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TEST BENCH BACKBONE

Mechanical

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1 Introduction

1.1 Problem definition

Fuel Fighter builds competition cars for Shell Eco-marathon. The goal of the competition is to develop a car to be as energy efficient as possible. Due to the challenging climate in Norway, it is difficult to get the car tested in the winter. To make testing more efficient and safer, we will develop a multifunctional workstation for the car. This workstation will perform several tasks such as testing and calibration of the car, tool storage and simulation capability. As well as acting as a transport trolley and used on the pit stop during the race.

1.2 The Workstation parts

The workstation is a brand new and independent subsystem for DNV GL Fuel Fighter. The board recognized that their current trolley/car stand was far to makeshift. They got inspiration from a competing team with a dyno-bench. Our workstation is different, however. It has several functions, and most importantly its adjustable so that future cars can also use it.

The workstation consists of:

- Two sets of rollers
- Two pulleys
- To motorcycle lifts
- Three electric motors
- A rigid steel frame
- Four air inflated rubber swivel wheels with brakes
- A plywood exterior
- Two sets of front wheel stands
- Various electrical hardware
- Belts, chain, sprockets, bolts, other smaller components

The workstation is not directly connected to any other subsystem of the car, but is dependent on gears, strap points on the car, wheels and obviously the dimensions of the car whenever there is a new car.

1.3 Related subsystems

1.3.1 Gears

The rollers dimensions and the gear ratios for the car are important. They play a huge role in the system, all the way from the electric motor in the car, to the electric motors on the workstation. This link of connections will act differently whenever there is a new gearbox or gear system.

1.3.2 Wheels
The front wheels must be able to turn in order to make simulation possible. The solution is a turntable for each of the front wheels. The turntable is 3D-printed with a groove to fit the wheels curvature, thus keeping the wheel in the correct position.

1.3.3 Strap points
The car must be strapped down whenever it runs on the rollers, to keep the car in place. The workstation is equipped with strap points of its own, and these must align with the strap points on the car.

2 Requirements/constraints

2.1 Price estimate

Price estimate for "test bench"		
parts	**Price estimate:**	
Steel frame	kr	6 000
wheels	kr	1 452
Plywood	kr	1 500
el.equipment	kr	3 500
Rollers	kr	3 000
Bearings	kr	1 000
Lifts	kr	1 198
Belts, bolts, etc.	kr	500
Dual lift solution	kr	1 000
LED and speakers	kr	10 000
Miscellaneous	kr	3 000
total price estimate	kr	32 150
Price for just the mechanical parts	kr	28 650

Figure 1 Price Estimate

2.2 SEM Rules
One rule applies for the workstation:

- Chapter I, 2C – art.24.j.iii

"Teams are only allowed to use a single multi-plug strip with internal overcurrent protection"

Shell Eco Marathon has a rule where you are only allowed to have 1 multi-strip power supply inside the paddock. This means we cannot use a multi-strip inside the test bench if we want to have it with us to the competition.

3 Goals

3.1 Possible award

The board was considering entering the workstation in the competition for Technical Innovation Award, with 2,500 € as reward.

3.2 User requirements specification

- The workstation must be adjustable so that it can be used for future Fuel Fighter cars that might have a different length or width than the current car.
- Must be able to get readings that gives us data about the car’s performance.
- Ease of use, the workstation will be used as a workstation for the car and will be used a lot for testing, transportation and at the pit stop during the race. Therefor it is critical that it is easy to use.
- Manoeuvrability, the workstation will essentially work as a trolley and must have wheels that can handle cobblestone roads. It also cannot be too heavy since we want to move it around.
- Stability, the workstation must be stable while the car is being tested.
- It is necessary to have mounting points to strap the car down securely.
- Good mounting for the electrical components is crucial.
- Possibility to lift the car up, makes it easier to work on the car.
- Storage area for tools, spare parts, and other components.
- Simulation elements, the front wheels must be able to rotate so that it is possible to use the wheel angel as an input for the simulation system. And we need a screen in front of the car for the driver to look at while running simulations.
- Design elements that represents NTNU, DNV GL Fuel Fighter and other sponsors.
- Extract the power from the test rollers and use that power in a different way (for example sound or lights).

3.3 Product requirements specification

- Functional requirements
    - Must be able to test each of the two driving wheels independently.
    - Must be able to lift the car with all the weight of the car resting on the chassis.
    - Adjustable for different wheelbases.
    - Wheels that can handle cobblestone
- Environmental requirements
    - Zero CO_2 emissions
    - Noise level during operation, below 95 decibels
- Operational requirements

- Max weight 300 Kg
    - Must be able to secure the car efficiently and properly.
    - A way to steer the workstation
- Dimensions
    - Max length 3,5 m
    - Max height 0,8 m
    - Max width 1,7 m
- Safety requirements
    - Emergency brake system

4 Concept

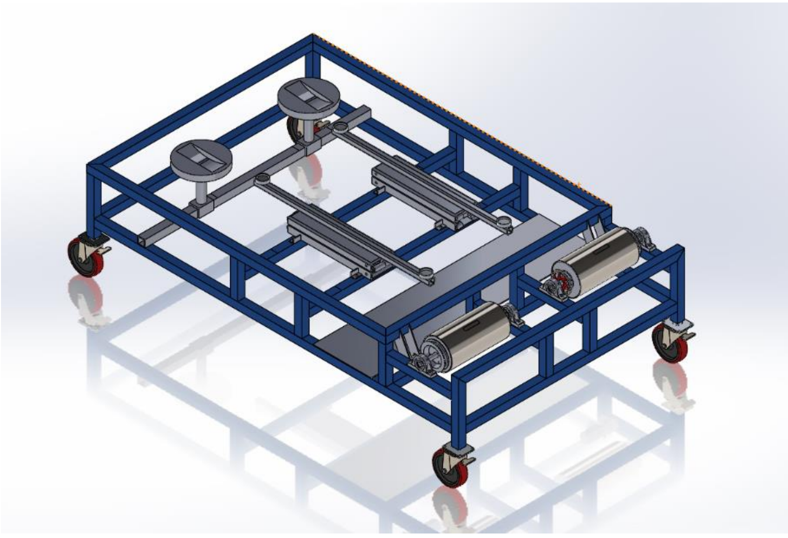


Figure 2 Workstation Concept Model

4.1 Adjustable solution

4.1.1 Width and length

The rollers are in a fixed position, but the rollers themselves are wide enough to allow for change on the car’s wheelbase. The front beam supporting the front wheels can be adjusted in both length and width. The beam is bolted to the frame rather than welded, which allows for adjusting the position depending on the wheelbase of the car.

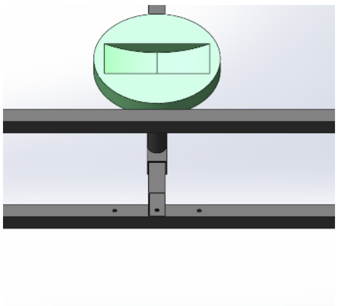


Figure 3 Width Adjustment

Figure 4 Length Adjustment

4.1.2 Lifts

The lifts are bolted on to two crossbeams, the position is set to match the strong points of the underbody of the car and this position will be changed whenever there is a new car with different dimensions. The crossbeams themselves are welded to the frame and will not be adjustable, which means that the car braces must be modified to ensure stability.

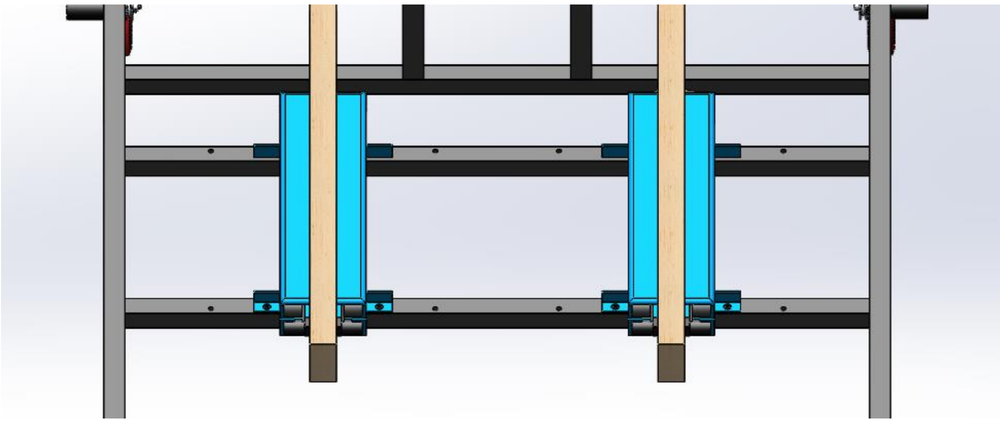


Figure 5 Adjustable Lift

The lifts are originally fitted with a thin rubber surface and comes with extra multi-purpose brackets. But to achieve an optimal contact surface and balance point, each car should have its own customized car brace.

Note that this is only one possible solution. The design of the car brace can be anything you like as long as the car is stable on the lift. Our solution is one plank of wood for each lift, shaped to match the underside of the car, and outfitted with rubber to improve friction and reduce wear and tear.

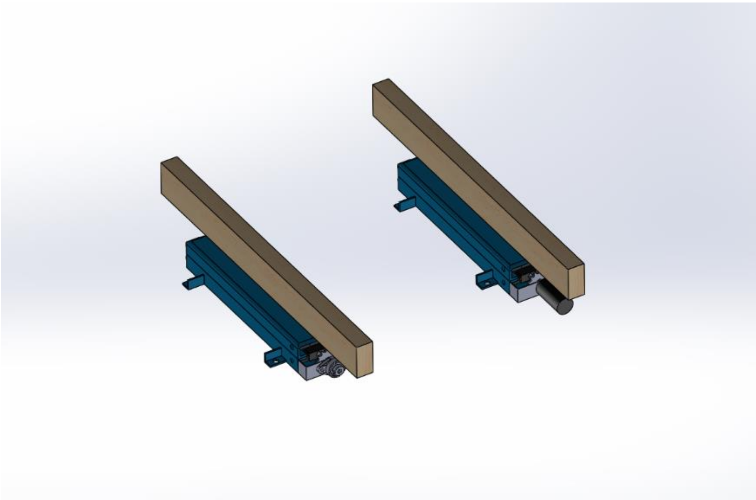


Figure 6 Modified car brace

4.2 Dyno system

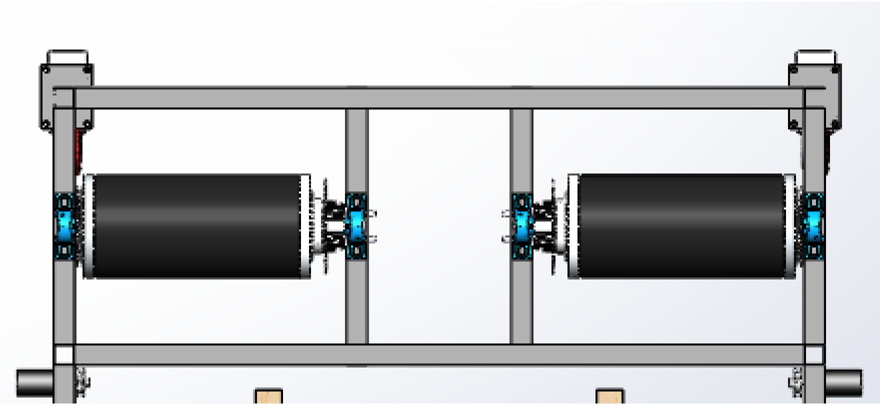


Figure 7 Dyno System

Arguably the most complex system of the entire workstation, the dyno system consists of four main parts. Rollers, pulleys, brakes, and the electric motors. Two separate rollers are required because the wheels on the car run independently.

The rollers are made from aluminium and PVC. A 200mm diameter PVC pipe with an aluminium piece on each side. The aluminium pieces are cut out from a bigger aluminium bolt and machined in a lathe.

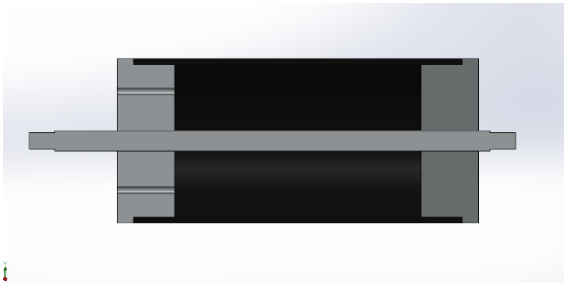


Figure 8 Rollers cross section

Pulleys are made from the same aluminium bolt as the rollers. Brakes are needed to perform emergency stops. An 20mm diameter aluminium axle runs through the rollers and is connected to bearings on each side.

4.3 Lift system

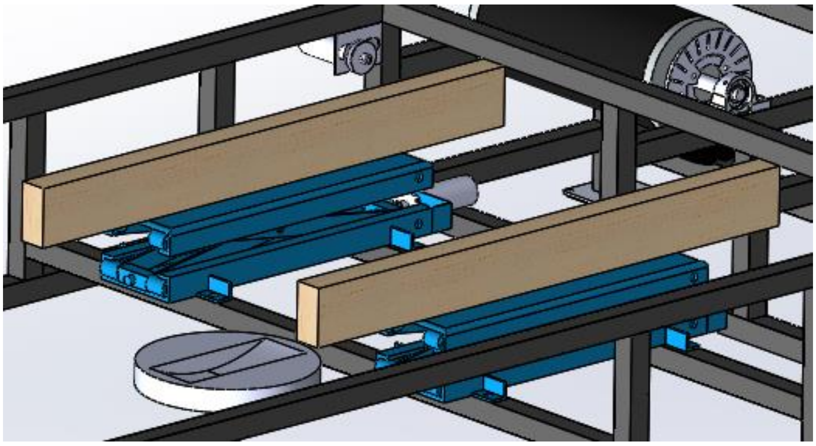


Figure 9 Lift Mechanism

The lift system is a dual lift solution, using two universal lifts, modifying them to add sprockets and joining them together with a chain to create a smooth, synchronized lift. An electric motor is connected to one of the lifts and operated by a up/down button.

4.4 Simulation possibility

At some point, the board want to use the workstation as a track simulator, therefore the front wheels must be able to turn. The solution: A 3D-printed wheel stand, mounted on a bearing allowing it to rotate. Using a potentiometer to measure the angel of the wheel.

4.5 Frame

The concept is broken down in to two parts, design, and material. Given the fact that time is limited, and we do not have expert welders helping us, we opted for a simple frame design with only straight angels. As part of choosing the material, we considered different profiles. Aluminium is by far the lighter option, but the lack of strength does mean that you need a bigger profile. Therefore, the actual weight difference is not significant. The price difference, however, is massive. Steel is a lot cheaper, and stronger, and a smaller profile is therefore enough.

5 How it's made

Figure 10 Workstation Frame

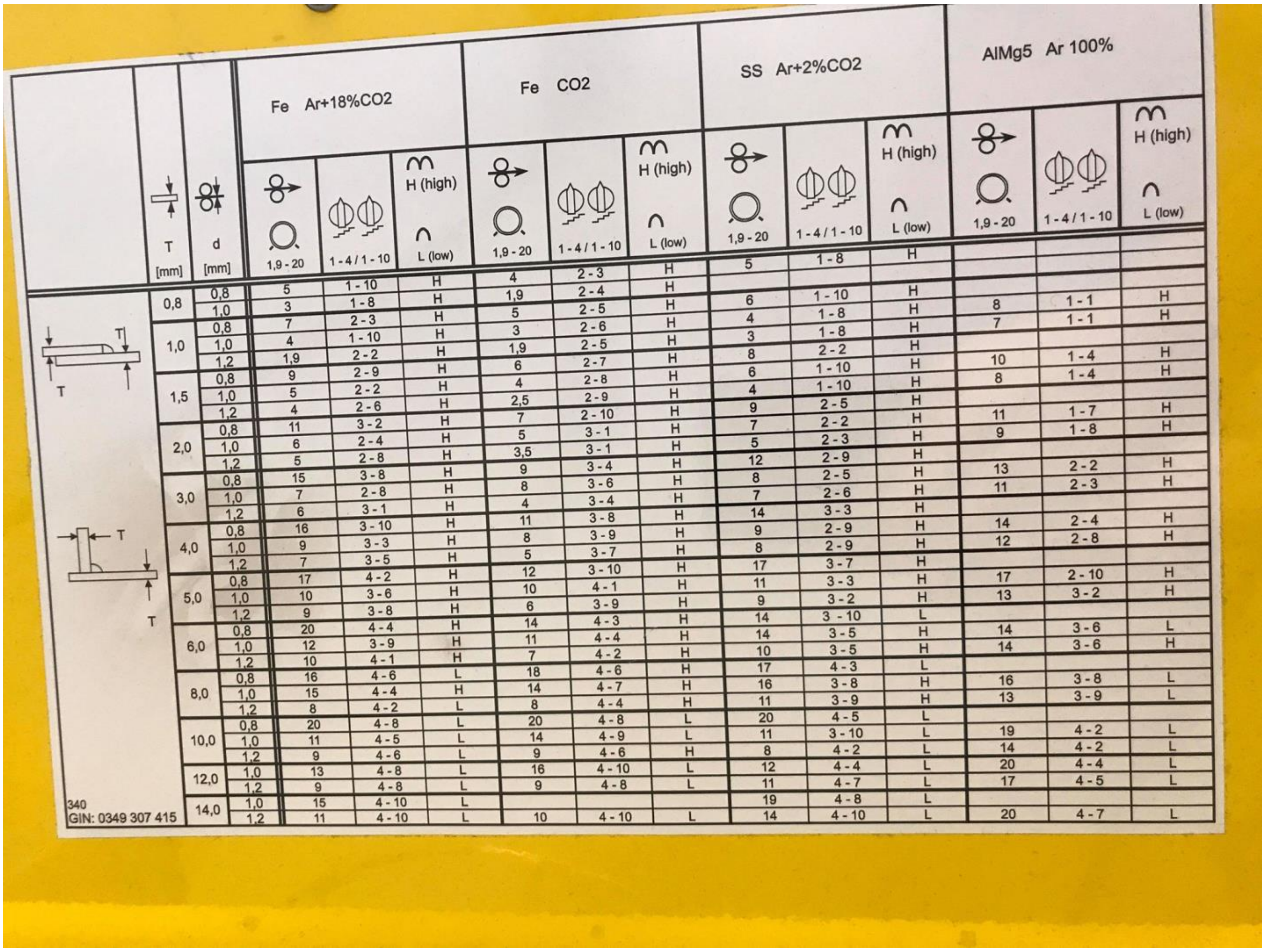
5.1 Welding the frame

5.1.1 Cutting steel

The steel tubes are delivered as standard in 6 m lengths. A cutting-plan is necessary to optimize use of the steel.

The teeth on the band saw are not made for steel as thin as these tubes, most of the cuts are therefore done using a reciprocating saw. This is an inaccurate method and every piece must be grinded on the belt grinder to smooth out the edges and get roughly the correct length. An angle grinder is a better tool to use, it is a lot more precise and easier to use, but workshop regulations prevents us from using one.

5.1.2 Weld settings



	T [mm]	d [mm]	Fe Ar+18%CO2 1,9 - 20	Fe Ar+18%CO2 1 - 4 / 1 - 10	Fe Ar+18%CO2 H (high) / L (low)	Fe CO2 1,9 - 20	Fe CO2 1 - 4 / 1 - 10	Fe CO2 H (high) / L (low)	SS Ar+2%CO2 1,9 - 20	SS Ar+2%CO2 1 - 4 / 1 - 10	SS Ar+2%CO2 H (high) / L (low)	AlMg5 Ar 100% 1,9 - 20	AlMg5 Ar 100% 1 - 4 / 1 - 10	AlMg5 Ar 100% H (high) / L (low)
	0,8	0,8	5	1 - 10	H	4	2 - 3	H	5	1 - 8	H			
		1,0	3	1 - 8	H	1,9	2 - 4	H						
	1,0	0,8	7	2 - 3	H	5	2 - 5	H	6	1 - 10	H			
		1,0	4	1 - 10	H	3	2 - 6	H	4	1 - 8	H	8	1 - 1	H
		1,2	1,9	2 - 2	H	1,9	2 - 5	H	3	1 - 8	H	7	1 - 1	H
	1,5	0,8	9	2 - 9	H	6	2 - 7	H	8	2 - 2	H			
		1,0	5	2 - 2	H	4	2 - 8	H	6	1 - 10	H	10	1 - 4	H
		1,2	4	2 - 6	H	2,5	2 - 9	H	4	1 - 10	H	8	1 - 4	H
	2,0	0,8	11	3 - 2	H	7	2 - 10	H	9	2 - 5	H			
		1,0	6	2 - 4	H	5	3 - 1	H	7	2 - 2	H	11	1 - 7	H
		1,2	5	2 - 8	H	3,5	3 - 1	H	5	2 - 3	H	9	1 - 8	H
	3,0	0,8	15	3 - 8	H	9	3 - 4	H	12	2 - 9	H			
		1,0	7	2 - 8	H	8	3 - 6	H	8	2 - 5	H	13	2 - 2	H
		1,2	6	3 - 1	H	4	3 - 4	H	7	2 - 6	H	11	2 - 3	H
	4,0	0,8	16	3 - 10	H	11	3 - 8	H	14	3 - 3	H			
		1,0	9	3 - 3	H	8	3 - 9	H	9	2 - 9	H	14	2 - 4	H
		1,2	7	3 - 5	H	5	3 - 7	H	8	2 - 9	H	12	2 - 8	H
	5,0	0,8	17	4 - 2	H	12	3 - 10	H	17	3 - 7	H			
		1,0	10	3 - 6	H	10	4 - 1	H	11	3 - 3	H	17	2 - 10	H
		1,2	9	3 - 8	H	6	3 - 9	H	9	3 - 2	H	13	3 - 2	H
	6,0	0,8	20	4 - 4	H	14	4 - 3	H	14	3 - 10	L			
		1,0	12	3 - 9	H	11	4 - 4	H	14	3 - 5	H	14	3 - 6	L
		1,2	10	4 - 1	H	7	4 - 2	H	10	3 - 5	H	14	3 - 6	H
	8,0	0,8	16	4 - 6	L	18	4 - 6	H	17	4 - 3	L			
		1,0	15	4 - 4	H	14	4 - 7	H	16	3 - 8	H	16	3 - 8	L
		1,2	8	4 - 2	L	8	4 - 4	H	11	3 - 9	H	13	3 - 9	L
	10,0	0,8	20	4 - 8	L	20	4 - 8	L	20	4 - 5	L			
		1,0	11	4 - 5	L	14	4 - 9	L	11	3 - 10	L	19	4 - 2	L
		1,2	9	4 - 6	L	9	4 - 6	H	8	4 - 2	L	14	4 - 2	L
	12,0	1,0	13	4 - 8	L	16	4 - 10	L	12	4 - 4	L	20	4 - 4	L
		1,2	9	4 - 8	L	9	4 - 8	L	11	4 - 7	L	17	4 - 5	L
	14,0	1,0	15	4 - 10	L				19	4 - 8	L			
340 GIN: 0349 307 415		1,2	11	4 - 10	L	10	4 - 10	L	14	4 - 10	L	20	4 - 7	L

Figure 11 Weld Settings

5.1.3 Wheel plates

The wheels are attached to the frame using thin plates of steel with four bolts running through them. The plates are cut in to four 105X135 mm squares, from a larger, 3 mm thick sheet of steel using a plasma cutter. Sharp edges and rough surfaces are removed using a belt sander. The pieces are then welded on to the frame, with the frame profile placed in the centre of the plate.

Holes are made in each corner of the plate, the prefabricated holes in the swivel works as a template. The holes can be made using a drill or a small milling machine. The plates and wheels are locked together with bolts.

Figure 12 Wheel Plates

5.2 Modify and mount lifts

Figure 13 Lifts, Under Production

5.2.1 Modify

There are two main aspects that has been modified:

- *Adjustment screw*
- *Brackets*

The lifts are delivered with the *adjustment screw* at the top end, meaning that it elevates along with the lift. The inner mechanism is flipped, so the adjustment screw is stationary at the bottom end. This makes the dual lift mechanism easier to build. Flipping the inner mechanism is simple, the lift can be dismantled and put back together the other way around.

Brackets are welded on each corner of the lift. The brackets are pieces of steel angle, with a bolt hole. The surface of each corner is treated with a pneumatic straight grinder before welding.

Figure 14 Lift Brackets

5.2.2 Mount

The lifts are placed apart on two crossbeams, holes are made using a drill. Bolts hold them in place.

5.3 Making rollers

The workstation has two rollers, one for each back wheel. The rollers are completely independent of each other. This makes it possible to see performance differences in the cars two engines.

Figure 15 Rollers, PVC, and End caps

One roller consists of three main components:

- *Roller pipe*
- *End caps*
- *Axel*

The *roller pipes* are PVC-tubes with an outer diameter of 200 mm and a wall thickness of 5 mm.

A band saw was used to cut the tubes to 400 mm lengths. The rollers are made to be as wide as possible, within the dimensions of the workstation, so the workstation is compatible to as many car designs as possible.

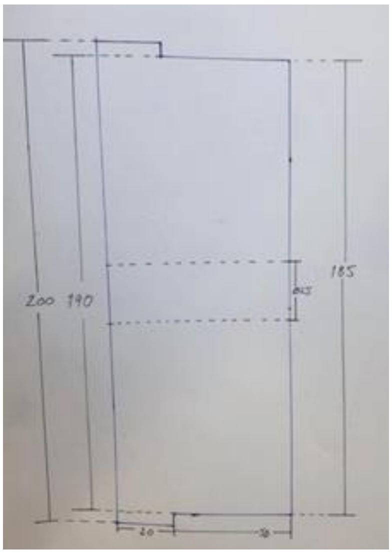


Figure 16 End Cap Drawing

Each roller has a two *end caps*, one in each end of the PVC tube.

The caps have been turned from a solid block of aluminium to ensure that they are as round and even as possible. They are turned with a 2-degree angle on the face that sits against the inner surface of the tube. This allows the caps to sit securely with a press fitting in the tube. The caps have a 20 mm lip which sits flush with the tube to prevent the caps from moving.

All the caps also have a hole in the centre with a diameter of 25 mm, this is for the axel.

Remaining work:

- Make mounting holes for pulleys and brake discs

The axels have not been made yet, but the development is complete.

The axels will be made from 20, or 25 mm solid aluminium rods and balanced on a lathe to ensure as little vibrations as possible. The axel will be mounted to ball bearings in each end.

To connect the caps and the axel the plan is to utilize welding. This might be challenging due to the thickness of the material. Other possibilities should be considered.

6 Further Development

6.1 Finishing the frame

6.1.1 Inspect and fix welds

The frame is welded in every connection, but none of the welds are inspected properly. A visual inspection is enough, welds with big cracks or other defects must be welded again.

6.1.2 Grind, wash, prime and paint.

Paint will not only make the workstation look better, but also protects it from corrosion. If possible, use an angle grinder to smooth out the external welds. If an angle grinder is unavailable because of workshop regulations, use a pneumatic straight grinder. Doing this will make the welds somewhat weaker, but they are still strong enough.

Wash the frame with Acetone or a similar solvent to remove oil and dust. Then apply a layer of primer, followed by one or two layers of paint. Letting each layer dry before applying the next.

6.2 Making the pulleys

The pulley system for each roller consist of one roller pulley and one motor pulley. Each of them was supposed to be turned out of aluminium.

We were planned on using a 3:1 ratio, where the diameter on the roller pulley would be 150 mm and diameter on the motor pulley would be 50 mm. This would result in an almost 1:1 ratio in-between the car motor and workstation motor.

The roller pulley is attached to the end caps of the roller with 4 bolts. The side that bolts to the roller is flat to allow the pulley to sit as close to the roller as possible, to make the potential wheelbase as wide as possible.

The motor pulley is locked onto the motor shaft with a set screw. The collar with the set screw is flipped so that the pulley wheel itself, sits close to the frame. This is so to match the frame proximity of the roller pulley.

6.2.1 Production method

The material for the pulleys is a 200 mm 6082-T6 aluminium bolt, the same material as the one for the roller end caps.

The plan was to use the CNC bore mill for the bolt holes. The bolt size depends on what is available in the workshop.

For the motor pulley we would use available material from the workshop. We would use an aluminium bolt with a diameter greater than 60mm.

For the set screw hole, we would first bore it out with a mill or drill press. Then we would tap the hole to the appropriate dimension. The dimensions of the set screw would depend on what we had available or could buy easily.

6.2.2 The groove

We first bought two Marathon II AVX10 v-belts from Optibelt, which we then used to design the pulleys. The manufacture's standards were available online, so we used that to calculate the exact dimensions of the groove. We were also presented with the minimum pulley size, which was around 50 mm for our belt.

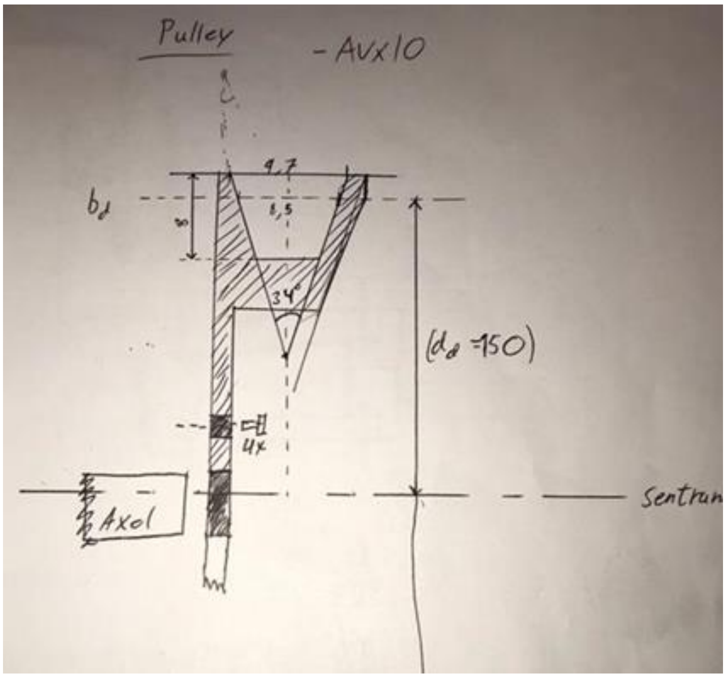


Figure 17 Pulley Drawing

6.3 Making front wheel stands

6.3.1 The crossbeam

The crossbeam is the same 40x40x1,5 mm steel square tube as the rest of the frame. This is the component that allows for adjusting both width and length. It must therefore be bolted on, rather than welded. To avoid using too long bolts, the crossbeam should be cut at a 45-degree angle at each end.

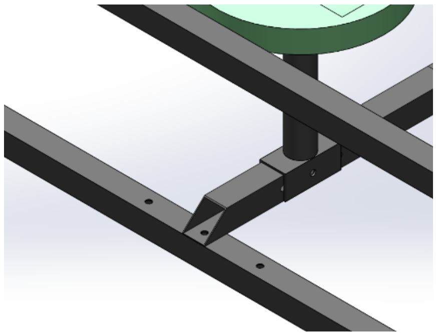


Figure 18 Crossbeam with 45-Degree Cut

Because of the inaccurate cuts, the frame is not the exact dimensions as the CAD-model. One must measure the wheelbase of the car and then mark the correct length when bolting on the crossbeam. The same procedure goes for adjusting the width.

6.3.2 The wheel stand

The wheel stand consists of four parts:

- A 3D-printed disc
- Ball bearing
- Support beam
- Potentiometer

A disc spins freely on a ball bearing, supported by a vertical beam.

Using a 3D-printer to make the disc is a good solution because it is cheap, ease to make several prototypes and allows for quick changes to the design. The disc is designed with a groove to match the curvature of the tire.

Figure 19 Wheel Stand Prototype

Some notes on the first prototype:

- They are too small, the disc must be printed on the bigger printer or made in to two halves that are later glued together. Using a bigger printer is the preferred option.
- The groove must be deeper to get more support on each side of the wheel.
- The tap that fits in the ball bearing must me slightly smaller and be equipped with the potentiometer.

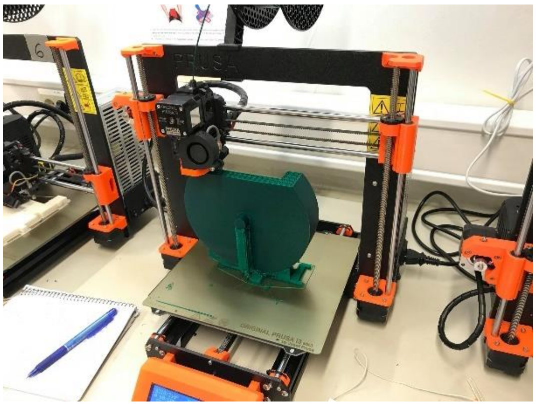


Figure 20 3D-Printed Disc Prototype

The potentiometer must be positioned right in the centre of the disc, between the ball bearing and support beam. One thing to keep in mind is the fact that usually when you turn the wheels on a car, the tires move in a slight arc. Meaning they cannot spin on a stationary disc. On FuelFighter 5 however, this is not a problem. But this problem must be addressed for future cars that might have a different set up.

Figure 21 Potentiometer

6.4 Finishing dual lift mechanism

6.4.1 Chain and sprockets

To make this solution work, the lifts need further modifying. The sprockets must be welded on to the screws of each lift. Both the screw and sprocket are made from steel, so a simple MIG weld should do the job. An electric motor will be directly connected to one of the lifts, this lift must therefore have a rod/axle going through the sprocket so the motor can drive the lift.

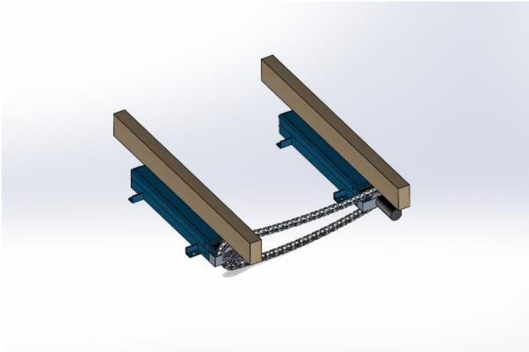


Figure 22 Lift with Gear and Sprockets

A platform or hinge to support the motor must also be made.

6.4.2 Contact surface

A plank of wood, a rubber mat and bolts are the three component that make out the contact surface for the lifts. Making this is a three-step process:

1. Drill two holes in the plank of wood. (This step is done).
2. Shape the wood to match the curvature of the underside of the car.
3. Make a paper template of the plank, use the template when shaping the rubber, attach the rubber to the plank with glue.

This is a custom part for the current Fuel Fighter car (FuelFighter 5) and will probably not fit a new car. The lifts are in a fixed position on the frame in the length direction which means the contact surface is the one part that can be adjusted to make sure the car is balanced on the lifts.

6.5 Exterior, storage, and other design elements

The exterior and storage areas will be made from plywood. Making speakers is an exciting way of giving the workstation a bit of show factor. They can either be bought in or made completely from scratch.

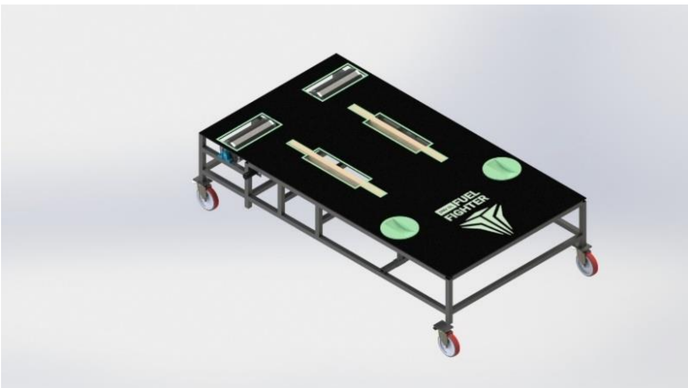


Figure 23 Complete model with plywood panels

6.6 Braking system

The braking system consist of braking callipers, brake discs, mounting brackets and roller-disc adapters.

The plan was to use callipers and discs from a previous braking system for the car. Unfortunately, no accurate measurements were ever made to the callipers, therefore the bracket must be designed from the bottom up. A ruff idea of how the brackets works can be found within the 3D model, using an alternative calliper. To achieve the accurate mounting for the callipers, the use of a CNC mill is advised.

The roller-disc adapter is made from the same material as the end pieces and pulleys. It consists of two bolt patterns layered on top of each other. This is to space the disc out from the roller and allow the calliper in-between. It is made by turning the piece of aluminium on the lathe.

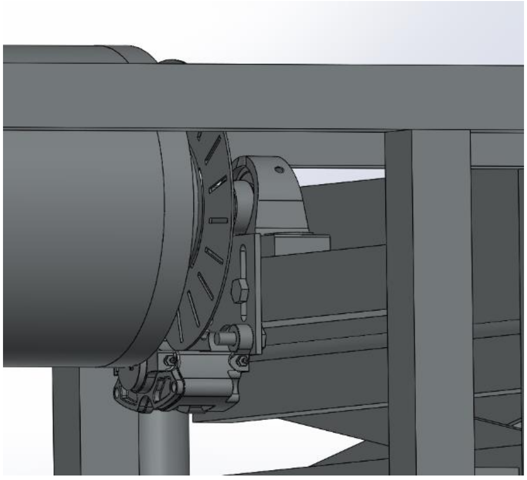


Figure 24 Brake System

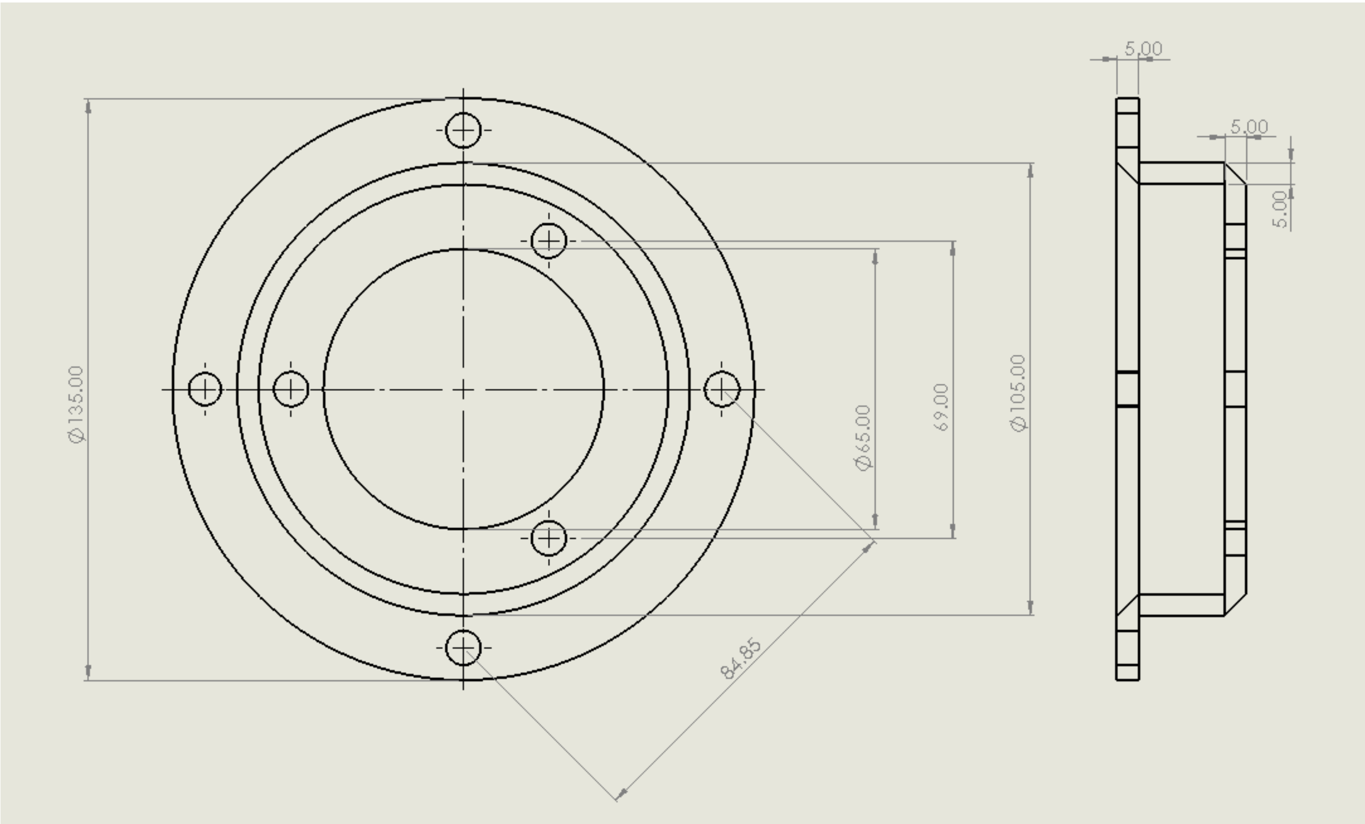


Figure 25 Roller-Disc-Adapter

7 Appendix

7.1 Technical data sheet