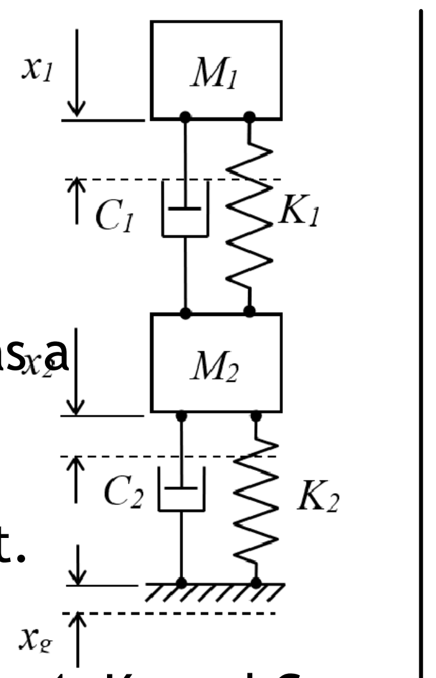
MECH2636 – Daring Dash

Group 30
Milo Fong Luana Kenny Kael Sood James Vivian Yecheng Wang
Zara Zeng Abdulrahman Hashem A Hassounah

Suspension Analysis

Parallel beam suspension has been chosen, since it provides a decent balance between soft and rigid suspension. To do the analysis, the suspension system can be thought of as a mass spring damper system with two degrees of freedom. The input can be modelled as a displacement step input.



M_1 is the mass of the chassis divided by 4, K_1 and C_1 are the stiffness and damping coefficients of the suspension system, M_2 is the mass of the suspension for each wheel and K_2 and C_2 are the stiffness and damping coefficients of each wheel. A damping effect can be introduced into the system by using multiple layers of aluminium in the sheet that connects the chassis and the suspension, the friction between the sheets providing the damping effect, or by adjusting the screw tightness to change friction. Using the masses calculated by SolidWorks, M_1 = 0.64kg, M_2 = 0.77kg.

Static Analysis

The static analysis of the suspension involves considering the forces that are in the system to calculate the ground clearance of the buggy. The stiffness of the wheel is known, where K_2 = 4.5kN/m. In order to calculate the value of K_1, The dimensions of the system must be considered. Since the bars are capable of freely rotating, they are not considered in the suspension calculations and only the beam connecting the chassis to the suspension. Using the dimensions of the beam:

$$k = \frac{3EI}{L^3}$$

$$where\ I = \frac{bh^3}{12}$$

E = 69GPa, b = 41.5mm, h = 1.5mm, l = 152mm,
∴ k = 688N/m

Since the beam is at an angle of 20 degrees to the horizontal, k_y = 646.5N/m.

Hooke's law is then used to find the total displacement when resting. Separating the system into two parts, the total static displacement due to gravity can be thought of as the vertical displacement of M_1 added onto the vertical displacement of M_2.

$$x_T = x_1 + x_2$$

$$where\ x_1 = \frac{M_1 g}{k_1}\ and\ x_2 = \frac{(M_1 + M_2)g}{k_2}$$

x_T is found to be 12.8mm. At an estimated ride height of 95mm, the ground clearance is found to be 82.2mm

Dynamic Analysis

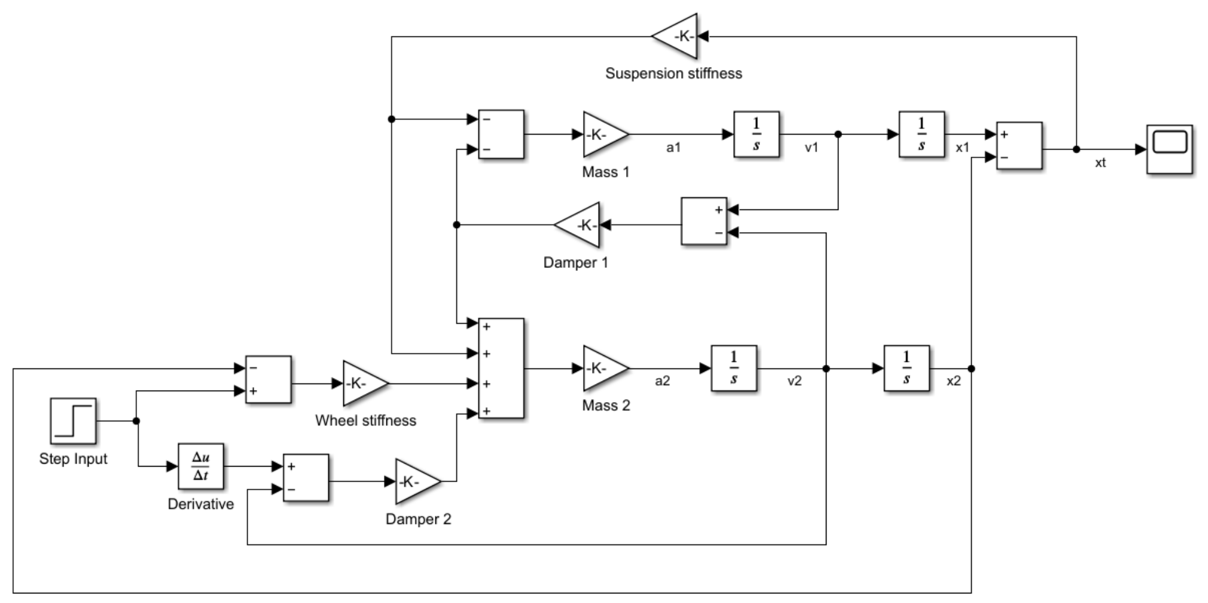
Estimating optimum values for damping coefficient can be done by rearranging the formula $\zeta = \frac{c}{2\sqrt{km}}$:

$$C = 2\zeta\sqrt{km}$$

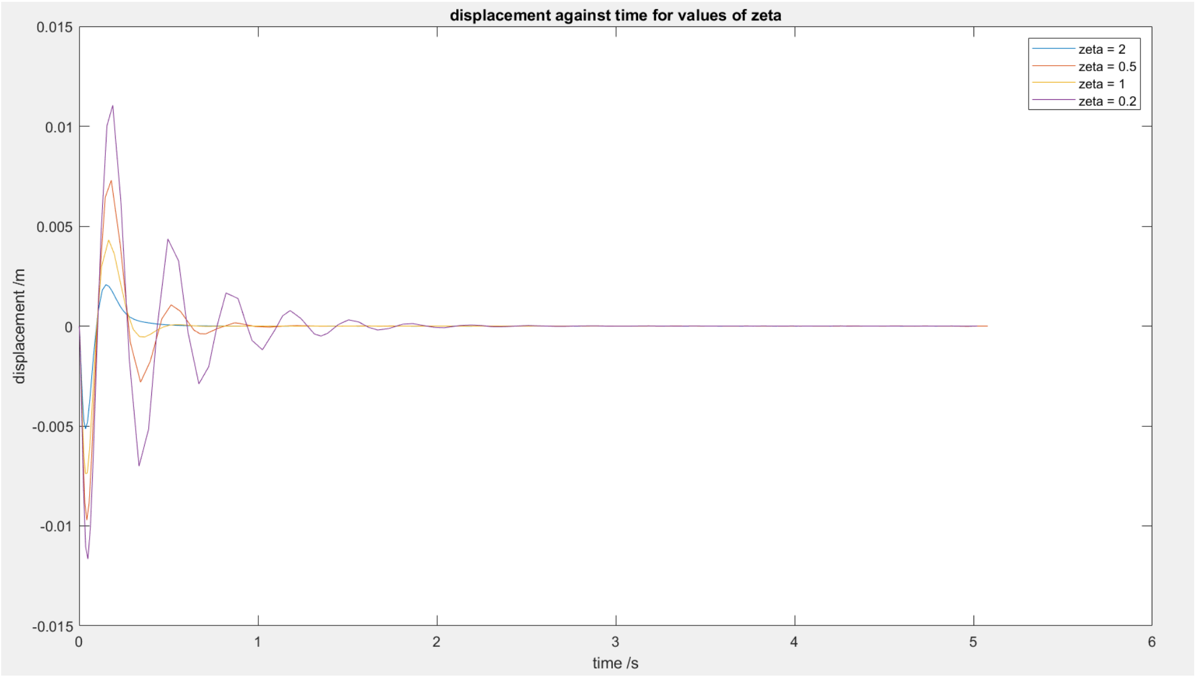
C_2 is assumed to be constant, where $\zeta = 1.1$, the wheel damping coefficient constant and slightly overdamped

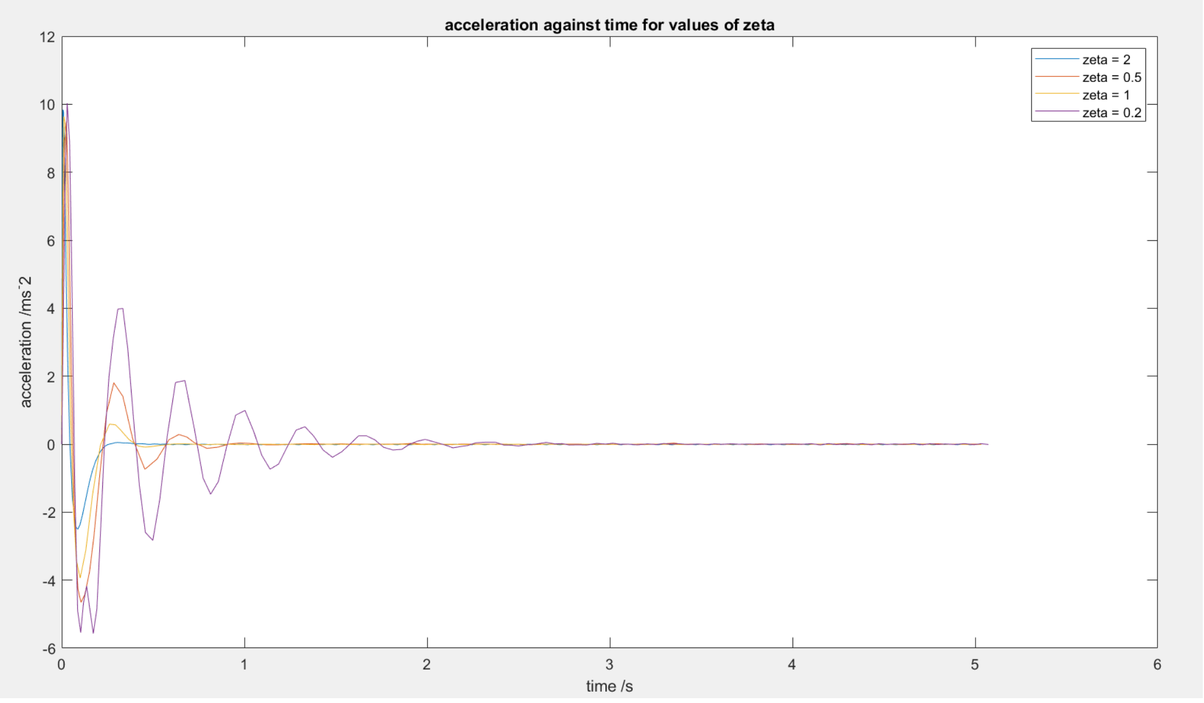
	C_1 /NSM^{-1}	C_2 /NSM^{-1}	RMS ACCELERATION
1	40.7	129.5	1.61
0.5	20.34	129.5	2.04
0.2	8.14	129.5	1.81
2	81.4	129.5	1.10

Considering the complexity of the analysis, the system is modelled in Simulink using the above calculated values for K_1, K_2, M_1 and M_2. The model used for Simulink is shown below:

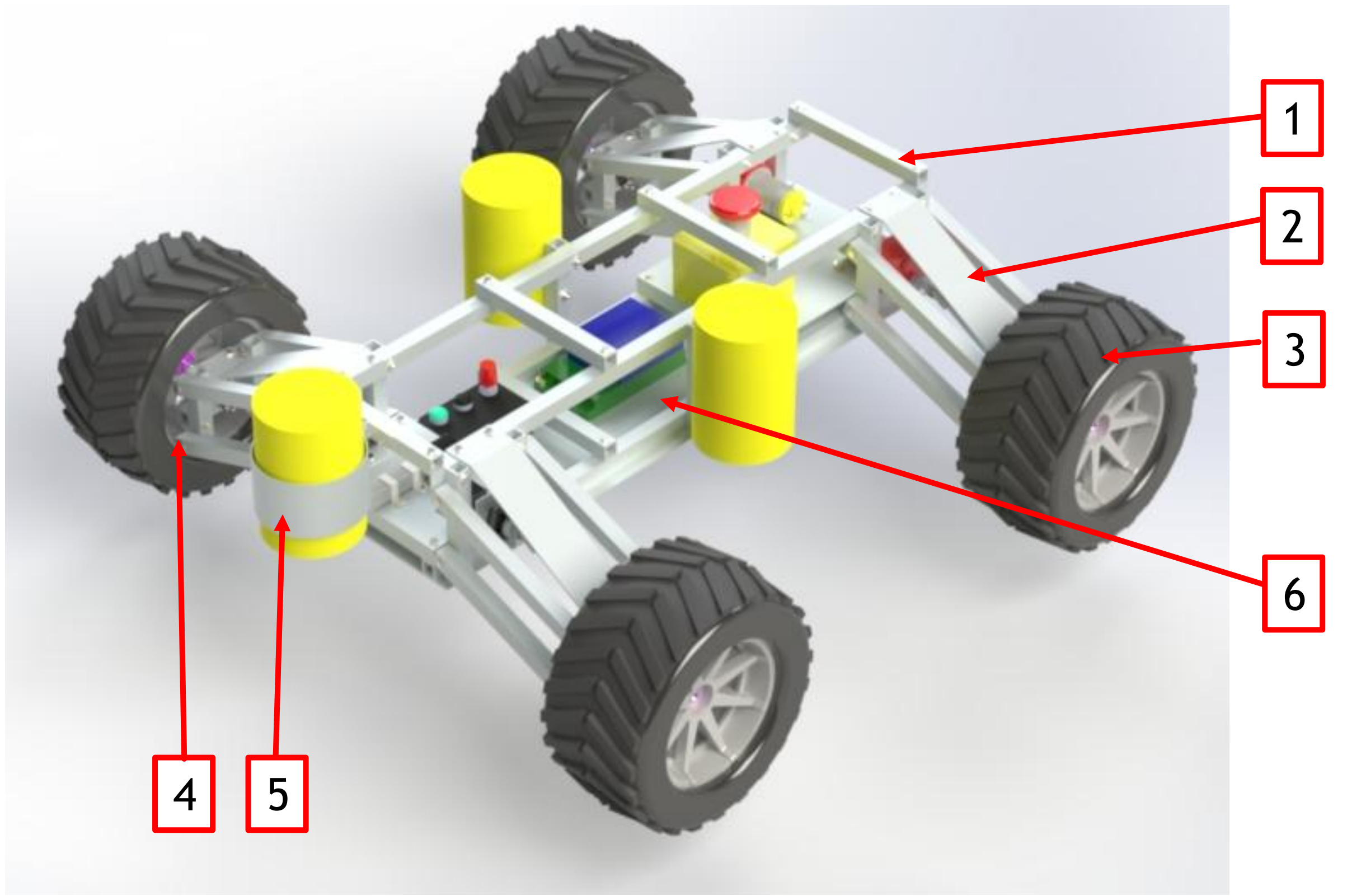


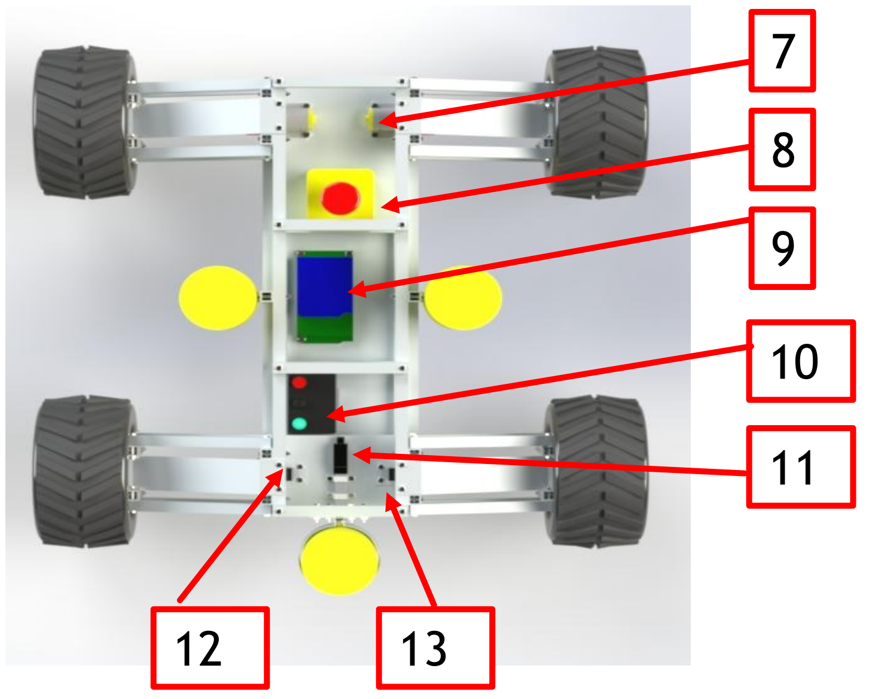
The maximum required step input for this system is estimated to be 20mm. At this value, displacement and acceleration are found.

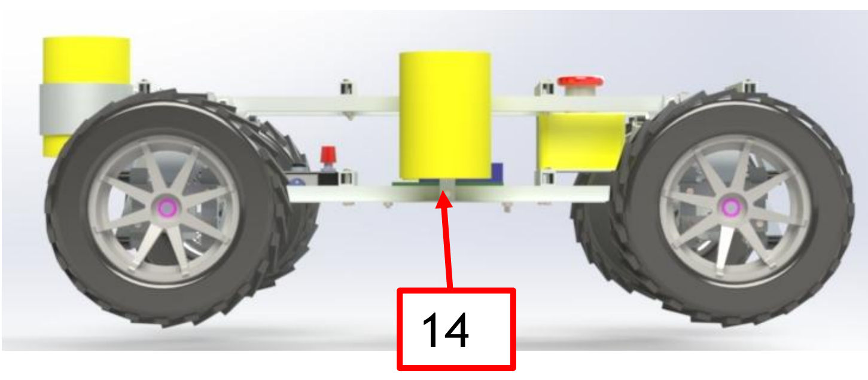




The settle time for the system is relatively fast and the system can settle within 1 second for all values of ζ, apart from 0.2, which is 2 seconds. Additionally, at higher values, the rms acceleration becomes much lower and settle times become lower. This has led to the conclusion that the system should aim for more damping and since the damping coefficient cannot be calculated, the system should be overdamped rather than underdamped to reduce the rms acceleration. As such, more layers of aluminium should be used and the screws should be tightened to introduce more friction. The weight in the buggy is distributed such that the centre of mass is in the centre and so these patterns of response are accurate. However, the model assumes an instantaneous step input, which is not a perfect assumption and so the rms acceleration is higher than the true value.







1	Narrow Chassis Frame
2	Parallel arm Suspension (long arms: 160mm)
3	Large Wheel
4	Suspension Wheel Mount
5	Circular Aluminium Payload Holder
6	Chassis Main Aluminium Sheet
7	Small Motor
8	Emergency Stop Button
9	Arduino
10	Button Box
11	Linear Actuator (retracts to release payload)
12	Optical Sensor
13	Optical Sensor holder (Aluminium L-Section)
14	Payload Holder type 2 (L-Section)

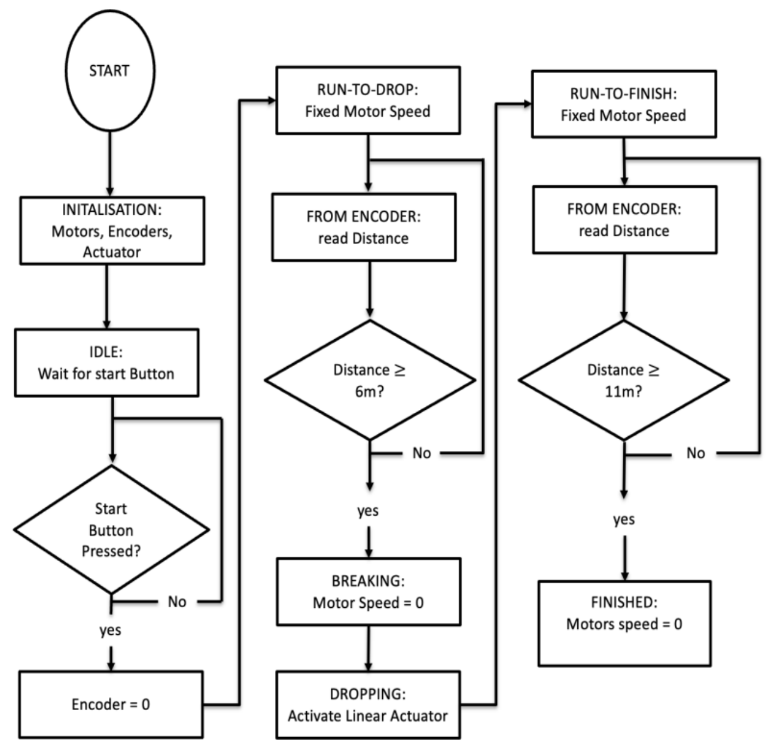
Control Algorithm

Simple Control:

A Finite State Machine (FSM) is implemented to control the buggy. A single state is desired at a time to provide maximum stability, predictability and safety. The buggy is controlled using an open-loop controller by moving at a set speed, which is defined by the motor speed. A threshold distance (measured using the optical encoders) in each state is also defined.

On power-up the buggy is in the Idle state. The Run state is transitioned into when the controller resets the encoder and the buggy goes into the Run-to-Drop state, moving in a continuous manner at a constant velocity towards the 6m drop zone. Approaching the correct distance, the system enters Braking in order to slow down and stop accurately. The Dropping state then takes over, powering the linear actuator to drop the payload.

After the drop, the buggy continues in Run-to-Finish mode until the encoders reach 11m, at which point the Finished state is reached. In this state, the motors are stopped and the brakes engaged. This method is simple, strong, and very reliable for operation on a known and repeatable track.



Complex Control:

This control scheme extends the basic FSM with a closed-loop Proportional Integral (PI) velocity controller yielding a better performance and stability when traversing uneven terrain. Even though the buggy is front wheel drive, the encoders are mounted on the rear non-driven wheels, which directly measure ground speed, so the error caused by possible front wheel slip is used as feedback to the velocity controller.

The controller compares the Target Velocity from the FSM with the Actual Velocity from the rear encoders whenever the robot is moving. The PI controller adjusts the motor power to keep the robot moving at constant velocity and make the left and right speeds equal to drive in a straight line.

The states of the FSM are: Idle, Run-to-Drop (PI controlled), Dropping at 6m, Run-to-Finish (PI controlled) and Finished at 11m. However, all the motion states are achieved in closed-loop velocity control mode. This enables the system to be more accurate, strong, and more responsive than a simpler system that has only open-loop control.

Payload Delivery System

A few possible designs were considered when deciding on the payload delivery system. One that was considered was one in which the actuator starts in a retracted position and the payload is launched backwards at the same speed that the buggy is moving, such that its velocity in relation to the floor is 0. This had been decided against, since it would be difficult to prevent the payload from toppling this way and the maximum speed of the actuator is 13mm/s, meaning the maximum speed the buggy could go in this process would be 13mm/s. Another design that was considered was the linear actuator retracting from where the payload was being held in a circular holding device.

To decide on the final design, the payload design was separated into two parts, the dropping mechanism and the holding mechanism. For these designs, concept variants were created.

Feature	Solution 1	Solution 2	Solution 3	Solution 4
Dropping mechanism	Trapdoor, actuator retracts and plate falls with payload	Extended actuator, payload rests partially on actuator	Actuator extends to push payload off buggy as it is moving, at the speed of the movement	Actuator initially extended, payload rests fully on aluminium sheet
Holding mechanism	Payload inside of the chassis, held in place by the body	Bent aluminium sheet in cylindrical shape Attached to the back of the chassis	Payload rests on top of the chassis	Rests in the middle of the body, on an aluminium sheet

Objectives had then been considered and a weighted table was created by scoring each solution out of 5 on how well they achieve each objective. The weighting was chosen by giving each objective and arbitrary 'importance' value out of 10:

Objective	Weighting	Solution 1	Solution 2	Solution 3	Solution 4
Fall accurately	10	2 x 10 = 20	4 x 10 = 40	5 x 10 = 50	4 x 10 = 40
Maintain speed	5	4 x 5 = 20	4 x 5 =20	3 x 5 = 15	2 x 5 = 10
Hold payload in place	7	2 x 7 = 14	5 x 7 = 35	1 x 7 = 7	2 x 7 = 14
Structurally strong	6	1 x 6 = 6	3 x 6 = 18	5 x 6 = 30	4 x 6 = 24
Fall without toppling	5	2 x 5 = 10	4 x 5 = 20	5 x 5 = 25	4 x 5 = 20
		70	133	127	108

As shown above, solution 2 had achieved the highest score and so is the chosen design

The design that was decided on is starting with the actuator fully extended. As shown in the SolidWorks model above. The payload sits in a piece of bent aluminium in the shape of a cylinder. The diameter of this is 80mm, compared to the payload diameter of 76mm. This allows the payload to be secured while also being able to fall without resistance when the actuator is retracted. The point from which the payload drops is above the bottom of the chassis to let the payload fully fall without requiring a much higher ground clearance than necessary. The placement of the payload dropping mechanism is at the back of the buggy, such that it does not get knocked over by any part of the chassis during or after falling. The actuator that the payload rests on has 20mm overlap and so when the actuator retracts at 13mm/s, it will only take 1.4 seconds for the payload to drop, reducing the amount of time the payload drops for and increasing the total average speed of the buggy, considering the speed is reduced during the dropping process.