilled into the upper corners of the tank | Eye hooks screwed into tank | Cradle based support system |

# 6. Completion plan

The completion plan for the leaky tank project includes a number of tasks still required to be completed. Aforementioned, in order to supply the technical resource team with a detailed plan of our desired experiment prototype. The exact dimensions for the water tank are required. However, to evaluate the optimal value for these dimensions COMSOL must be utilised. Using COMSOL, the desired experimental prototype can be designed on the software and a series of different simulations can be ran to determine the optimal dimensions of the experimental prototype. However, as previously mentioned COMSOL has not yet been acquired after misinformation was acquired from the IT department regarding how to gain access to the software. Thus, the group has not yet been able to complete any COMSOL simulations. However, once these dimensions are evaluated, the design team can begin construction of the experimental prototype. Further simulations using Ansys software can also be used to verify and validate the results of the simulations made using COMSOL software.

After the technical design team has completed construction of the water tank and its supporting rig, physical experimentation can begin. This includes testing the motion of the water tank, using different amounts of water, hanging the water tank from different heights in addition to numerous other trials that monitor the motion of the tank in relation to a change in any of the variables. The specific motion to monitor is the displacement of the tank resultant of the law of conservation of momentum. The displacement of the tank will likely be quite minute and thus difficult to measure, hence measurement will occur using a laser sensor. Once a sufficient number of trials testing each of the variables has occurred, a large data set will have been compiled. Using a combination of this data, and our knowledge of the forces and laws present, we will be able to shed light on the mystery that is the leaky tank problem. Furthermore, future studies on the leaky tank problem could utilise a different experimental set up in order to gain answers. One potential set up could include using an actual scaled-size rail car, much like the one in the origin of the problem.

# 7. Summary

In summary, the initial conceptualisation and primary research has been concluded. From this a base foundation of how the desired prototype should function and be constructed has been determined. Required components have been identified, and the only factor preventing the technical resource team from beginning construction are the physical dimensions of the water tank. Therefore, once this parameter has been evaluated through **OB1** and the design has been finalised and constructed, testing will begin with aims of validating theoretical results produced by COMSOL and Ansys simulations and analysis.

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