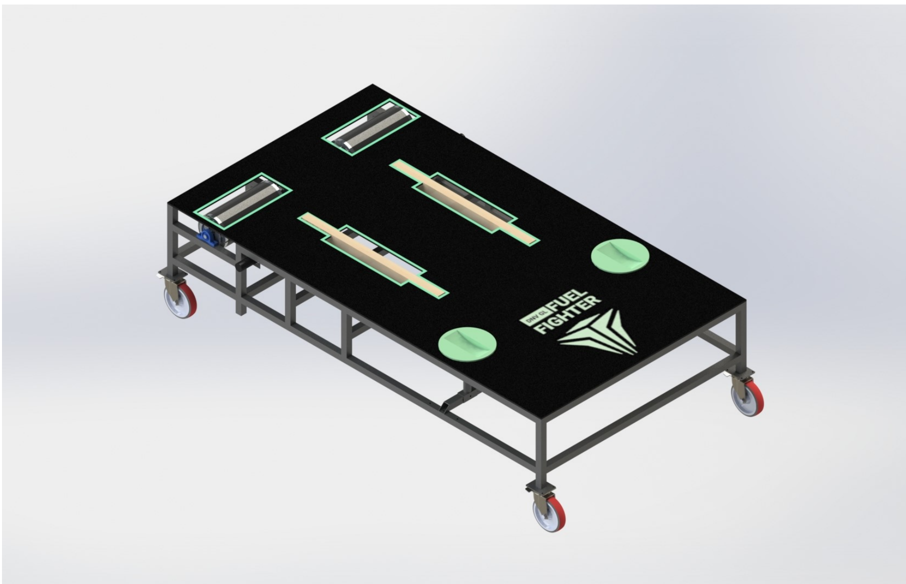
Espen Furuli Kvil, John-Arne Nyheim, Daniel Vennestrøm

Development of Multifunctional Workstation

Bachelor's project in Mechanical Engineering
Supervisor: Detlef Blankenburg
May 2020

Bachelor's project

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering



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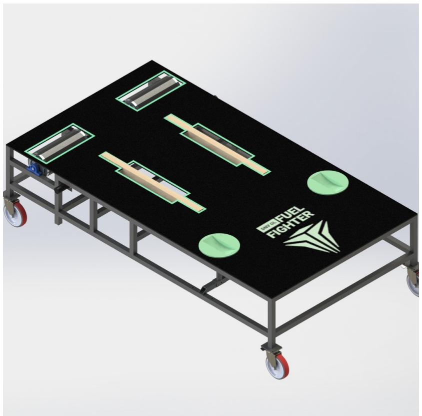

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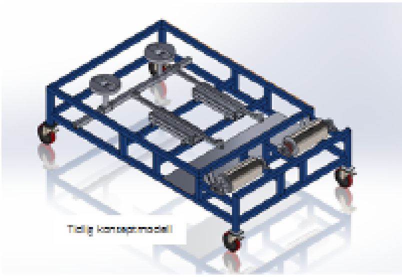
Science and Technology

Institutt for maskinteknikk og produksjon

BACHELOROPPGAVE VÅR 2020
ESPEN FURULI KVIL; JOHN-ARNE NYHEIM
DANIEL VENNESTRØM

UTVIKLING AV MULTIFUNKSJONELL ARBEIDSSTASJON
Development of multifunctional workstation



Fuel Fighter har bygget biler til Shell Eco-Marathon siden 2007. Målet med konkurransen er å utvikle en bil til å være så energieffektiv som mulig. Grunnet det utfordrende klimaet i Norge er det et problem å få testet bilen på bane i vinterhalvåret. For å gjøre testingen mer effektiv og trygg skal det utvikles en arbeidsstasjon til bilen. Ønskelista til stasjonen er lang, blant annet: testing og kalibrering av bilen, oppbevaring av verktøy, mulighet for banesimuleringer, transporttralle og pit-stop under løpet.

Oppgaven gjennomføres i samarbeid med NTNU og DNV GL Fuel Fighter og omfatter følgende punkter:

1. Kort analyse og beskrivelse av produkt, teknologi og marked
2. Utvikling av nødvendige spesifikasjoner som grunnlag for arbeidet.
3. Utvikling, evaluering og presentasjon av alternative konsepter.
4. Valg, videre detaljering og raffinering av de mest lovende konseptene.
5. Utvikling av struktur, utforming og dokumentasjon av utvalgte komponenter.
6. Fremstilling og test av utvalgte komponenter.
7. Evaluering og presentasjon av resultatene.
8. Evaluering av valgt metodikk og resultatene i forhold til læringsmålene.

Oppgaven skal aktiv ta i bruk PU - journal. Senest 3 uker etter oppgavestart skal et A3 ark som illustrerer arbeidet leveres til faglærer. Arket skal også oppdateres en uke før innlevering av bacheloroppgaven.

Arbeidet skal risikovurderes. Risikovurdering er en løpende dokumentasjon og skal gjøres før oppstart av enhver aktivitet som KAN være forbundet med risiko.

Besvarelsen skal ha med signert oppgavetekst, et sammendrag på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse, etc. Ved utarbeidelse av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Ved bedømmelse legges det stor vekt på at resultater er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte og diskuteres utførlig.

Kontaktperson: Jens Buvik Bugge, Prosjektleder Fuel Fighter

Detlef Blankenburg
Faglærer

NTNU
Fakultet for ingeniørvitenskap

Foreword

This Bachelor thesis is directed towards members of DNV GL Fuel Fighter as well as the sensor and supervisor of the bachelor thesis.

The thesis is written in collaboration with DNV GL Fuel Fighter, a student organization at NTNU Trondheim that builds electric cars to compete in Shell Eco-marathon. This is a competition with several category's, DNV GL Fuel Fighter are competing in "Urban Concept, Battery-Electric". The goal is to build the most efficient electric car.
The team are currently using a makeshift trolley when they work on the car, they have faced several problems with it, and therefore wants a new workstation.
This report showcases the work put in to develop the mechanical parts of the new workstation.

We came across an assignment for DNV GL Fuel Fighter when we read through recommended assignments available at Blackboard. In a meeting with DNV GL Fuel Fighter, we were told that the task we originally wanted was taken, but they wanted to build a new workstation. We were intrigued by the size, level of practical work and freedom of the project.

The project is sponsored by DNV GL Group AS and is considered as a subsystem in the 2019/2020 DNV GL Fuel Fighter program. Development and production take place at Verkstedteknisk, Institute of Mechanical Engineering and Manufacturing.

We are mechanical engineer students, with structural engineering as our specialty.
We want to thank Detlef Blankenburg, associate professor, Institute of Mechanical Engineering and Manufacturing, for helping us throughout this project. And Jens Buvik Bugge, Project manager, DNV GL Fuel Fighter, for giving us the freedom and resources to work on this project.

Trondheim 19. May 2020

Espen Furuli Kvil | Daniel Vennestrøm | John-Arne Nyheim

Summary

How do you attack a problem where you have no previous experience and the product you are developing does not exist anywhere else? The product in question is an assembly of concepts and ideas which need to function together smoothly to create a tool that only brings benefits and no draw backs. Sounds like a challenge.

This bachelor thesis documents the development of a multifunctional workstation for DNV GL Fuel Fighter's electric cars. The purpose of the project was to create a system that streamlined maintenance and testing. The task was open and with few restrictions, however the leaders of Fuel fighter had some wishes for elements they wanted. Our challenge was to develop a product which integrated all the desired features.

The project consists of a concept stage, design stage and production stage.
Mechanical theory, product development, project management and production methods are centre points in this project and are very present in this thesis. It showcases how we have worked, and the different methods utilized in each step of the development. The task at hand was a big undertaking and therefore required thorough planning and clear goals for what we wanted to achieve. The workstation is a tool and a showpiece, it will display Fuel Fighter and its cars in the best way possible. Therefore, aesthetics also plays a big role in the development.

The main portion of the thesis focuses on the development of the workstation as a whole, and all its components. There are very few products that resemble the workstation. This means a lot of work had to be put into deciding what would be possible to pull off, and which features, and materials would be most beneficial to the design. Fuel fighter makes new cars with new parameters every other year, meaning every feature in our design needed to be adjustable. Picking the right solution and the thought process behind the decisions are described in detail, as well as alternative solutions.

When such a big project is set in motion unforeseen events will occur, and these must be handled in the best way possible. Through this experience we have been tested on the knowledge we have acquired throughout our studies, as well as our ability to work in a team and solve problems as a group. The challenges we have met and the experience we acquired through this process is valuable and is shared in this thesis for you to enjoy.

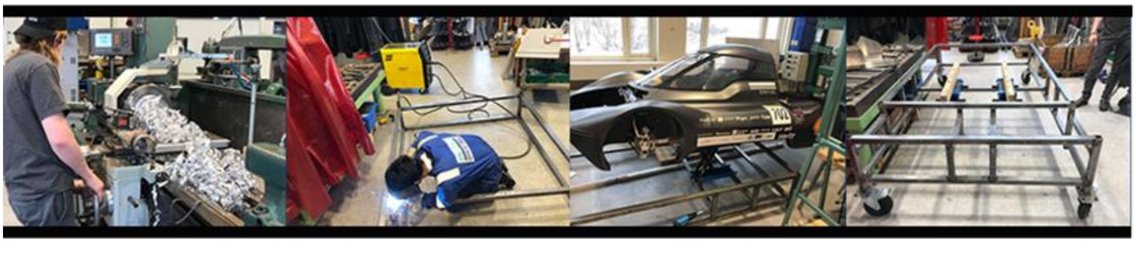
Oppsummering
Hvordan angriper du et problem der du ikke har tidligere erfaring og produktet du utvikler ikke finnes andre steder? Produktet det er snakk om er en samling konsepter og ideer som må fungere sammen for å lage et verktøy som bare gir fordeler og ingen ulemper. Høres ut som en utfordring.

Denne bacheloroppgaven dokumenterer utviklingen av en multifunksjonell arbeidsstasjon for DNV GL Fuel Fighters elbiler. Hensikten med prosjektet var å lage et system som effektiviserte vedlikehold og testing. Oppgaven var åpen og med få begrensninger, men lederne av Fuel Fighter hadde noen ønsker for elementer de ønsket. Utfordringen vår var å utvikle et produkt som integrerte alle de ønskede funksjonene.

Prosjektet består av et konseptstadium, designprosess og produksjon.
Mekanisk teori, produktutvikling, prosjektledelse og produksjonsmetoder er hovedtemaer i dette prosjektet og er godt beskrevet i denne oppgaven. Den viser hvordan vi har jobbet, og de forskjellige metodene som ble brukt i hvert trinn i utviklingen. Oppgaven var et stor og krevde derfor grundig planlegging og klare mål for hva vi ønsket å oppnå. Arbeidsstasjonen er et verktøy og en stand, den vil vise Fuel Fighter og bilene på best mulig måte. Derfor spiller estetikk også en stor rolle i utviklingen.

Hoveddelen av oppgaven fokuserer på utviklingen av arbeidsstasjonen som en helhet, og alle dens komponenter. Det er veldig få produkter som ligner arbeidsstasjonen. Dette betyr at mye arbeid måtte legges i å bestemme hva som ville være mulig å gjennomføre, og hvilke funksjoner og materialer som ville være mest fordelaktig for sluttproduktet. Fuel Fighter lager nye biler med nye parametere annen hvert år, noe som betyr at alle komponenter i designet vårt måtte være justerbare. Å velge riktig løsning og tankeprosessen bak beslutningene er skrevet om i detalj, i tillegg er alternative løsninger beskrevet.

Når et så stort prosjekt settes i gang vil uforutsette hendelser oppstå, og disse må håndteres på best mulig måte. Gjennom dette prosjektet har vi blitt testet på kunnskapen vi har tilegnet oss gjennom studiene, samt vår evne til å jobbe i team og løse problemer som en gruppe. Utfordringene vi har møtt og erfaringen vi har tilegnet oss gjennom denne prosessen er verdifulle og deles i denne oppgaven.



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1 Project Foundation

1.1 Problem Definition

DNV GL Fuel Fighter builds 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 test the car during the winter. To make testing more efficient and safer, a multifunctional workstation will be developed. This workstation will have features that enables testing and calibration of the car, tool storage and facilitate for track simulation, as well as acting as a transport trolley and used on the pit stop during the race.

Building the workstation requires both mechanical and electrical solutions. The task is split in to two teams.

- Mechanical team:
  - John-Arne Nyheim
  - Espen Kvil
  - Daniel Vennestrøm
- Electrical team:
  - Alexander Johnsgaard
  - Halvard Hanisch

This bachelor thesis focuses on the mechanical aspect.

1.1.1 Marked

Shell Eco-marathon is a worldwide competition with teams from all over the world. The workstation is a custom-built tool for DNV GL Fuel Fighter and is meant to give them an edge in the competition. Therefore, not a product that can be advertised and mas-produced to other competing teams. The workstation has no value outside of the Shell Eco-marathon competition. All though the principal concept can be modified to fit the normal car industry, this product is meant to be a "one off" just for DNV GL Fuel Fighter.

1.2 Goals

1.2.1 Performance goals

The goal is to develop, build and test a multifunctional workstation that will be used for the 2019-20 Fuel Fighter car, and future Fuel Fighter cars. With the main criteria in mind, a concept solution and design a 3D-model will be developed. In addition, strength tests will be run on the prototype to see if there is room for improvements.
The project will run over the course of roughly seven months, starting 22. September and ending 20. May.

1.2.2 Impact goals

By creating a multifunctional workstation for the car, the goal is to increase the number of test hours and decrease the general wear on the car. The workstation will also give DNV GL Fuel Fighter the opportunity to test the car no matter the season or weather. At the same time cutting down the time spent on "set up" by having the tools and the car in one place, and also the car can be lifted up so you have easy access to all parts of the car.
The workstation should be a tool Fuel Fighter can use for several years to come regardless of whether changes are made to the car or the car's design changes altogether.

Personal goals for the project:

- Improve our English skills.
    - In a way of improving our English we have decided to write our bachelor thesis in English. We also look at this as particularly important going forward into our careers, because a lot of companies today require English.
- Use our technical knowledge and gain experience with project work.
    - In the future we will encounter problems where our technical knowledge is needed. It is therefore important for us to learn how to utilize the knowledge we have acquired in a useful way. This project will give us a good experience doing exactly that.
- Develop new technical and practical skills through our work.
    - When we encounter problems that we have never seen before, it becomes a necessity to evolve. That is why we emphasize the importance of being able to develop new skills through our work.

- Achieve good group synergy and get a good result.
    - Achieve good group synergy and with that, we hope to get the best possible result out of this project.

1.2.3 Success criteria

Given the time frame and lack of experience with projects of this sort, there is a chance that the project will not complete all its goals. The success criteria are therefore divided into two parts: One, a minimum list of criteria where we are making sure to set up the workstation the best way we can for further development. And two, a more comprehensive list that reflects a scenario where most things go according to plan. To complete either one of the lists will be considered a success.

Minimum success criteria:

- Finished frame
    - Produced a welded frame, complete with rollers, lifts, and front wheel rack.
    - The frame does not need to be painted.

  - The parts do not need to function, but they must be set up in a way that makes it easy to mount electrical equipment.
- Able to handle surfaces like cobblestone
  - Supplied the workstation with wheels that can handle rough surfaces.
- Backbone to use for further development
  - Written a comprehensive paper that includes a concept description, explanation of production methods, data sheet, and plan for further development.
- Adjustable
  - The design allows for adjustments to fit different wheelbases.
  - Fuel fighter develops a new car every other year. Because of this it is crucial that the workstation is adjustable to ensure it will fit future cars.
- Moveable by two people
  - Weight is an important factor in the design. It cannot be so heavy that two people will not be able to move it around.
- The car can be stored safely on the workstation without putting weight on the tires
  - To ensure that the tires stay perfectly round the car must rest on the chassis instead of the tires while not in use.
- Safe to use
  - People will be working in and around the workstation. Safety is important and precautions need to be made to ensure secure use and operation.

Comprehensive success criteria:

- Completed minimum success criteria
- Accurate data from testing
  - It is important that the data registered from the workstation is correct, if not the modifications made to the car might be incorrect.
- Have a working workstation by the end of march
  - The car is set to be ready for testing at the start of April, which means the workstation must be done before that.
  - Paint and additional design elements do not need to be finished by then.
- Possibility for a track simulator
  - The workstation is set up to facilitate for track simulation.
  - A future goal is to be able to simulate a race on the workstation.

1.3 Specifications

As part of the initial talks about this project, Jens (project manager) and Ole (technical leader) had a small list of requirements:

- The workstation must be able to work for future Fuel fighter cars as well as the current one.
- It must fit inside their trailer to make sure it is easy to transport.
- The weight on the car must be supported by the chassis rather than the tires for most of the time to avoid flat spots.
- Ability to test each of the driving wheels independently.
- Have the possibility to integrate a track simulator into the workstation.

1.3.1 User requirements specification:

User requirements specification is a list of what the user expects the product to deliver.

- 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 provides data about the car's performance.
- Ease of use, the workstation 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 needs to be light enough to move 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.
- 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 angle as an input for the simulation system. And 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.

1.3.2 Product requirements specification

Product requirements specification is the developers list of features that are necessary to satisfy the user requirements.

- 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

1.4 Stakeholders

"In practice, stakeholder work has two angles: partly analysis of who the project must relate to, and partly activities to deal with these different stakeholders. It is therefore important not only to list stakeholders, but also to plan for how stakeholders should be followed up."
(Rolstadås & Olsson & Johansen & Langlo, 2014, p. 79)

1.4.1 Stakeholder Mind map

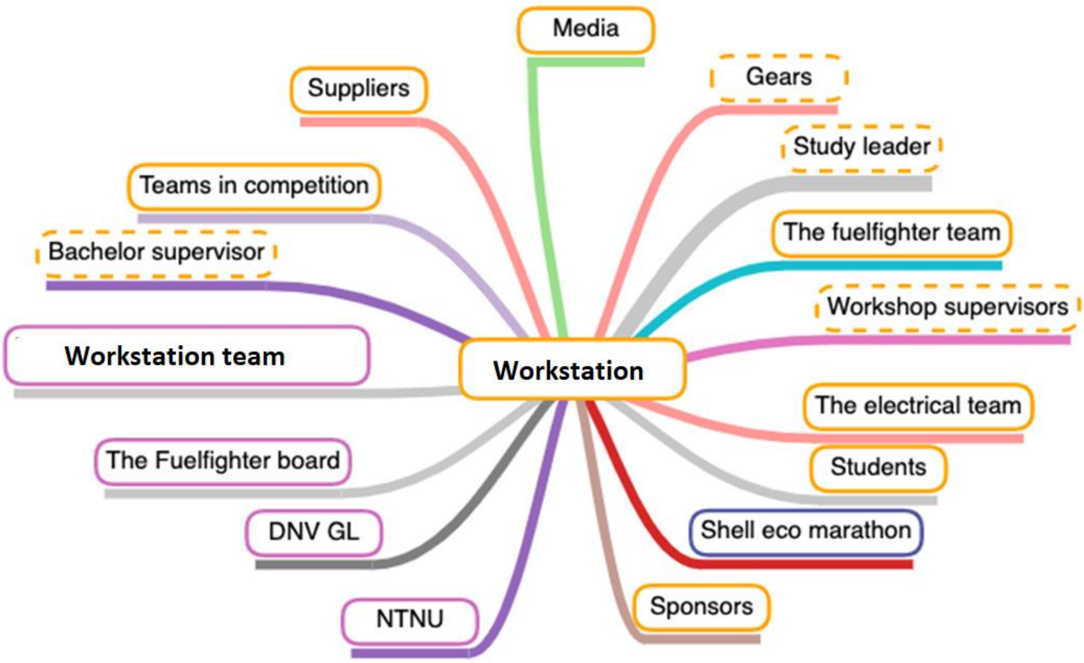


Figure 1 Stakeholder mind map

1.4.2 Demands, expectations, and goals

Primary	Secondary	Demands, expectations and goals
DNV GL		They expect good representation and puplisity for their compnay through our product and actions. They also expect sensable use of their funds and to see progress being made for the Fuel Fighter team
NTNU		Same as DNV GL but our image and representation of NTNU is more important here.
Fuel Fighter board		A solid, functional and relyable product that will serve Fuel Fighter for many years. It must be easy to use and adjustable to fit future needs. Some style points is also wanted.
Project group		We expect of eachother that everybody works hard, communicate, show up on time and give good effort
Shell eco-marathon		They want cool ideas and inovative solutions that showcases the event in a good way.
Workstation electrical team		We all expect to finish the product on within our time plan. Good communication between us and a clear idea of what we are triyng to achive.
Bachelor supervisor		Keep posting PU-journal and keep any deadlines. We expect him to help us if we have questions or other problems.
Study leader, Bachelor of mechanical engineering		We have to deliver milestones within deadlines and stick to the bachelormanual
Workshop supervisors		They expect us to behave at the workshop, respect the rules and clean up after our self.
Gears		We are dependent on his gir system, for us to determine roller/pulley ratio etc.
	Fuel Fighter Team	They expect us to finish the workstation somewhere around mars, so that they have time to do some testing.
	Sponsors	N/A
	Suppliers	We expect them to deliver the correct product and on time.
	Media	N/A
	Students	N/A
	Other teams in SEM	N/A

Table 1 Stakeholder overview

1.4.3 Groups

Groups		
Stakeholders	**Importance**	**Benefits and expectation**
Fuel Fighter board Fuel Fighter team Workstation electrical team Gears Bachelor supervisor	1	We will all help each other. FF is a big team with lots of diverse knowledge.
DNV GL NTNU Sponsors Study leader Workshop supervisors Shell Eco-marathon	2	Financial and academic support. Guidelines and rules.
Suppliers Media	3	A supply of materials, potential coverage that
Students Other teams in SEM	4	N/A
Project group		

Table 2 Stakeholder groups

1.4.4 Final analysis

Stakeholders	Primary	Secondary
DNV GL	X	
NTNU	X	
Fuel Fighter board	X	
Shell Eco-marathon	X	
Workstation electrical team	X	
Project group	X	
Bachelor supervisor	X	
Study leader	X	
Gears	X	
Sponsors		X
Workshop supervisor		X
Suppliers		X
Media		X
Students		X
Other teams in SEM		X
Fuel Fighter team		X

Stakeholder	Name	Level of influence	Level of interest	Stakeholer Risk level	Strategy
DNV GL	Kristina Dahlberg	Low	High	2	Keep updatet through status updates from FF board.
NTNU		Low	Low	1	N/A
Fuel Fighter board	Jens Bugge and Ole Wammer	High	High	4	Weekly meetings and regular communication. Information and filesharing through TEAMS.
Shell Eco-marathon		Low	High	2	Try and give the workstation an "x factor" with use of paint, lights and sound.
Workstation electrical team	Alexander Johnsgaard and Halvard Hanisch	High	High	4	Bi-weekly meetings, and regular communication. Also internal meetings when necessary. Filesharing through TEAMS.
Project group	Espen Kvil, John-Arne Nyheim and Daniel Vennestrøm	High	High	4	Weekly meetings, daily communication. A general plan and timetable. Filesharing through TEAMS.
Bachelor supervisor	Detlef Blankenburg	Low	High	2	PU-journal in TEAMS. Communication and meetings if necessary.
Study leader	Anna Olsen	Low	High	2	Deliver milestones, follow bachelormanual. Ask questions if necessary.
Workshop supervisors		High	Low	3	Keep them informed of our activities in the workshop, ask for help when needed.
Gears	Stein Pedersen	High	Low	3	Get status updates weekly. Communcate when necessary.
Sponsors		Low	Low	1	N/A
Suppliers		High	Low	3	Get hold of the right suppliers, that delivers quality materials and are nearby so delivery time doesn't become an issue.
Media		Low	Low	1	N/A
Students		Low	Low	1	N/A
Other teams in SEM		Low	Low	1	N/A
Fuel Fighter team		Low	High	2	Communication and filesharing through TEAMS.

Influence	Low	1	2
	High	3	4
		Low	High
		Interest	

Table 3 Stakeholder final analysis

1.5 Organization

1.5.1 Fuel Fighter

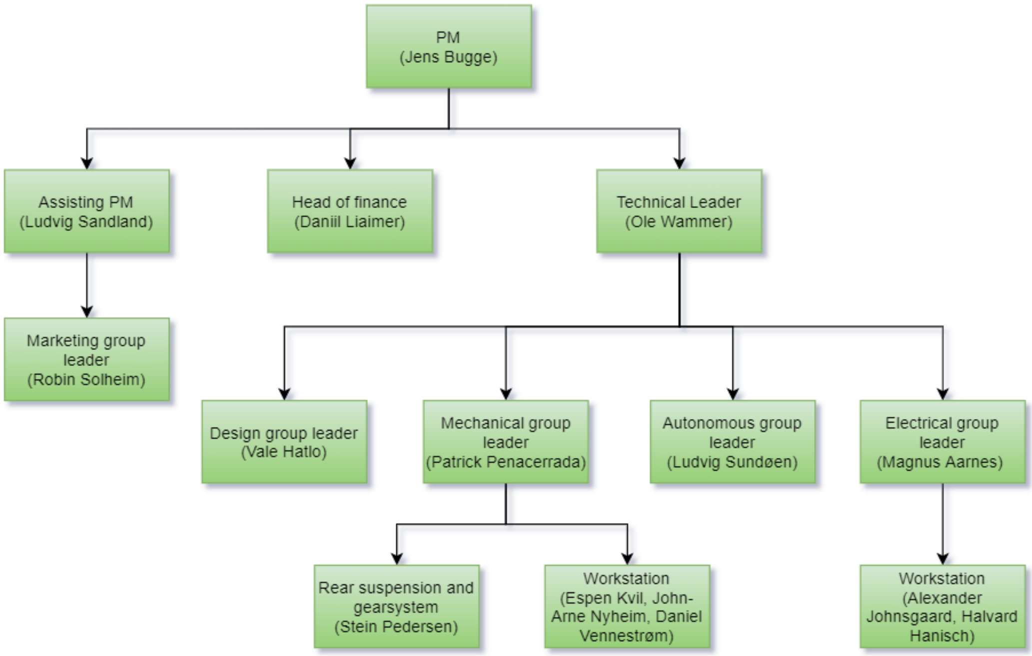


Figure 2 DNV GL Fuel Fighter organization map

This organization map showcases the structure of DNV GL Fuel Fighter. It highlights our own position and our most important collaborators positions in DNV GL Fuel Fighter organization.

1.5.2 Bachelor project group

Figure 3 Project group organization map

Espen acts as the group leader, he oversees planning, deadlines, and has a general overview of the project. He does not have the authority to impose sanctions. The group share an equal responsibility for the success of the project. The group uses an isomorphic group structure. Some tasks will be considered as a group task, others will be delegated. One person has the main responsibility for that task, and the rest of the group looks over the work when he is done.

1.6 Planning

1.6.1 Work breakdown structure

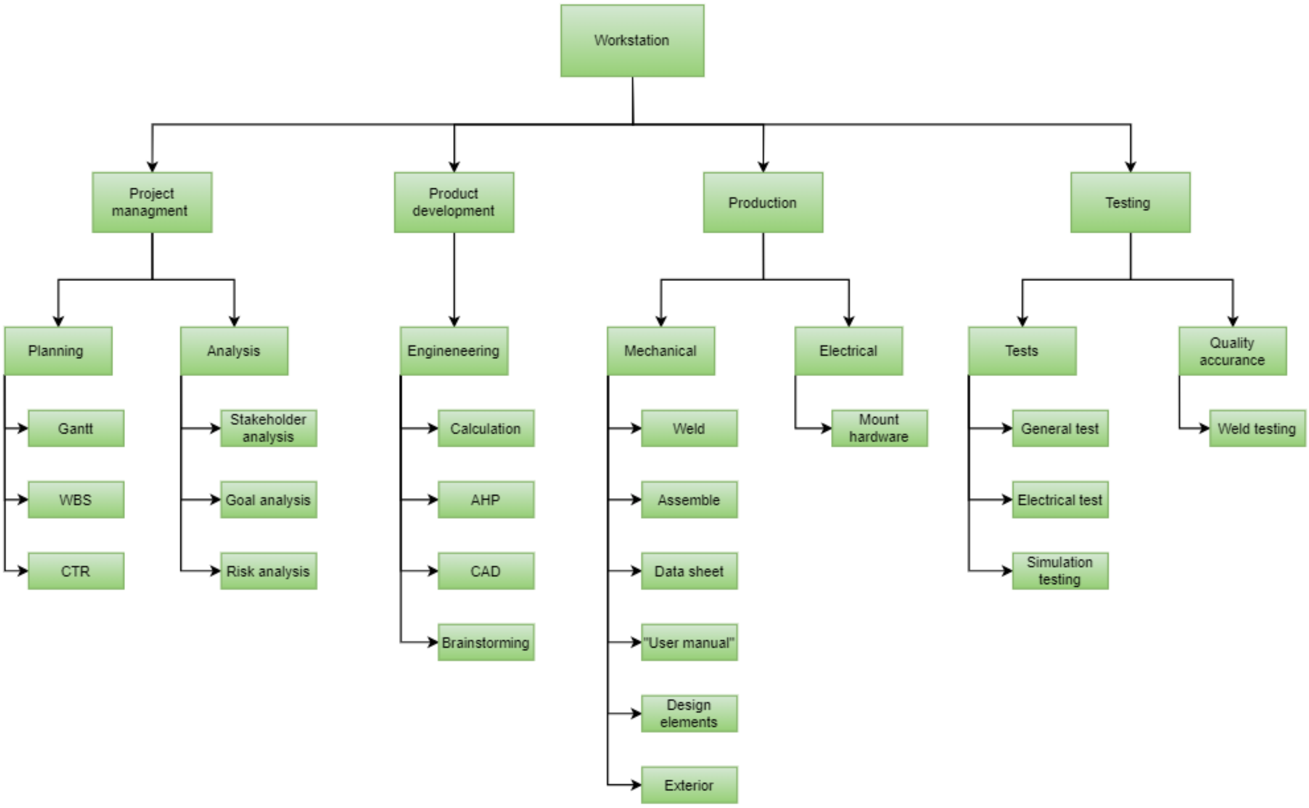


Figure 4 Work breakdown structure

1.6.2 Milestones

Milestones		
M1	Timetable and schedule completed	4. oktober 2019
M2	Principal concept is ready	25. oktober 2019
M3	End of work for 2019	15. november 2019
M4	NTNU bachelor agreement delivered	17. januar 2020
M5	Pre-project delivered	17. februar 2020
M6	Poster delivered	27. mars 2020
M7	Present the workstation	Cancelled
M8	Bachelor report delivered	20. mai 2020
M9	Bachelor presentation	29. mai 2020

Table 4 Milestones

1.6.3 Time schedule

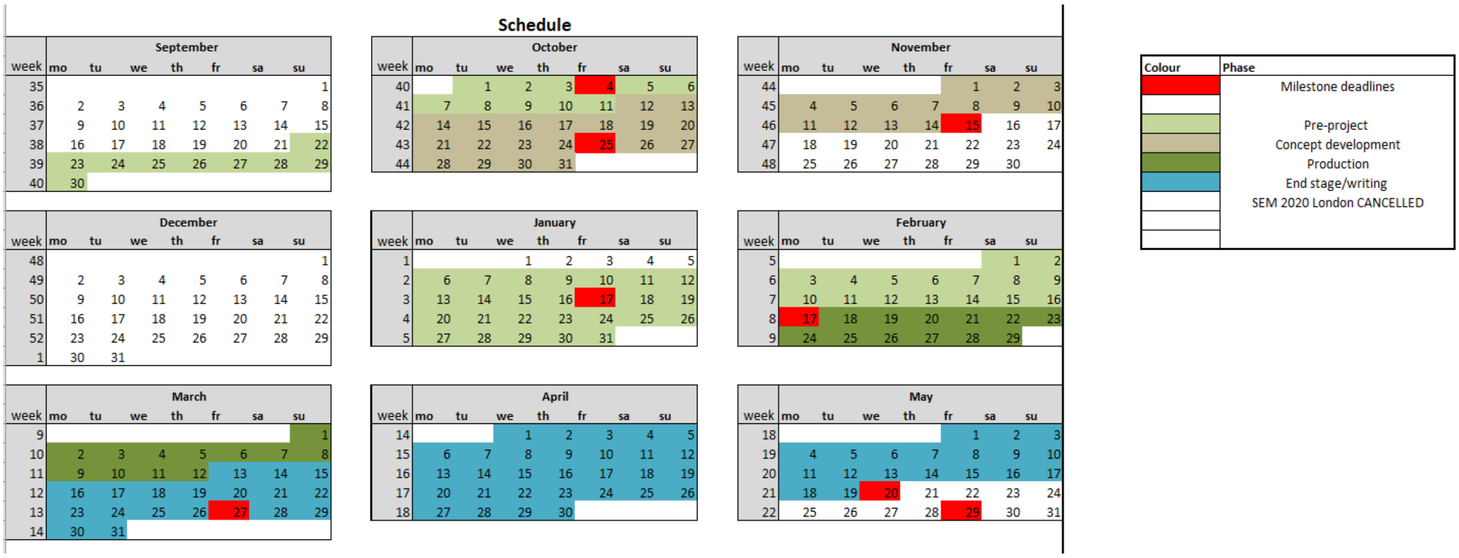


Figure 5 Time schedule

1.6.4 Economical scope

Price estimate for "Workstation"		
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

Table 5 Price estimate

The project is financed by DNV GL Fuel Fighter. All purchases will go mainly through Fuel Fighter's financial manager but can also go through technical manager or project manager. Parts or solutions with a substantial price tag must be discussed with technical manager or project manager.

1.7 Follow-up and Quality Assurance

1.7.1 Quality assurance

This project is an iterative process which means to constantly look back and re-evaluate the work previously done. Rely on feedback from other group members to ensure that the individual work is at a standard that the whole group is content with. The project supervisor will give feedback on parts of the writing, the group will then reassess the work based on his feedback.

In addition to this there will be a reflection meeting every third week. The point of the meeting is to discuss how the process is going, look back at the work that has been done up until that point, and bring up other concerns.

Quality assurance measures:

- Critical use of sources.
- Actively use planning tools.
- Regular dialogues with Fuel Fighter and the project supervisor.
- Good planning.
- Weekly meetings.

1.7.2 Reports

- Weekly meetings with DNV GL Fuel Fighter-mechanical team.
- Bi-weekly meetings with DNV GL Fuel Fighter.
- Weekly meetings with DNV GL Fuel Fighter-board.
- “PU-journal” on Microsoft Teams.
- Contact with project supervisor if necessary.
- Minutes of meeting.
- Timesheet (individual and activities).

1.8 Workflow Risk Assessment

Risk analysis

Consequence		1	2	3	4	5	
	Unfinished project	5	10	15	20	25	5
	Greater delays	4	8	12	16	20	4
	Minor delays	3	6	9	12	15	3
	Greater issue	2	4	6	8	10	2
	Minor issue	1	2	3	4	5	1
		Very low	Low	Moderate	High	Very high	
				Probability			

Probability:

1 Very low Once	2 Low Every other month	3 Moderate Monthly	4 High Weekly	5 Very high Daily

Risk assesment for work flow	Risk					Remaining risk		
	See risk matrix for value description of probability.	See risk matrix for value description of consequence.	All remaining risk should be considered. Red and yellow should be assigned preventive measures.	Preventive measures to reduce probability or impact value.	Responsible for implementing measures.	Likelihood of it happening after preventive measures.	See risk matrix for value description of consequence.	All remaining risk should be considered. Red and yellow should be assigned preventive measures.
Risk	**Probability**	**Consequence**	**Risk value**	**Preventative measures**	**Responsible person**	**Probability**	**Consequence**	**Risk value**
Sickness and injury. Sickness and/or injury will stop or at least slow down our work.	2	3	6	1: Eat well 2: Get enough sleep 3: Hygiene 4: Follow HSE 5: Stay focused on the work you are doing	Espen, Daniel, John-Arne	1	3	3
Simulation error. Simulations in SolidWorks are notorius for beeing troublesome some times.	4	2	8	1: Check results with someone who has expertice on the subject 2: Run several simulations 3: Real life material testing	Espen, Daniel, John-Arne	2	2	4
Unrealistic goals. This is a new project for all of us and given tha lack of experiance, its commen to underestimate the scope of the project.	1	5	5	1: Be realistic, don't be silly 2: Plan ahead 3: Good comunication with the board 4: Know what reasaurces you hava available	Espen, Daniel, John-Arne	1	5	5
Bad group synergy. This leads to bad communication, lack of effort, no emitional attachment to the project.	5	3	15	1: Talk together 2: Have reflection meetings 3: Clear work structure 4: Social events	Espen, Daniel, John-Arne	1	3	3
Material delay. We have to run our orders up the chain of command in Fuel Fighter, this chain could make our orders go very slow.	3	4	12	1: Follow up 2: Contingency plans 3: Few and clear instructions	Espen, Daniel, John-Arne	2	4	8
Workshop limitations. There is a lot of students in need of the workshop and the workshop might struggle to meet this demand.	5	4	20	1: Good dialouge with the workshop supervisor 2: Follow the rules and work etiquet of the workshop 3: Give early notice	Espen, Daniel, John-Arne	3	4	12
Bad communication. Poor communication between ourselfs and our most important stakeholders will lead to misunderstandings and confusion.	4	3	12	1: Clear instructions 2: Pass on information directly to the right person 3: Weekly meetings/regular updates	Espen, Daniel, John-Arne	2	3	6
Design flaws. Should the design have a major problem it would lead to a total do-over.	2	4	8	1: Revaluate regulary to be sure that the smartest solution has been chosen 2: Get feedback from eachother 3. Research thourouly	Espen, Daniel, John-Arne	1	4	4

Table 6 Workflow risk assessment

2 Concept Evaluation

With the product requirements specification as a basis the project moves forward to the different concept solutions. A product like this have a lot of parts with a huge number of potential solutions. The biggest and most defining parts are evaluated before further specifications are made. Six parts are evaluated:

- Frame design
- Frame material
- How to provide adjustability
- Wheels and wheel contraption system
- How to test each driving wheel individually

These main systems go through an Analytical Hierarchy Process or AHP. It is a method used for evaluating different solutions based on some set criteria and priorities. The process is subjective.

Because of the specifications given by the Fuel Fighter board, there are certain aspects that are predetermined and will limit the number of possible solutions.

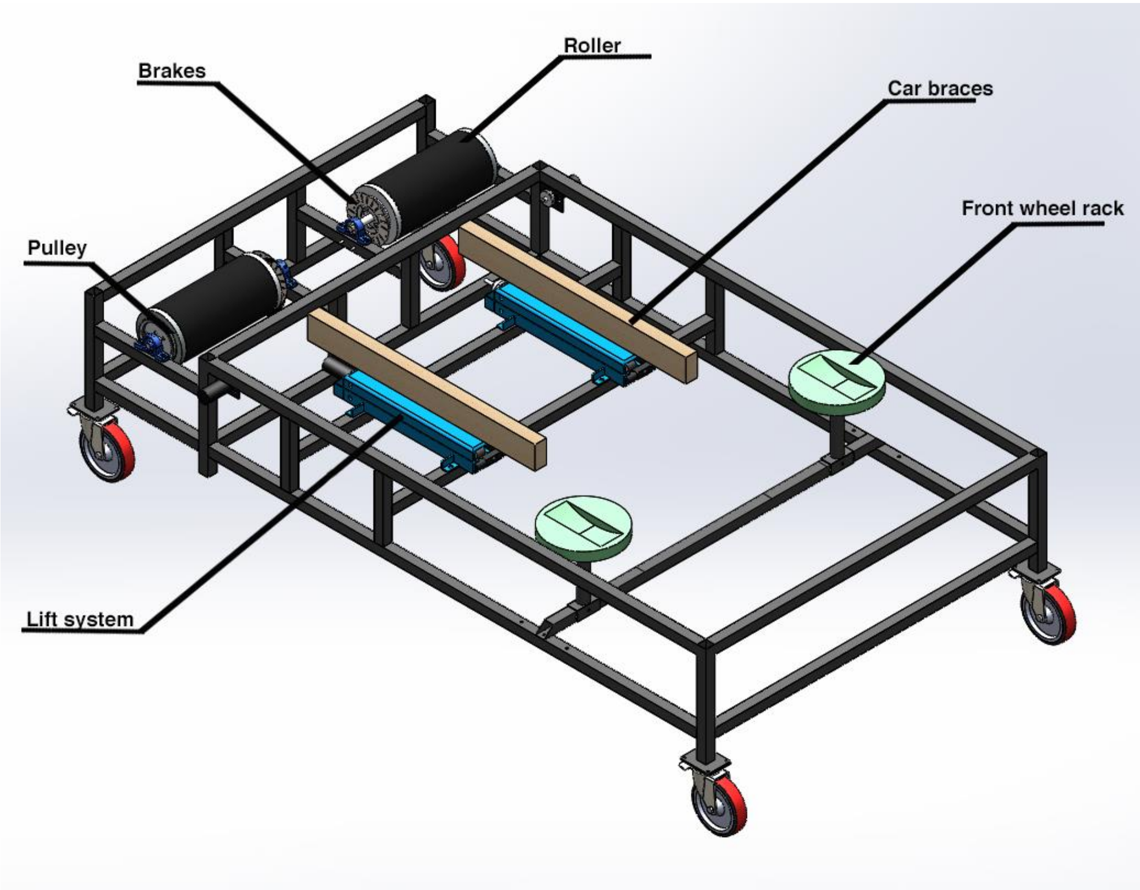


Figure 6 Workstation CAD model

2.1 Concept Mind Map

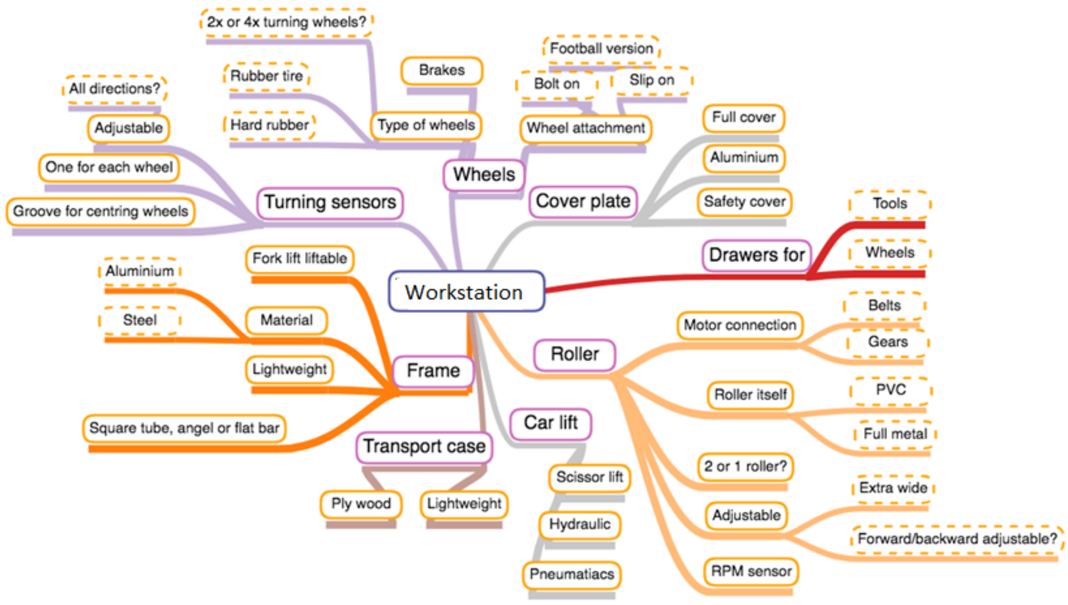


Figure 7 Concept mind map

2.2 Frame

The frame is an essential part of the project, as it is the part that connects everything together. Whilst designing the frame it is important to consider certain aspects:

- Strength
- Weight
- Size
- Material
- Complexity
- Cost
- Placement of mounting holes and brackets

The size of the frame is important due to the constant evolution of the car and transportation purposes. Since the workstation is going to cost a substantial amount of money, DNV GL Fuel Fighter wants the frame to fit future cars with different wheelbases. This means making the frame adjustable within the foreseeable range of allowed wheelbases. Which is all described within the SEM rule book. Another purpose for the workstation is to bring it to SEM and other events. For this to happen, in most cases, the frame will need to fit inside the trailer.
Taking into consideration these limitations it is still desirable to design the frame as simple as possible. To achieve this, the frame is utilizing a two layered square form which through

easy mounting of crossbeams allows for good versatility. This also makes the production as simple and effective as possible. The frame will be tested using 3D simulation tools. Depending on the results, the material or the design of the frame will be changed if structural weaknesses are discovered

2.2.1 Material

One of the main requirements of the workstation is manoeuvrability. To achieve this the frame needs to be light. The material used plays a big role. Aluminium weighs approximately 1/3 the weight of steel but is not nearly as strong. To compensate for this more material is required to achieve the same strength as steel. Aluminium was initially favoured due to its low density, but eventually neglected due to its low weldability. Aluminium has a natural oxide layer which needs to be penetrated in order to weld. Extremely high temperatures are necessary to dissolve the oxide. This presents the risk of melting the aluminium entirely during welding because of the high heat input needed. To solve this problem special welding methods must be used. The welding method mostly used for aluminium is TIG welding with alternating current. This distributes the heat development equally on the electrode and the workpiece. MIG is also used.
TIG welding has a lower deposition rate than MIG/MAG welding so welding becomes more time consuming.
Due to the lack of welding experience and the time frame of the project, choosing aluminium as the material would not be beneficial.
The increased strength of steel allows the frame profile and thickness to be smaller. Steel has a density roughly three times higher than aluminium but has a higher yield strength as well. This means that less material can support more force before deformation occurs. This makes the weight difference between steel and aluminium minimal, which combined with steel's high weldability, results in steel being the better alternative.

Frame material	Weight	Welding suitability	Price	Strength			Total priority
Aluminum	0,065	0,043	0,015	0,081			0,204
Steel	0,008	0,343	0,120	0,324			**0,796**

Table 7 Frame material AHP

2.2.2 Adjustability

Making the workstation adjustable so it can be adapted to multiple cars can be solved in many ways. Through brainstorming and much discussion, some fundamental solutions became apparent. Different wheelbases require length and width adjustment for both the front and back wheels. To make the workstation easy to use, it is preferable to reduce the number of adjustments needed.
Length adjustment can be achieved by having either the back wheels in a fixed position, with the front wheels able to move, or the opposite.

Both the front and back wheels must be adjusted for width. But, by having wide rollers, the workstation immediately becomes compatible with several wheelbases, without the need for changing the positions of any components.
This leaves us with a solution that only requires one length adjustment and one width adjustment.

There are three different solutions in the AHP:

- *A "adjustable roller"*
- *B "fixed roller (belt outside)"*
- *C "fixed roller (belt inside)"*

Alternative A "*adjustable roller*" is a solution where the roller-system is part of a rack that can be moved in the length direction while the front wheels are in a fixed position.

Alternative B and C are in principle the same but have a different set up in the roller-system. Both alternatives are solutions were the back wheels are fixed, with both length and width adjustment happening on the beam supporting the front wheels.
The main difference is the placement of the pulley/gear system between the rollers and electric motor. No matter the solution, the roller-system will have a belt or chain of some sort. This is a potential safety hazard, but also a part that requires maintenance and should be easily accessible.

"fixed roller (belt outside)" have the belt on the outside of the rollers, towards the frame. This makes it more accessible, but there is a bigger hazard. The belt is therefore under a cover to protect people from getting their hair or clothing dragged into the spinning belt.

The third solution is *"fixed roller (belt inside)"* were the belt is on the inside of the roller, sitting in the middle of the workstation. This is easier and faster to build because there is no need for a safety cover. But the solution is slightly more inconvenient for maintenance.

After going through the analytical hierarchy process, alternative B stood out as the best option.

Roller placement	Ease of use	Serviceability	Safety	Simplicity			Total priority
Adjustable roller	0,017	0,081	0,167	0,003			0,268
Fixed roller (belt outside)	0,069	0,136	0,255	0,024			**0,484**
Fixed roller (belt inside)	0,069	0,047	0,108	0,024			0,248

Table 8 Roller placement AHP

2.3 Wheels

2.3.1 Wheel type

One of the more important criteria from the project manager is to have wheels that can handle cobblestone. The wheel type has a massive impact on the workstations ability to achieve this.

Industrial trolleys typically have hard rubber wheels because they operate in workshops with a flat and smooth floor. This is also the case for the workstation most of the time. However, there are times when it will be used on gravel, cobblestone, or just tarnished asphalt. Hard rubber wheels are not good at absorbing shocks and implementing a suspension system adds weight and complexity. An alternative option is therefore to use air inflated wheels.

Hard rubber wheels and air inflated wheels are the type of wheels that are evaluated.

Wheels	Noise	Suspension	Lifespan	Capacity			Total priority
Air inflated rubber	0,061	0,437	0,027	0,057			**0,583**
Hard rubber	0,009	0,073	0,107	0,229			0,417

Table 9 Wheels AHP

Both types of wheels vary in capacity depending on price and size. Comparisons are only made for wheel types of the same price- and size bracket. Air inflated wheels have better shock absorbing qualities and makes less noise but does not achieve the same capacity and lifespan as hard rubber wheels, and they require more maintenance because you need to replenish air.
The most important criteria are suspension, and the other criteria are very evenly matched. Air inflated rubber wheels are the best alternative.

The wheel has several parameters. There may be swivels on two or all four of the wheels, with or without brake. That the car is to be transported to and from the stands on campus and various such things are taken into account, and it that situation will two fixed wheels and two swivel wheels at the front give better control. But the car is for the most part in the workshop and it will be easier to move it around if it has four swivel wheels. This is prioritized, four swivel wheels makes it easier to work with in the workshop and it is still very manageable by two persons during transportation.

2.3.2 Wheel system

To facilitate the workstation to be shipped on a trailer or in a shipping container, it is desirable to have a solution where the bench stands on legs instead of the wheels. Having the bench stand on legs makes it lower, there is no danger of it rolling and it is easier to strap down.

Our three most promising options are:

- Simple bolt on/off
  - The wheels attach to the frame legs with four bolts. Steel plates are welded on to the legs of the frame. Whenever the workstation is used for transportation the wheels simply bolt off.
- “Slip on”-solution
  - A similar solution to bolt on/off but using just one bolt rather than four per wheel. A steel tube with a slightly smaller profile than the frame is welded on to each wheel. The smaller profile slips inside the bigger profile and is locked in place with a bolt.
- “Hinge”-solution
  - A solution where the wheels never comes of but is fasten to a hinge that allows for the workstation to either stand on its legs or wheels.

Wheel system	Ease of use	Weight	Price	Simplicity	Stability		Total priority
Bolt on/off	0,021	0,078	0,034	0,086	0,381		**0,599**
Slip-on	0,034	0,035	0,022	0,028	0,111		0,229
Hinge	0,104	0,015	0,009	0,010	0,032		0,172

Table 10 Wheel system AHP

Stability is the most important criteria, given the fact that the workstation must be able to handle cobblestone roads it is undesirable to have a wobbly contraption system. And we must factor in that the workstation will rarely be moved on a trailer or shipping container. Only 1-2 times a year is expected. It is therefore better to have a stable system that works optimally all year, despite it not being the best solution for transportation. The least complicated, and most stable solution, which is the “bolt on/off” solution is therefore considered the best.

2.4 Roller-System

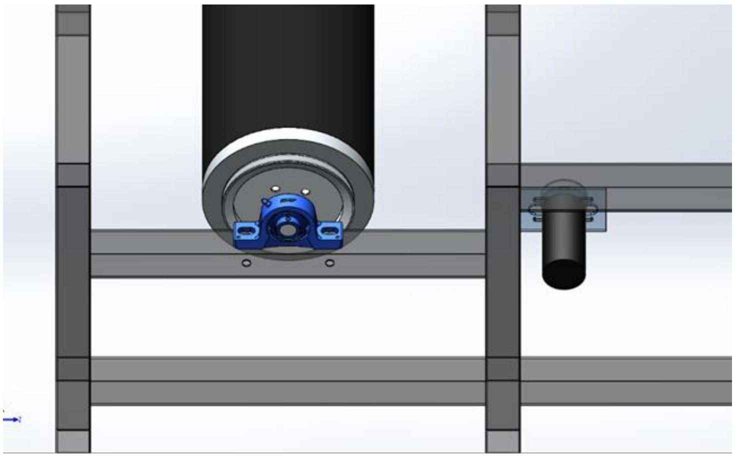


Figure 8 Roller-System

The roller-system consists of two sets or rollers, each roller consists of an axle, two bearings, a PVC pipe, two aluminium end caps, a pulley, and brakes.

2.4.1 Roller concepts

The alternatives are one made entirely out of aluminium, whilst the other consist of an aluminium axle, two end caps and a PVC pipe. Both alternatives require considerable turning.
The first alternative would need 600 mm of 200 mm aluminium bolt each roller. The benefits of producing the roller with this method is the simplicity and the fact that the pulley and brake disc adapter would be part of the roller. No need for any mounting which may throw off the centre of gravity. On the other hand, this solution would be expensive, as each of the aluminium bolts would cost about 5000 Kr, and one mistake could ruin the entire piece. All in all, it is a simple solution, but at the same time very risky.
The other option consists of an aluminium axle, two end caps turned out of a 200 mm aluminium bolt and a 200 mm OD PVC pipe. Benefits to this solution is largely the cost, whilst still maintaining the stability aspect of turning. However, one of the downsides is that the end caps must be welded to the axle, which requires a certain level of welding skill.

Rollers	Weight	Stability	Price	Simplicity			Total priority
Aluminum	0,057	0,102	0,029	0,019			0,207
PVC/Aluminum	0,284	0,305	0,147	0,057			**0,793**

Table 11 Rollers AHP

2.5 Lifts

The fuel fighter cars are in constant development and are always being modified and tweaked. It is therefore important that the workstation allows for quick repairs and modifications. A way to enable this is to implement a system that lifts the car of the ground.

Criteria

Since this system serves as a tool for making other tasks easier, the criteria for the lift system is based mostly on safety and ease of use.

- Quick set up time: Makes the job of lifting the car faster than with an external system
- Stable
- Failsafe: The system will stay in a set position even if power is lost
- Adjustable: Can fit a large variety of dimensions
- Compact: Takes up as much, or less space than an external system would do

Design process

An assessment of the parameters and measurements is necessary to see if solutions will fit in the available space. The frame is spacious, but the spare room can be utilized for storage, so a compact solution is desirable.
The current car has two parallel beams of strong carbon fibre running along the underbody of the car which can be utilized as jack points. The beams are 500 mm. apart. Spreading the load evenly on these beams ensures sufficient stability when the car is in the air.
Adjustability is a key factor since new cars are being developed every other year or so.

2.5.1 Lift concepts

The area of the frame where the lift system is supposed to sit is spacious and therefore there is very few restrictions as to the placement of the components and the finished unit. The only specifications that are decided is the jack points on the car which the lift system needs to fit.

Single lift

A system that works of the scissor concept is beneficial in the way that it provides good lifting height and becomes very compact when fully folded down. The concept shown below is a scissor lift with one joint. This simple design can be powered by an electric motor, hydraulic or pneumatic piston, or manually. The design is based off a pre-manufactured lift which is modified with pivoting arms to fit the car. This solution is compact but can be unstable and as a result develop slackness in joints over time.

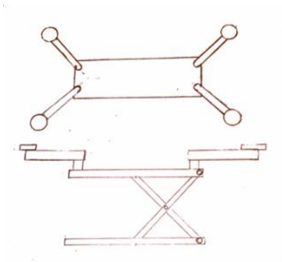


Figure 9 Lift drawing

Double lift

This type of system provides a lot of stability
Using two pneumatic pistons to power the system gives many design possibilities since the pistons can be placed in different positions and transfer force by the help of different mechanisms. The drawing below is an example of a possible system which can be

implemented to the workstation. However, it takes up a lot of space and is over dimensioned for the purpose of this project.
Another option would be to create a double lift system from scratch but due to the time frame it is not a valid solution.

Figure 10 (QuickJack, 2020)

2.5.2 Power source

Powering sources for the system presents a few valid options:

Hydraulic piston

Utilizes pressurized oil to produce force on an object. Oil is almost incompressible and therefore a hydraulic system can operate under heavy load if other components of the system are dimensioned correctly. Hydraulic systems need a pump to pressurize the fluid. The pump can be manually operated or be electric. With low loads a manual pump is beneficial as it reduces complexity and eliminates electricity from the system. In heavy duty systems, electric pumps are used since they can produce higher and more constant pressure. Hydraulic systems are prone to oil leaks and require a high level of cleanliness to function optimally.
If the load were higher on the system a hydraulic solution would be good. The area of operation is clean, and leaks can occur without any big consequences. Hydraulics usually come with a lot of components and is not the most compact of systems. This means unnecessary weight on a system that aims to be light and easy to move.

Pneumatic piston

Works of the same concept as the hydraulic system. However, the medium is air. A pneumatic system needs a compressor and is therefore quite big. Since air is a compressible medium, the load capacity Is less.
Pneumatics is a valid option for this application but requires adds complexity in the form of pumps and pistons which is not beneficial for weight.

Electric engine

Electric engines can produce high torque on low rpm. There are many types of electric engines and choosing the right one comes down to looking at what torque you need and what rpm range is desirable for the application.
Electric engines operate without fluids and can work in all sorts of environment. Since an electric motor produces torque, it needs to be hooked up to a system which converts the torque to axial motion.

A conventional car lift often uses hydraulics. The Fuel Fighter cars are built to be as light as possible and the current car only ways 73 kg. This means that the lift system needs far less force than for a normal car lift. Because of this, hydraulics may not be the best choice in this case.

Considering the pros and cons of each power solution, we rule out hydraulics and are left with three different options to evaluate using the analytical hierarchy process:

- Pneumatic
- Single lift powered by electric motor
- Double lift powered by electric motor

Lift	Ease of use	Size	Price	Simplicity	Stability	Weight	Total priority
Pnuematic	0,022	0,013	0,003	0,006	0,218	0,009	0,272
Single jack	0,101	0,060	0,015	0,042	0,051	0,047	0,315
Double jack	0,058	0,035	0,024	0,042	0,234	0,021	**0,413**

Table 12 Lift AHP

For the lift system, ease of use and stability is the most important criteria. Double lift is the best solution mainly because of its stability.

3 Concept Development

3.1 Frame Development

Using 3D simulation, the different profiles and materials are tested. The one with the correct amount of weight and strength is chosen. Several profiles of both aluminium and steel are considered:

Aluminium profiles:

- 50x50x2,3,4 mm
- 40x40x2,3,4 mm

Steel profiles:

- 50x50x1.5 mm
- 40x40x1.5 mm
- 30x30x2,3 mm

The simulations show that the width of a profile gives more strength towards bending than the wall thickness. This results in choosing the 40x40x1.5 mm square tubes, as this is able to withstand the loads within a good margin with minimal deflection. The width of the bearing is also taken into consideration. In this case the bearing has a width of 38 mm, allowing it to fit on top of the profile without any addition modification.

3.1.1 Strength simulations in SolidWorks

The frame is made from 40x40x1,5 mm precision steel tube. These tubes are made from steel bands of E235+CR1 which are welded together, this is a mild type of steel specifically used for making precision profiles. Precision profiles are made with a tighter tolerance making it easier to work with.

The simulations run through three different scenarios:

1. Only the car on the rollers and front wheel rack:

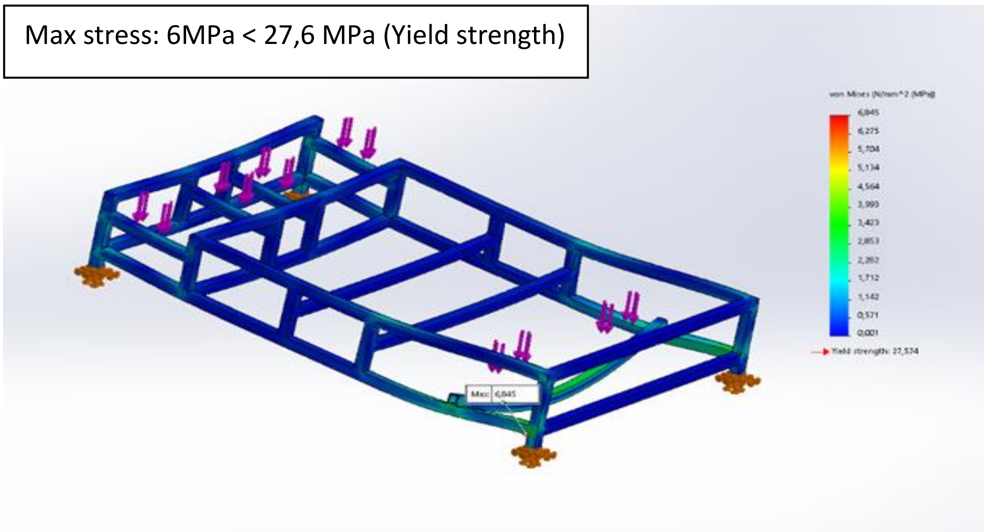


Figure 11 SW Simulation: Frame scenario 1, stress

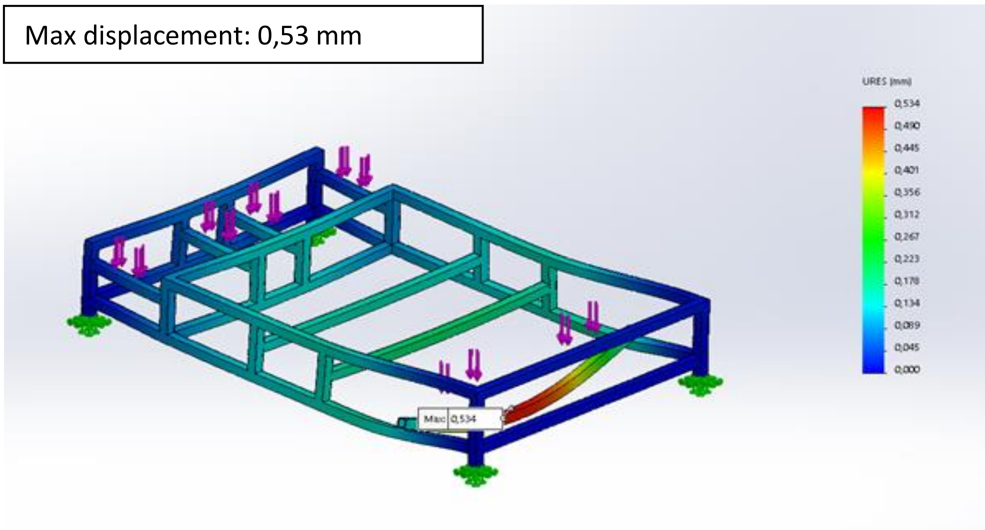


Figure 12 SW Simulation: Frame scenario 1, displacement

2. Driver and car on the rollers and front wheel rack:

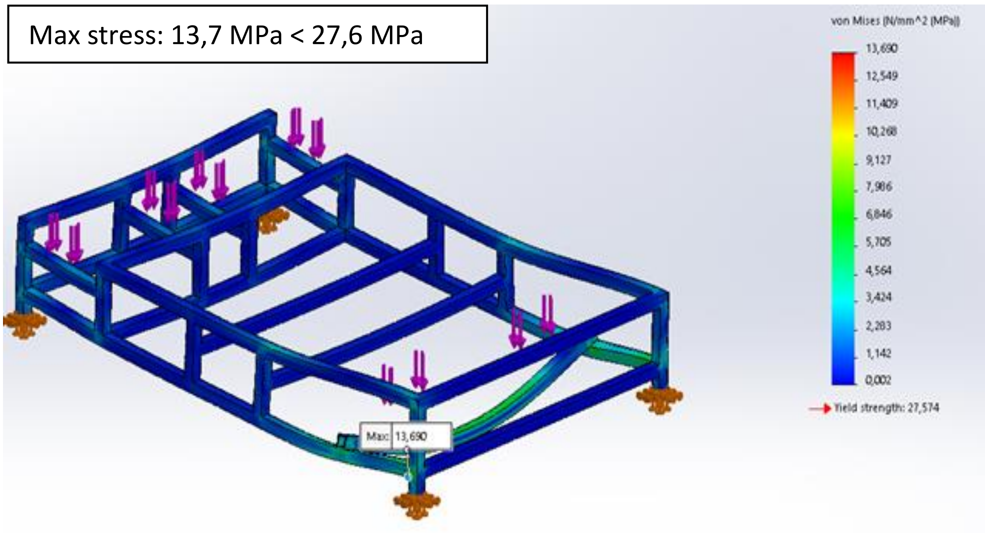


Figure 13 SW Simulation: Frame scenario 2, stress

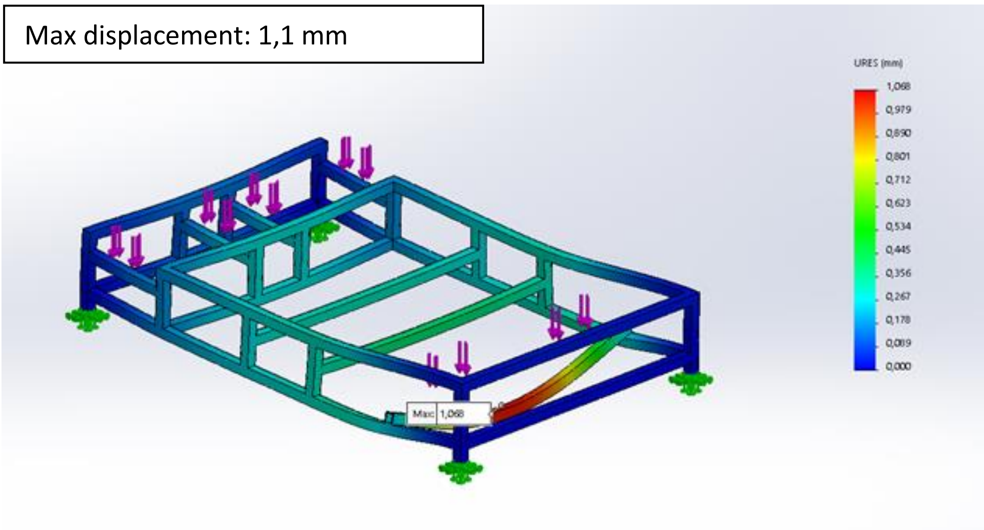


Figure 14 SW Simulation: Frame scenario 2, displacement

3. Only the car on the lift

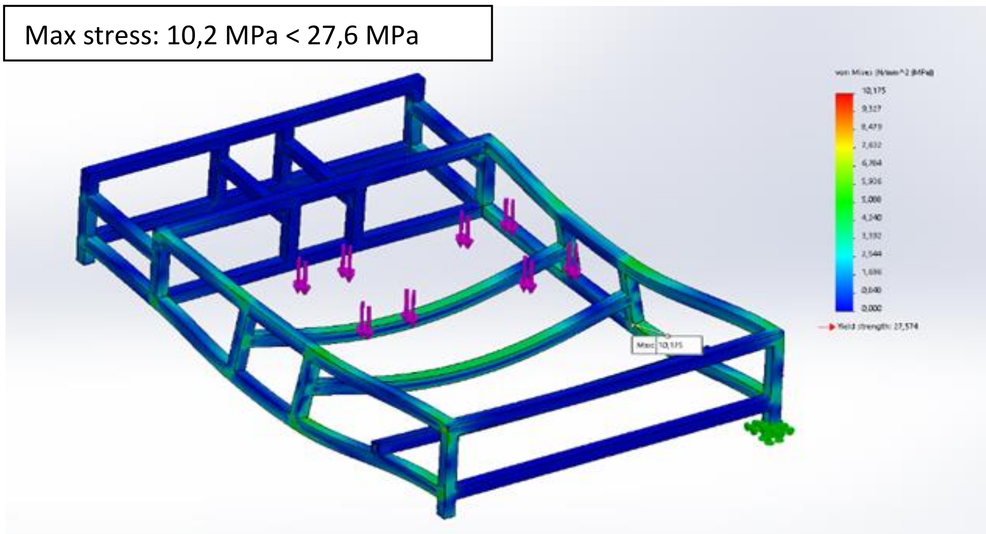


Figure 15 SW Simulation: Frame scenario 3, stress

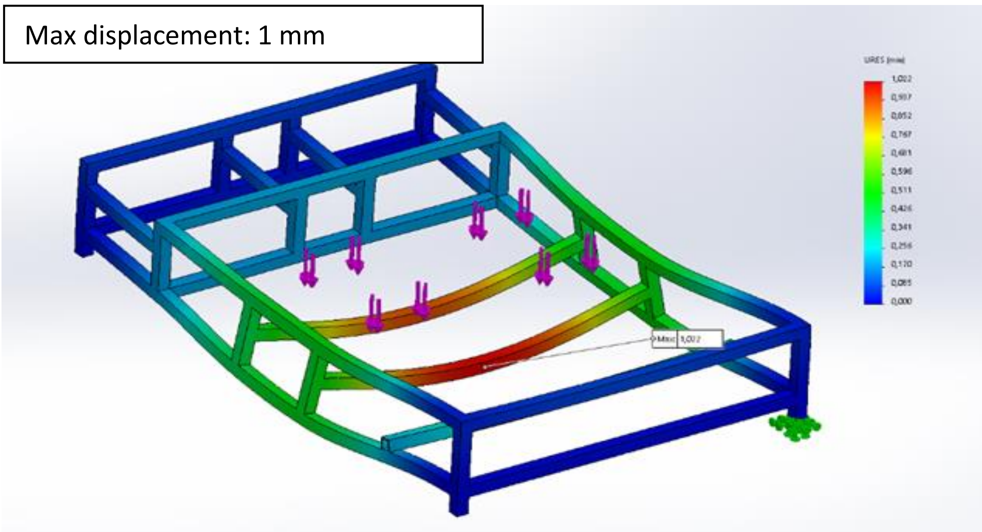


Figure 16 SW Simulation: Frame scenario 3, displacement

Testing the car and driver on the lifts is unnecessary as this will not be a scenario in real life. According to simulations made using possible load scenarios, the stress concentrations will not exceed the yield limit of the material used.

In all these scenarios, the stress concentrations only reached a maximum of 13,7 MPa. Which is tolerable considering E235+CR1 yield strength of 27,6 MPa. The stress concentrations would appear in welded joints. This is not a problem as welds normally are considered as strong, or stronger than the base material. That is of course only if it has been done correctly.

3.1.2 Welding

The workstation has a lot of permanent connections in the frame. Since it will be under some load the connections should be as strong or stronger than the steel tubes itself. Welding uses heat to fuse two components together and if done correctly, welds will be strong. However, there are many defects that can happen under the welding procedure. It is important to inspect the welds and localize and assess defects that may have occurred.

When welding steel, MIG welding is most commonly used. This method has a high efficiency and is easy to control. Unlike TIG welding a MIG welder has the additive material automatically fed through the gun. Newer MIG elders are easy to adjust and will automatically regulate to ensure an even weld. This is great for the production of the workstation since nobody on the team has much experience with welding in practice.
The frame will have fillet welds in every corner as well as butt welds.

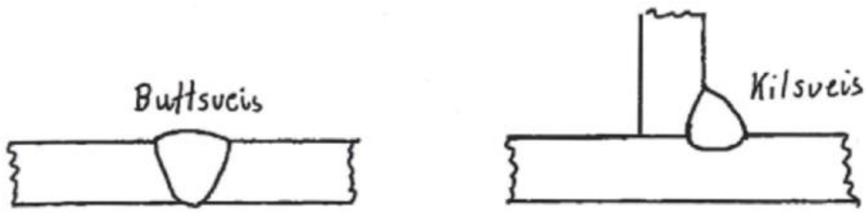


Figure 17 Butt weld, fillet weld (Pedersen, 2019)

The square tubes have a wall thickness of 4 mm. This is considered to be quite thin and easy to burn through when welding. The amperage and welding speed needs to be adjusted so that sufficient heat is reached and the desirable amount of additive material is added to the weld.

Weld defects

- Slag inclusions
- Lacking penetration
- Cracks
- Pores
- Fusion defects
- Root defects
- Surface flaws
- Edge sores

Weld defects are split into two categories:
Geometrical defects

- Cracks
- Air pockets
- Inclusions
- Binding and root defects

These defects cause the stresses in the weld to be higher than they would in a flawless weld

Metallurgical defects

- Unwanted structure in the material
- Grain growth
- Martensite
- Changes and reduces the characteristics in the welding zone or HAZ
- Welding can result in weakened strength and toughness
- Metallurgical defects can lead to Geometrical defects
- Can cause corrosion if the weld metal is not matched with the

Weld defects may occur because of:

- The welding procedure
- Skill of the welder
- The material being welded
- The environment

Sharp defects are much more critical than rounded ones
Depth of the defect
If it is on the surface it may lead to fatigue cracks
(Pedersen, 2019)

Inspection
The workstation is not developed to handle extreme loads and therefore there is no requirement for testing of the welds other than visual inspection. The welding is not performed by professionals and it is not to be expected that the welds meet any standard requirements other than what is agreed upon between Fuel Fighter and the bachelor group. For the project to be successful the workstation frame must be finished and functional. This presupposes that the welds on the frame is able to handle the loads it is expected to experience during use.
Since the weld work is performed by amateurs it is important to be aware that imperfections are guaranteed. Fatigue cracks can come very suddenly and grow rapidly after the initial notch has cracked. Cyclic loads and vibrations are the most important factors for fatigue.

The workstation will for the most part be standing stationary and when moved it is transported on rubber tires which reduce vibration. The load applied to the workstation will be near constant since it only supports its own and the car weight. Tolls and other equipment will be removed and added but these do not but any significant stress on the construction. Because of this there is very little risk of quick development of fatigue cracks. A good solution here is to inspect the welds once every year and document the results. This way results from past years can be compared with the present state of the welds to reveal crack growth or other defects.

3.1.3 Making the front wheel rack

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.

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.

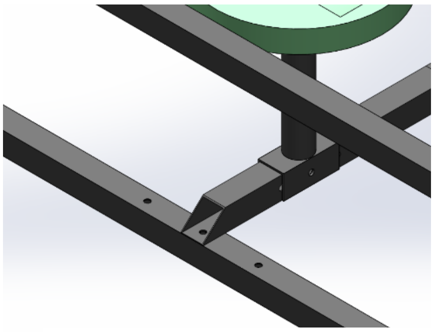


Figure 18 Crossbeam with 45-Degree Cut

The wheel rack

The wheel rack consists of four parts:

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

A disc turns 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, easy 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 rack prototype

Some notes on the first prototype:

- It is too small, the disc must be printed on a 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.

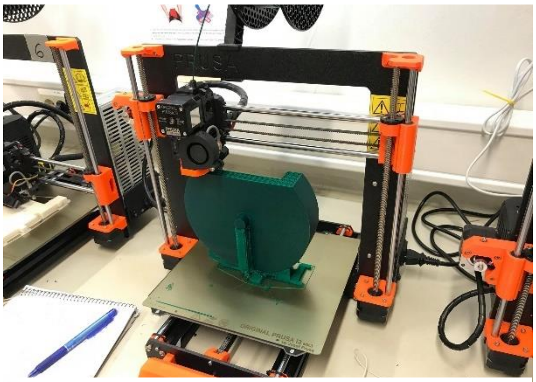


Figure 20 3D-Printed disc prototype

The potentiometer is 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

3.2 Roller Development

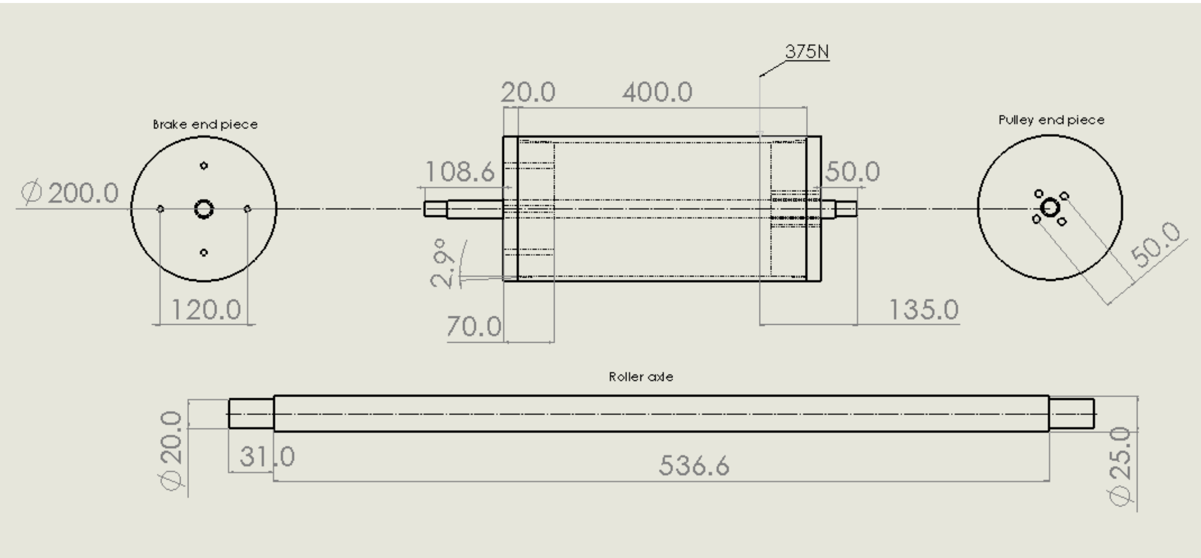


Figure 22 Roller dimensions

The roller consists of two end caps, a PVC pipe, and an axle. The end caps are turned on a lathe from a 200 mm 6082-T6 aluminium bolt. They are identical other than the mounting holes, one set for the pulley and another for the brake disc adapter. The end caps have a 2-degree taper, allowing for the PVC pipe to be press fitted on. The roller axle material is aluminium 6082-T6, the same as the end caps. This allows the axle and end caps to be welded together, locking the rest of the roller onto the axle.

3.2.1 Dimensioning

Roller diameter

The diameter of the roller determines the angular speed. Bigger roller equals lower angular speed, which is desirable. This is because high angular speeds require increased precision. The car we will be testing has a maximum speed of 40 Km/h. This allows us to use a smaller diameter roller than most normal dynamometers.
To increase precision and reduce vibrations, the end caps are turned out of solid aluminium. This production method limits the maximum roller diameter. The same goes for the PVC pipe.

$$\frac{40\ Km/h}{3600\ s/h} = 11{,}1\ m/s$$

$$\omega = \frac{v}{r}$$

$$\omega = \frac{11{,}1\ m/s}{0{,}1\ m} = 111\ rad/s$$

$$\frac{111\ rad/s}{\frac{2\pi}{60}\ rad/s} = 1061\ rpm$$

Using a 200 mm diameter roller with the car running at maximum speed, results in an angular speed on the roller of approximately 1100 rpm. Depending on the deformation of the axel this might be too high of an angular speed. Therefore, calculations regarding the axle's size, deformation and critical speed must be made.

Axle diameter

The bearings being used has a bore of 20 mm. The workshop does not have any aluminium rods in that dimension. Therefore, it was decided to use 25 mm aluminium rod instead. This can be turned on lathe to fit the bearings. The stress induced on the roller axle largely depends on the weight and width of the car being tested. To stay safe the axle is dimensioned taking into consideration the worst possible scenario. This applies that the force will be placed in the middle of the axle, as well as the car being at its heaviest with a driver. The roller assembly will also be dimensioned neglecting the stiffening provided by the end caps and PVC pipe.

In this scenario the car weighs about 75 kg, which with the driver leads up to a total weight of 150 Kg.

Material: 6082-T6 Aluminium

- Modulus of Elasticity: $0,71*10^5$ MPa
- Yield strength (axle diameter < 25 mm): 280 MPa (Possibly higher)

(6082 aluminium alloy, 2020*)*

P=368 N   l=536.6 mm   d=25 mm σ_{till}=280 MPa

$$M_{max} = \frac{P * l}{8} = \frac{368\ N * 0{,}537\ m}{8} = 24{,}7\ Nm = M_b$$

$$W_x = W_Y = \frac{\pi * d^3}{32} = \frac{\pi * (25\ mm)^3}{32} = 1533{,}2\ mm^3$$

$$\sigma_b = \frac{M_b}{W} = \frac{24700\ Nmm}{1533{,}2\ mm^3} = 16{,}11\ MPa < \sigma_{till} = 310\ MPa$$

According to the calculations, a 25 mm axle should be able to support the weight of the driver and car. To confirm this, we do a simulation in SolidWorks:

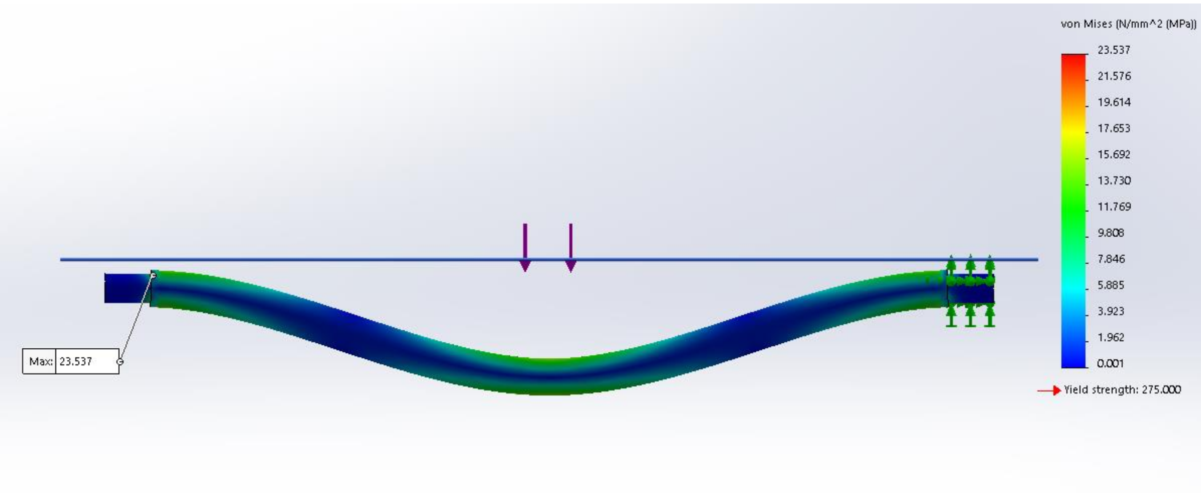


Figure 23 SW Simulation: Axle, stress

The stress concentration does not exceed our material's yield strength. However, it is also important to investigate what sort of deformation will be present. Too much deformation is not desirable, since too much will result in the axle not contacting the entire bearing surface.

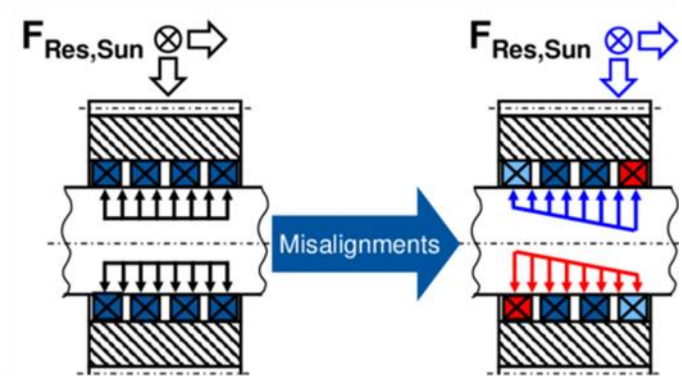


Figure 24 (Schlüter & Jacobs & Bosse & Brügge & Schlegel, 2020, p. 3)

Area moment of inertia:

$$I_x = I_y = \frac{\pi d^4}{64} = \frac{\pi * (25\ mm)^4}{64} = 19165\ mm^4$$

Displacement:

$$f = \frac{Pl^3}{192EI} = \frac{368\ N * (537\ mm)^3}{192 * 0{,}71 * 10^5\ MPa * (19165\ mm)^4} = 0{,}22\ mm$$

According to calculation the axle will experience a deformation of 0,22 mm. Can confirm this through simulations in SolidWorks.

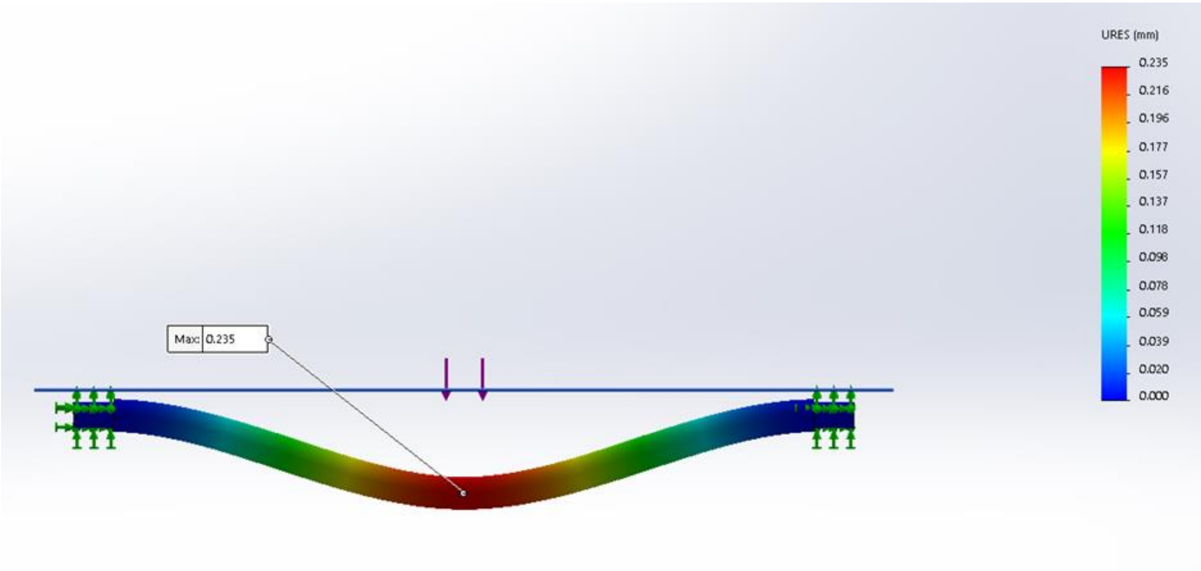


Figure 25 SW Simulation: Axle, displacement

Using an axle with diameter of 25 mm will result in about 0,22 mm of deformation. According to *Maskindeler 1* by Arne Dørum, an axle supported by solid bearings should not have deformation exceeding:

$$\frac{f}{L} \leq 1/3000$$

(Dørum, 2001, p. 6.4)

Using an axle with a diameter of 25 mm results in this:

$$\frac{f}{L} = \frac{0{,}22\ mm}{537\ mm} = 0{,}000041 > \frac{1}{3000} = 0{,}000033\ \ => too\ much\ deformation$$

According to this, the axle's dimensions are too small. Since these calculations neglect the stiffening effect of the end caps and PVC pipe, and the deformation is not high above the limit, the axle still passes in this category.

The next thing to consider is the angle speed this axel will experience. Will now calculate the critical speed of the axle.

$$n_{crt} \approx \frac{30}{\sqrt{f}} = \frac{30}{\sqrt{0{,}00022\ m}} = 2022{,}6\ rpm$$

With the current deformation the critical speed will be around 2000 rpm. This means that the maximum operation speed of 1061 rpm is well below the limit.

Result

The results from the conservative calculations and simulations show that the axle and roller diameters are suitable. The roller, as a unit, will be able to operate well according to what forces it is expected to see.

3.3 Pulley Development

3.3.1 Pulley design

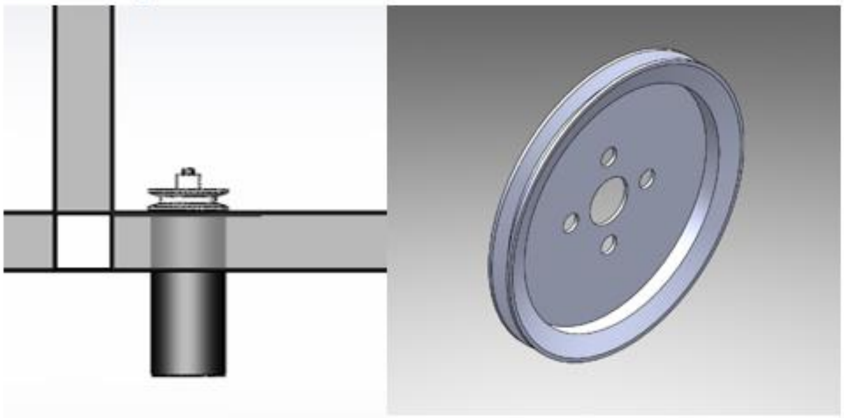


Figure 26 Pulley

Each of pulleys are turned out of aluminium. The side of the pulley that bolts to the roller is flat, this is to allow the pulley it to sit as close to the frame as possible. The motor pulley is locked onto the motor shaft with a set screw. On the motor the shaft has a flat spot grinded down for the set screw to lock against. The collar with the set screw is flipped so that the pulley wheel itself sits close to the frame. This is to match the frame proximity of the roller pulley. The roller pulley has 4 bolt holes and bolts to the outside of the roller. The roller end piece has four blind holes. They are bored and tapped into it with a M10x1,5 tap according to the pulley's bolt pattern. The bolts securing the pulley are dimensioned according to what is easily available of bores, taps and bolts at the workshop. Additionally, calculations are made to make sure the bolt can withstand the shear force induced by the system.

First the allowed shear stress must be calculated. For bolt grade: 8.8 it is defined accordingly:

Bolt: M10x1,5 Bolt grade: 8.8 σ_b=800 N/mm^2 Υ_{M2}=1,25

$$\sigma_{allowed} = \frac{0{,}5 * \sigma_b}{\gamma_{M2}} = \frac{0{,}5 * 800 \frac{N}{mm^2}}{1{,}25} = 320 \frac{N}{mm^2}$$

$\sigma_{allowed}$: The maximum allowed shear stress

Now that maximum allowed shear stress is calculated, the actual shear stress must be calculated. Start by calculating the conservative cross-section of the bolt in question.

d_3=8,376 mm *(Johannessen, 2002, p. 121)*

$$A_s = \frac{\pi d_3^2}{4} = \frac{\pi * (8{,}376\, mm)^2}{4} = 55{,}07\, mm^2$$

A_s: Conservative cross-section of the bolt
d_3: Most conservative diameter of the bolt utilized

There are four bolts, the force caused by the torque on the roller will therefore be divided by four.

$T_{R,\, maz}$=40 Nm n=4

$$T_b = \frac{T_{R,max}}{n} = \frac{40\, Nm}{4} = 10\, Nm$$

$T_{R,\, max}$: Maximum torque at the roller axel
T_b: Torque on bolt
n: Number of bolts used

The torque is then converted to the shear force experienced by the bolts.

d=60 mm T_b=10 Nm

$$F_z = \frac{T_b}{\frac{d}{2}} = \frac{10\ Nm}{0,03\ m} = 333,3\ N$$

F_z: Shear force
d: Diameter of bolt pattern

The shear stress is then calculated:

$$\tau = \frac{F_z}{A_s} = \frac{333,3\ N}{55,07\ mm^2} = 6,05 \frac{N}{mm^2}$$

τ: Shear stress

Finally, the allowed shear stress and actual stress is compared:

$$\tau = 6,05 \frac{N}{mm^2} < \sigma_{allowed} = 320 \frac{N}{mm^2}$$

According to these calculations, the bolts are more than strong enough to withstand the shear force that occurs.

3.3.2 Gearing

The pulleys are geared using a 3:1 ratio, where the diameter of the roller pulley would be 150 mm and 50 mm on the motor pulley. This results in an almost 1:1 ratio in-between the car motor and workstation measuring motor whilst in 2nd gear on the car. Considering the measuring motor has a maximum rpm of 9500 rpm, this is a quite conservative angular speed which will benefits the longevity of the motor. More information regarding the gearing system, and the torque it will experience, can be found in the Gearing input appendix.

3.3.3 Belt

When designing a pulley system, the first consideration should be how much force is going through it. Then consider what level of tension on the belt is possible. Finally, choose the belt strong enough to withstand the force created by the driving pulley and tensioning. Some types of belts require less tension than others. In this application it is desirable to keep the design simple. For this to apply, a simple “slide to tighten” method is being utilized. This method is not able to produce an excessive amount tension. Therefore, the application requires the use of a V-belt. This type of belt has a larger surface area allowing for 5 times more efficient power transfer. This means less tension, while still sustain good power transfer and minimal slipping.

3.3.4 Groove

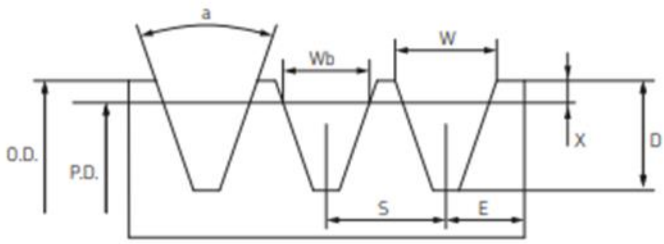
MARATHON 1/MARATHON 2 AUTOMOTIVE V-BELTS TO RAW EDGE, MOLDED COGGED

AVX 10	10 x 8	4.9	8.5	OUTSIDE LENGTH L_a	—	$L_d = L_a - 13$	$L_i = L_a - 51$	SEE OEM SPECS.	.076
AVX 13	13 x 10	5.8	11		—	$L_d = L_a - 18$	$L_i = L_a - 63$		.118

Table 13 (Optibelt Product Catalog, 2013)

The V-belt being used is a 1000 mm long Optibelt AVX10 Marathon I. This is a 10 mm wide, cogged automotive specific V-belt which reduces energy consumption by negating the compression stress induced by the belt wrapping around the pulleys. Main reason for choosing this belt is because it fits the application well, and because it was available at nearby stores.

Due to this being a specialized belt it is difficult to find specifications on the pulley groove. SPZ is the standard dimension for “10 mm” V-belts. The only difference between this belt and a standard SPZ belt is that the top width is 10 mm instead of 9,7 mm. The datum width B_d/W_b is still 8,5. Since they are so similar it was decided to design the pulley around a standard SPZ groove. This means it will work with the current belt, but it can also easily be replaced with a SPZ belt in the future.



Wedge belt pulleys

Belt series	Pitch Diameter Range	Groove Angle	Dimensions					
		a	W	W_b	D	X	S	E
		°	mm	mm	mm	mm	mm	mm
SPZ	Up to 80 Over 80	34 38	9,7	8,5	11	2	12	8
SPA	Up to 118 Over 118	34 38	12,7	11	13,8	2,75	15	10
SPB	Up to 190 Over 190	34 38	16,2	14	17,5	3,5	17	12,5
SPC	Up to 315 Over 315	34 38	22	19	23,8	4,8	25,5	17

Table 14 (SKF Pulley Catalogue, 2014)

3.3.5 Calculations

Maximum allowed torque before slipping:

The motor being used in the car during this project is an Alva X100 motor. It is capable of outputting a maximum torque of 8 Nm, which is what will be used during these calculations. The gearing results in the output torque on the roller being 40,9 Nm. It is important to note that it will never utilize this amount of torque due to energy efficiency. The torque figure being used in the calculations will only function as a safety in case of controller failure.

$M_{input(roller)}$=8 Nm i_{tot1}=14,06 i_3=0,36

$$M_{input(roller)} = M_{\max\,(motor)} * i_{tot1} * i_3 = 40{,}49\ Nm$$

$M_{input(roller)}$: Torque being applied to the roller by the wheel
$M_{max(motor)}$: Maximum torque the Alva x100 can generate
i_{tot1} and i_3: Gearing constants, see Gearing input

When setting the maximum allowable tensioning force, the weakest part must be considered. In this case, it is the shaft of the measuring motor. According to the technical data sheet for the motor, the maximum radial force 15 mm from the flange is 110 N. While considering longevity and reduce wear on the motor; a safety factor of 1,5 is applied. Using this safety factor, the maximum allowable tensioning force is 73 N (N_0). Whilst the system is stationary this force will be divided by the two belt sides.

N_{max}=110 N SF=1,5

$$S_1 = S_{resting} = \frac{N_0}{2} = \frac{73\ N}{2} = 36{,}5\ N$$

$S_{resting}$: Tension on the belt while resting
N_{max}: Maximum radial force on motor shaft
N_0: Maximum allowed radial force on motor shaft

There will be a coefficient of friction in-between the pulley and the belt. Unfortunately, the exact coefficient is unknown, due to the pulleys being made from scratch. Test could be made to determine the coefficient, but due to time restraints and the nature of the project it was neglected. Instead the coefficient was decided by using a standard chart.

Belt material	Pulley material						
	Cast iron, steel			Wood	Compressed paper	Leather face	Rubber face
	Dry	Wet	Greasy				
1. Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
2. Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
3. Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
4. Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
5. Rubber	0.30	0.18	—	0.32	0.35	0.40	0.42
6. Balata	0.32	0.20	—	0.35	0.38	0.40	0.42

Table 15 (Chaudhari, 2015, Table 1)

Going with the combination of a steel pulley and rubber belt the coefficient ends up being 0,3. V-belt grooves for 50 mm pulleys have an angle of 34 degrees. This results in the coefficient of friction being increased to 1,03.

$$\mu = 0{,}3 \qquad \acute{\alpha} = 34$$

$$\mu_{s(enh)} = \frac{\mu}{sin\frac{\acute{\alpha}}{2}} = \frac{0{,}3}{sin\frac{34}{2}} = 1{,}03$$

μ: friction coefficient between belt and pulley
μ_s: enhanced friction coefficient between belt and pulley due to v groove
α: angle of pulley groove

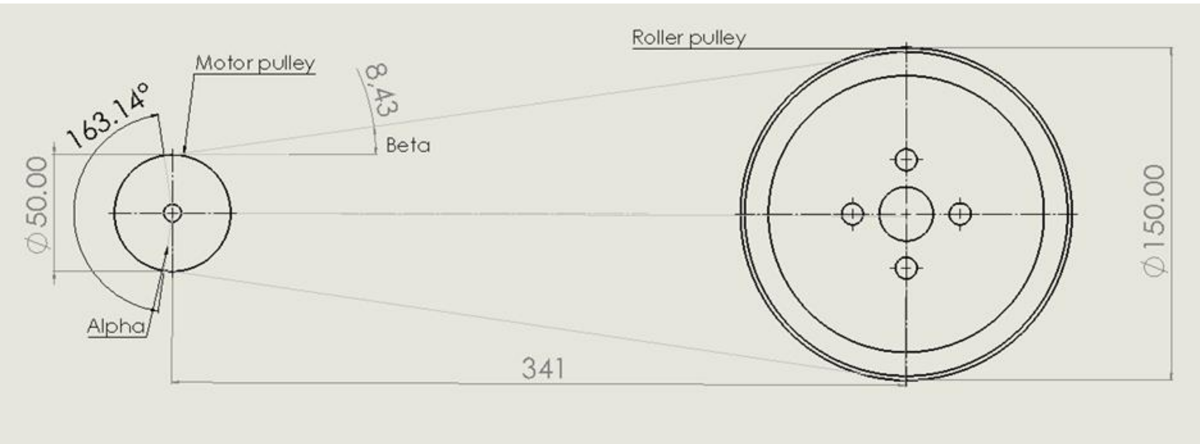


Figure 27 Pulley dimensions

The pulley setup consists of two pulleys, one 150 mm, the other 50 mm. They are 341 mm apart. To calculate the tension during load it is necessary to know the smallest angle of contact.

$$sin\beta = \frac{(D-d)}{2a} = \frac{(150\,mm - 50\,mm)}{2 * 341\,mm} = 0{,}1466$$

$$\beta = 8{,}43°$$

$$\alpha = 180° - 2\beta = 180° - 2 * 8{,}43° = 163{,}14°$$
$$\alpha = 2{,}85$$

α: Angel of contact
β: Input angle

The maximum input torque allowed can now be calculated:

$$M_{\max\,(roller)} = (S_{2max} - S_1) * r_{roller\,pulley}$$

$$S_{2max} = S_1 * e^{\mu_s \alpha} = 36{,}5\,N * e^{1{,}03*2{,}85} = 687.33\,N$$

$$M_{\max\,(roller)} = (687{,}33\,N - 36{,}5\,N) * 0{,}075\,m = 48{,}1\,Nm$$

$$M_{input(roller)} = 40{,}9\,Nm < M_{\max\,(roller)} = 48{,}1\,Nm$$

According to these calculations the maximum torque on the roller ($M_{input(roller)}$) does not exceed the maximum allowed torque ($M_{max(roller)}$). This means that even with the car's motor accelerating with maximum torque, the belt will not slip.

3.4 Double Lift System

3.4.1 How it works

The workstation has a double lift system. The system consists of two modified pre-manufactured universal lifts.
These lifts' function of a threaded rod that is connected to four arms on each lift by two points. One of the two points are threaded and as the rod turns the points are being pulled towards each other which then lifts the car.
This style of lift has been chosen because of its simple design and the capacity which ensures a large factor of safety based on the load applied during operation (max 200 kg).

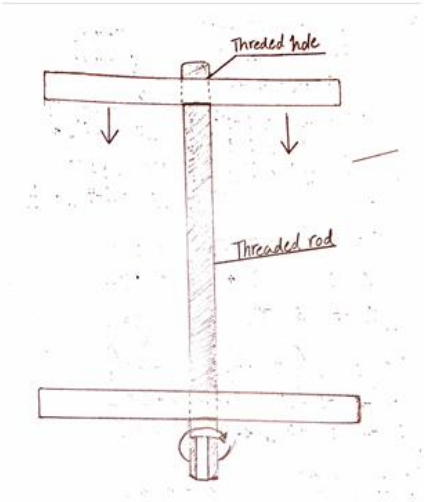


Figure 28 "Miniløfter" (Biltema, 2017)

The two lifts run synchronized of one electric motor.
To enable this each lift is modified with identical sprockets welded to the ends of the threaded rods. A 520-motorcycle chain runs between these sprockets. Due to the low load on the system it is possible to connect the motor directly on to the rod without any gearing. The ratio between the sprockets is 1:1. This always ensures that the lifts run synchronized and stay at the same level.

3.4.2 Car Braces

To maximize stability, the lifts are equipped with wooden beams resting on top of the top plates to increase surface area. These are secured by two recessed bolts. Wood is a softer material than carbon fibre and wont scratch the underbody of the car. It is also more vibration absorbent than metal. To ensure there is enough friction between the car and the holders, the beams have a layer of rubber to prevent the car from sliding when lifted. These holders are one of the adjustable parts of the system which can be swapped out or modified for future cars.

3.4.3 Lift assembly

The lifts are mounted 500 mm apart on two steel square tubes (3x40x40 mm). From the factory, the lift comes with two mounting brackets, one on each side. These sit flush with the underside of the lift to give stability. Since the lifts are mounted of the ground on the workstation the underside of the lift will not provide any stability and therefore, a second pair of brackets are added to compensate.
The lift system is adjustable, and the lifts are mounted with four through bolts each. These bolts are 8.8 because this quality is easy to acquire and strong enough
If the system is to be adapted to a new car, new holes must be made.

3.4.4 Safety

Whenever there are parts in motion and load being applied it is important to look at safety. The lift system is modelled in SolidWorks and through simulations in the program it is possible to get a good idea about the strength. When the max operation load is applied the model has high factor of safety and small displacements.

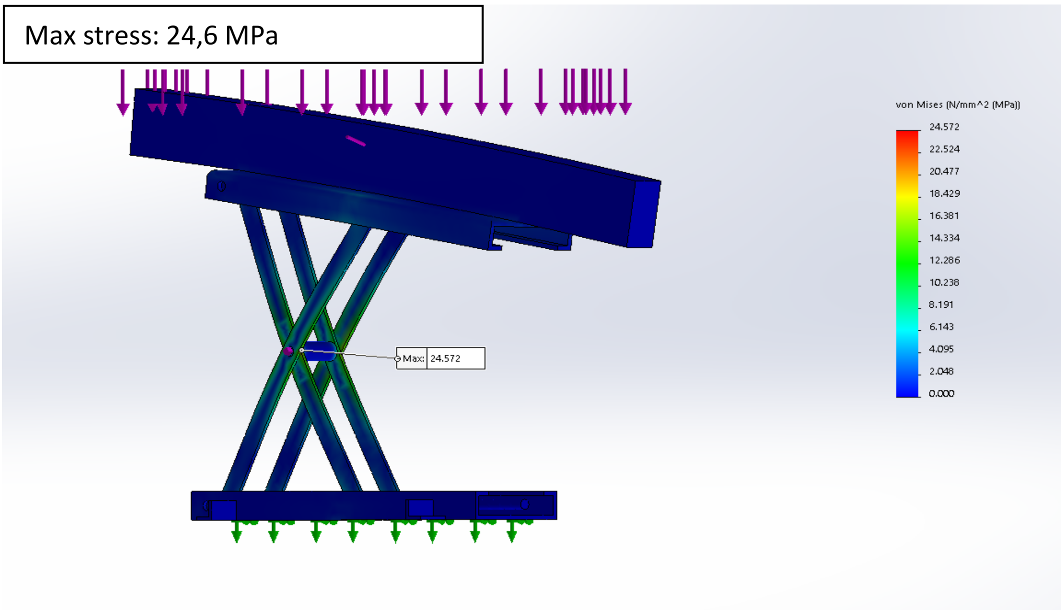


Figure 29 SW Simulation: Car brace, stress

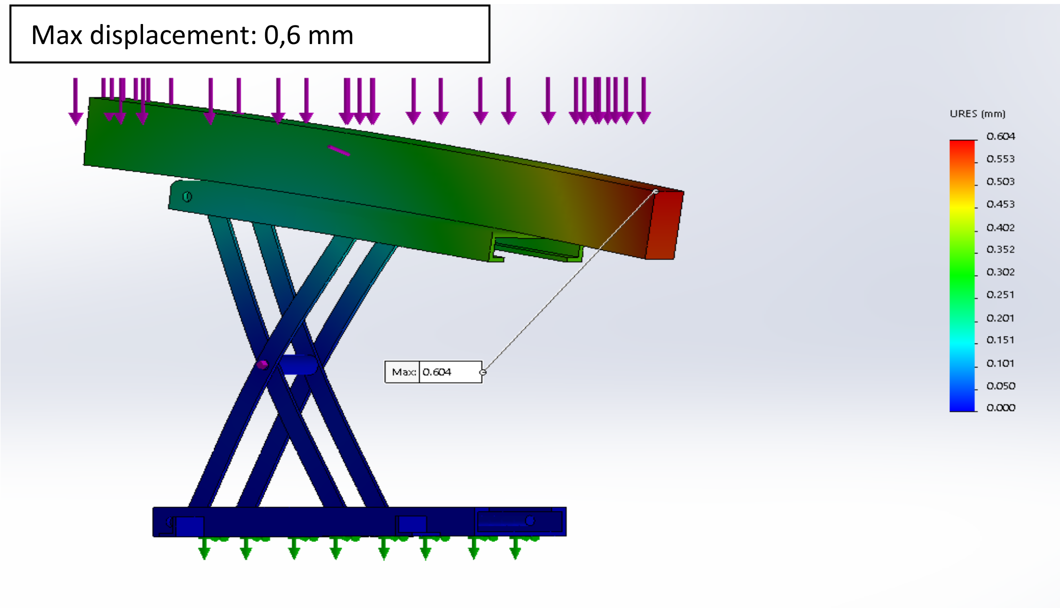


Figure 30 SW Simulation: Car brace, displacement

3.5 Adjustable Solution

The solution is to use wide rollers in the back and two-dimensional adjustable steering discs in front. SEM have rules that dictates the dimensions of the cars. The current car is on the outer limit of width and length. The adjustability is therefore made so that the maximum value would match up with the maximum of the SEM rules.

3.5.1 Width

This value is limited by the total width of the bench, roller placement and disc size.

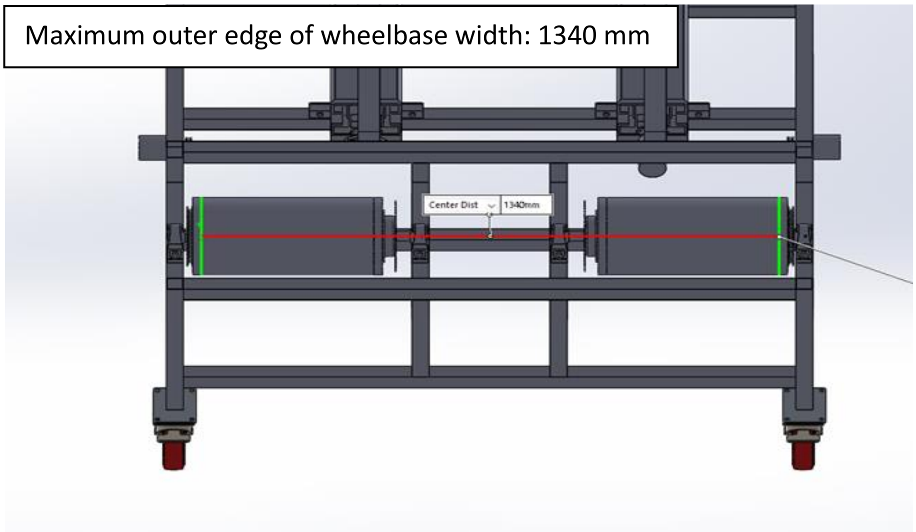


Figure 31 Maximum width

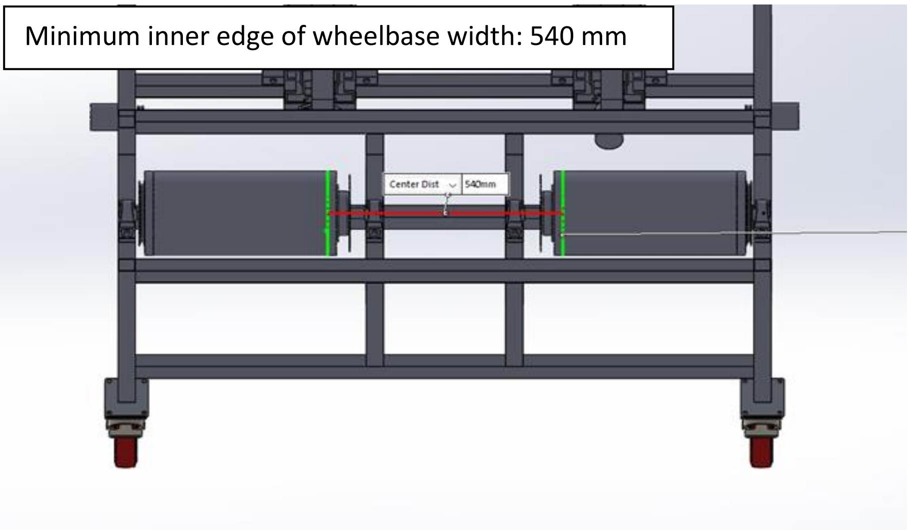


Figure 32 Minimum width

3.5.2 Length

This value is determined by the total length of the frame, lift placement and steering assembly.

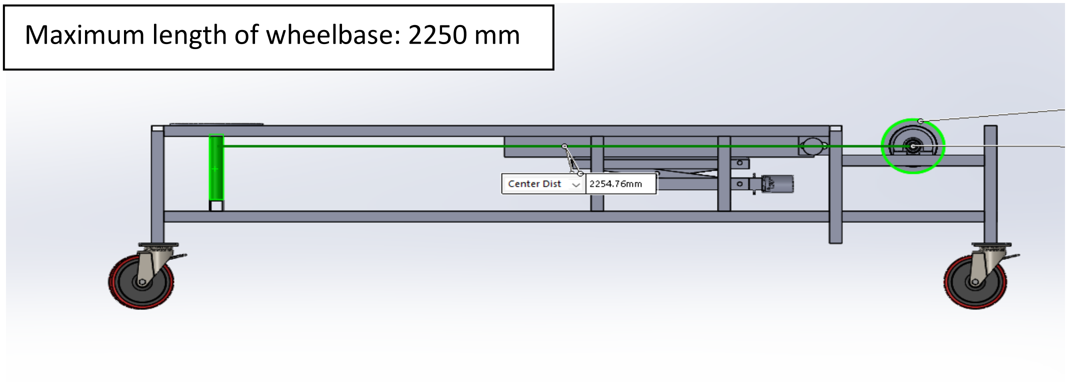


Figure 33 Maximum length

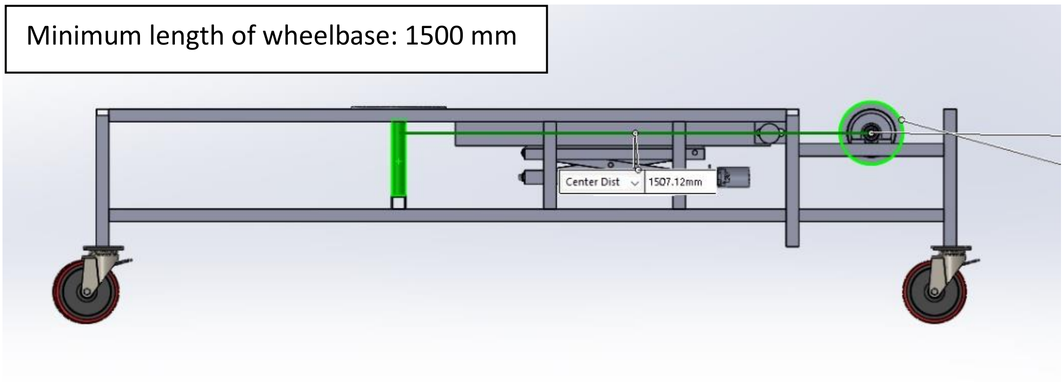


Figure 34 Minimum length

3.6 Brake Simulation

On the workstation one of the main goals are to measure the performance of the drivetrain during load. The tractive torque is the torque that must be applied on the wheels for the car to move. It consists of several elements which largely depends on the current velocity and acceleration of the car. By knowing the tractive torque, one may simulate it by applying the translated braking torque at the given speed/rpm on the measuring motor.

The tractive torque is defined by the following equation:

$$T_w = F_t * r_w$$
$$F_t = F_r + F_g + F_d - F_{ie}$$

T_w: Tractive torque at the wheel
F_t: Tractive force
r_w: Radius of the wheel

F_r = tyre rolling resistance
F_d = aerodynamics drag
F_{ie} = equivalent inertial force (during acceleration) - (including linear and rotational inertias, due to vehicle mass and rotating component of gear train and wheels)
F_g = forces due to gradient

Since it is the roller that will be applying the tractive force, it is the torque used on the roller to achieve the tractive force on the wheel that must be clarified. The same formula may be used with minor tweaks:

$$T_R = F_t * r_R$$

T_R: Torque at the roller
r_R: Radius of the roller

After this has been clarified, all that must be done is to convert the torque necessary at the roller to the motor.

$$T_R = F_t * r_R * i_3$$

i_3: Ratio in between the roller pulley and motor pulley

The tractive force

For the equation above to function, the individual components of the tractive force must be defined.

First the rolling resistance will be defined. In this case the rear tyres are still experiencing rolling resistance. Therefore, the only rolling resistance that must be added are from the front tyres. Considering there are two measuring motors, each motor will apply the brake for one front tyres. To calculate the rolling resistance of the wheels it is necessary to, either do extensive testing with the tyres in question, or use a provided data sheet from the tyre's manufacturer. In this case Michelin 90-80 R16 tyres are being used, which the data sheet is provided for. This makes it possible to make an expression for the rolling resistance using the following equation:

$$F_R = C_R * N$$

$$N = mg = mass * 9{,}81 \frac{m}{s^2}$$

C_r: constant defined by the manufacture through thorough testing. It is a constant specific to the speed.
N: normal force due to gravity

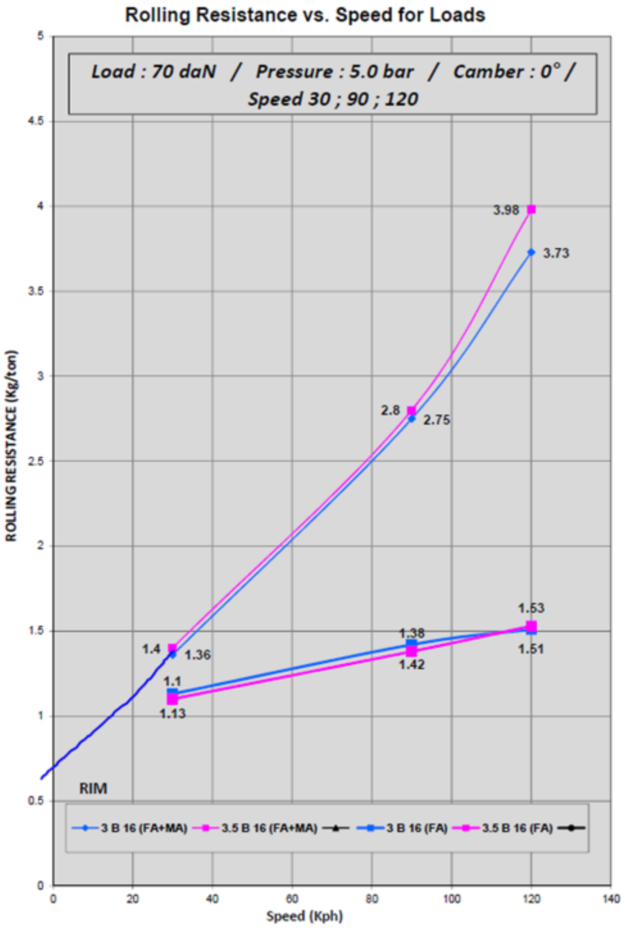


Figure 35 Rolling Resistance vs. Speed for Loads (Michelin, 2015)

Since the graph for the tyre is provided, one may find an estimated equation for the rolling resistance throughout the rpm range by using interpolation:

$v_{@0,0015}$=35 km/h=9,72 m/s

$C_{R@9,72m/s}$=0,0015 $C_{R@0m/s}$=0,00075 m=143 Kg (Car=75 Kg, driver=78 Kg)

$$F_R(v) = ((C_{R@9,72\frac{m}{s}} - \mathrm{C}_{\mathrm{R@0}\frac{\mathrm{m}}{\mathrm{s}}}) * \frac{v}{9,72\frac{m}{s}} + \mathrm{C}_{\mathrm{R@0}\frac{\mathrm{m}}{\mathrm{s}}}) * mg = 1,05\ \mathrm{N} * \frac{v}{9,72\frac{\mathrm{m}}{\mathrm{s}}} + 1,05\ N$$

This is the rolling resistance for all four wheels. Each motor will only have to simulate the resistance caused by one front wheel. This results in the following equation:

$$F_{R1}(v) = \frac{\mathrm{F_R(v)}}{4} = \frac{1,05}{4}\mathrm{N} * \frac{\mathrm{v}}{9,72\frac{\mathrm{m}}{\mathrm{s}}} + \frac{1,05}{4}N = 0,263\ N * \frac{v}{9,72\frac{m}{s}} + 0,263\ N$$

F_{R1}: Rolling resistance for a single wheel

The next force to consider is the equivalent inertial force. Since the purpose of the dyno system is to measure the car's performance, the equivalent inertial force caused by the rollers and pulleys must be removed. Both of which functions as a flywheel, braking the rotation of the car's wheel.

To simplify the expression, only the barrel of the roller is considered. More in depth calculations may be done, but they are not included in this report.

The expression that will be used is defined accordingly:

$$T = I * \alpha$$
$$Inserting: I = \frac{1}{2}mr^2 \; and \; \alpha = \frac{a}{r}$$
$$\frac{T}{r} = \frac{1}{2}ma$$
$$F_{ie} = \frac{1}{2}ma$$

I: Moment of inertia for solid cylinder
T: Newtons second law
α: Angular acceleration
m: mass of roller

The equivalent inertial force is largely dependent on the acceleration of the car. The acceleration will have to be real time monitored so that the equivalent inertial force can be subtracted from the total tractive force.

Then the forces due to aerodynamic drag needs to be calculated. This force is variable, meaning that the motors will need to apply more braking power the faster the car drives. The aerodynamic drag is defined by the following equation:

$$F_D = C_d * \frac{\rho * v^2}{2} * A$$

C_d: Drag constant
ρ: Air density
v: Speed measured in m/s
A: Reference area being affected by the drag

For the equation to function there are a couple of constants that must be known. The approximate drag coefficient and reference area of the current car is defined in the backbone of DNV GL Fuel Fighters. Which is based on simulations made in openFOAM.

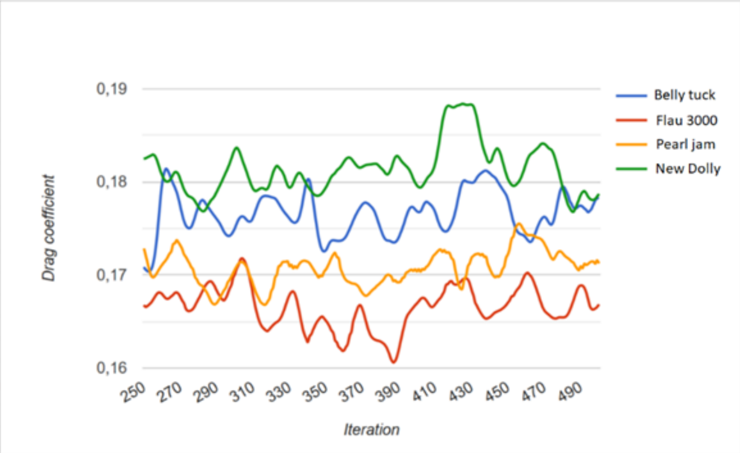


Figure 36 (Trefall, 2019)

Flau 3000=Flow 3000 (The type of grid refinement which gave the most accurate results), snappyHexMeshDict used

Depending on where SEM will be held, the density of air will vary. In this instance the density at sea level and 15C will be utilized. This is a normal setting which also functions as a worst-case scenario.

A_{Front}=0,779 m^2 C_d=0,166 $\rho_{@15C\&0masl}$=1,225 Kg/m^3

$$F_D = 0{,}166 * \frac{1{,}225\,\frac{\mathrm{kg}}{\mathrm{m}^3} * v^2}{2} * 0{,}779\ \mathrm{m}^2 = 0{,}0792\,\frac{Kg}{m} * v^2$$

Using the formula, it is clear that the only variable will be the speed. The speed variable can be scaled accordingly to a rpm sensor attached to the measuring motor. By using the rpm sensor and a gearing constant the speed of the car can be calculated.

The final force to consider are forces due to gradient. This will however be neglected during this phase of the subsystem. The reason for this is because the track simulator is not finished yet, so there is no way of knowing the gradients the car will experience. Additionally, the different gradients and turns would cause the angel of the car, relative to the flow of air, to change. This would ultimately cause the reference area to change, causing the need for more aerodynamic testing.

Result

Now that the individual tractive forces have been defined, it is important to consider that there are two motors delivering the braking power. Therefore, the final tractive force for each wheel must be defined like this:

$$F_t = \frac{F_r}{4} + \frac{F_d}{2} - F_{ie}$$

Now that the basis for the tractive force is established, that can be used to make an expression for the torque needed on the roller to achieve this braking force:

$$T_R = \left(0{,}263\ N * \frac{v}{9{,}72\,\frac{m}{s}} + 0{,}263\ N + 0{,}0792\,\frac{Kg}{m} * v^2 - \frac{1}{2}ma \right) * r_R$$

Finally, the gearing constant in between the roller pulley and motor pulley can be used to calculate the needed braking torque on the measuring motor at the given speed and acceleration:

$$T_M = T_R * i_3 = \left(0{,}525N * \frac{v}{9{,}72\,\frac{m}{s}} + 0{,}263 + 0{,}0792\,\frac{Kg}{m} * v^2 - \frac{1}{2}ma \right) * r_R * 0{,}33$$
$$See\ Gearing\ input$$

This is the formula that must be inputted into a motor controller to achieve the correct amount of tractive torque on the wheels.

4 Result

Figure 37 Workstation

4.1 State of Progress

The project was abruptly halted on March 12. When the government announced a nation-wide lock down due to the COVID-19 pandemic. The project was 78 % completed at that point and only 60 % of the workstation was built.

Workstation Mechanical						78 %					
	Weight	Completion		Weight	Completion		Weight	Completion		Weight	Completion
DESIGN	40 %	100,0%	PURCHASING	10 %	90,5%	PRODUCTION	40 %	63,4%	TESTING	10 %	31,0%
Frame	30 %	100 %	Steel	60 %	100 %	Frame	40 %	95 %	CAD Simulation	25 %	100 %
Lifts	10 %	100 %	Lifts	20 %	100 %	Dual Lift system	10 %	90 %	Weld testing	10 %	60 %
Rollers	25 %	100 %	Bolts, belts, etc.	5 %	100 %	Rollers	20 %	80 %	Simulation testing	20 %	0 %
Brakes	10 %	100 %	Plywood	5 %	0 %	Pulleys	15 %	0 %	General testing	15 %	0 %
Front wheel discs	5 %	100 %	Wheels	5 %	100 %	3D-print discs	4 %	10 %	Electrical testing	30 %	0 %
Pulley system	20 %	100 %	"extra stuff"	5 %	10 %	Brakes	6 %	0 %			
						Plywood	3 %	0 %			
						Design details	2 %	0 %			

Table 16 Progress map

Frame status

The frame is the part that is closest to completion. All the welds are completed, both wheels and lifts are bolted on. At 95 %, the only thing remaining is bolting on the beam for the front wheels, grinding down the outer welds, prepping the whole frame for paint, and then apply paint.

Lift system status

The lifts are bolted on to the frame and two planks are bolted to the lifts, making out the car brace. However, the planks must be shaped and fitted with rubber. The sprockets must be welded on to the lifts, as well as a rod to connect one of the sprockets to the electric engine.

Rollers status

Both sets of rollers are complete The PVC pipe for both rollers are cut to the correct length, and the end caps are machined to the correct specifications except for the bolt holes.

Figure 38 Rollers

4.2 Evaluation

It is impossible to give a thorough evaluation of the workstation given that it is not finished and in no way can be tested. We will however evaluate the parts that have been made and take a closer look at some of the challenges we faced.

The welding process was a challenge at first. We needed practice before we could weld the frame, and even then, it proved difficult. Some mistakes were made, but we got considerable help from staff at the workshop and members of DNV Gl Fuel Fighter, so the process got smoother as it went along.
Working at Verkstedteknisk workshop also proved challenging at times. We were unable to use the band saw for most of the build and were not allowed to use an angle grinder. We had to resort to using a reciprocating saw for most of the cutting of steel. The cuts got inaccurate and we had to use a belt grinder to try and get the correct length.
The result ended up being less accurate and less pretty than imagined. However, the most critical part of the frame, which is the back end where the rollers sit, became accurate and level.

DNV GL Fuel Fighter will continue working on the workstation and the fact that it was not finished in this project does not matter to much.

5 Further Development

5.1 Enclosure

To prevent the car from being damaged during transportation an enclosure that covers the workstation has been considered. Due to the time frame of the project this concept has not been prioritized.

The idea is to make a light wooden frame which covers the workstation and the car. The enclosure will be plated with thin plywood. This way the car is protected against the environment and objects that can potentially scratch or damage the car. To secure the enclosure to the frame mounting points can be welded to the frame. A quick release system is desirable to make mounting and dismounting the enclosure as easy as possible. The enclosure is light but has a lot of surface area. This can be utilized as commercial space for sponsors.

In addition to this, handlebars should also be added to the frame to make it easier to move.

5.2 Track Simulator

As mentioned earlier in the report, one of the future goals for the workstation is to use it as a track simulator. The rollers, electrical motor and front wheel rack are the three most important components to enable a track simulation. The rest of the development relies on simulation software and data input from the workstation.

A potentiometer measures the steering angle of the front wheels, the resistance in the rollers are determined by the electrical motor which is controlled by the software to match the situation in the simulation.

5.3 Electrical Equipment

The electrical equipment falls under the responsibility of the electrical team. At the time of writing, none of the equipment is fitted. electric motors, circuit boards and various other electrical equipment must be fitted. Plywood panels will be used as a platform for most of the equipment and brackets mounted to the frame will be used for the electric motors.

5.4 Braking System

During the design phase it was early on decided that there would be a need for an emergency brake. This has to a certain degree been designed and drawn in CAD. However, there are still uncertainties regarding how well it would function. Additionally, there has not been made any measurements to the actual components that are being considered. This includes: the calliper, brake disc, brake cylinder, the list goes on.

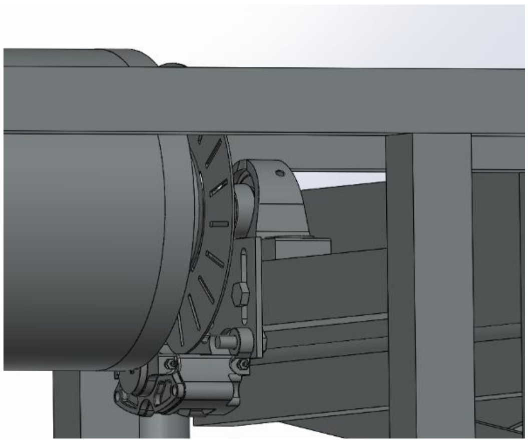


Figure 39 Brake system

The concept itself is relative clear. It consists of a calliper, brake disc, mounting bracket and roller-disc adapter. The system will utilize the calliper and disc combination from a previous braking system for the FF-car. This will then be connected to a brake master cylinder with a lever that can be pulled should an emergency arise.

A ruff idea of how the brackets fits can be found within the 3D model, using an alternative calliper. To achieve accurate mounting of the calliper, the use of a CNC mill is advised.

The roller-disc adapter is made from a 200mm 6082-T6 aluminium bolt. 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.

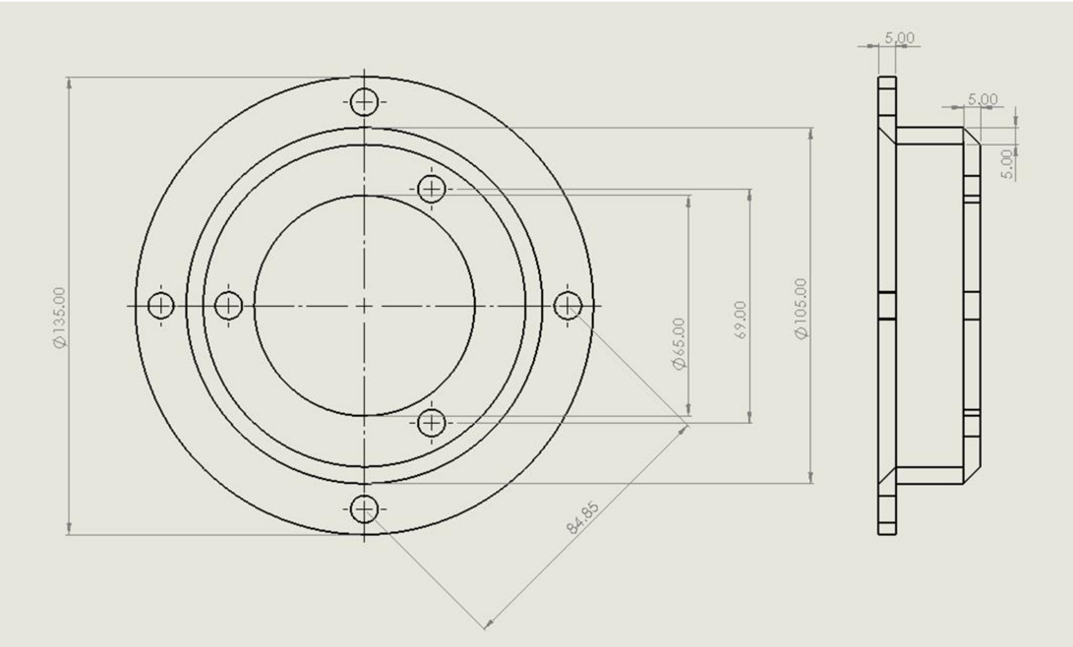


Figure 40 Roller-disc adapter drawing

6 Process & Methodology

6.1 Method

With this project we started with the idea of using the Agile methodology. Agile is an iterative process, with focus on adapting to new situations and regularly evaluate the current state of the project. It does not rely heavily on pre-planning. It is flexible and allows for changes. Although Agile is not technically a methodology but rather a set of principles, it works well in a project like this where there inevitably will be changes. The principles are based on four values:

- Individuals and interactions over processes and tools;
- Working software over comprehensive documentation;
- Customer collaboration over contract negotiation;
- Responding to change over following a plan.

(Aston, 2019, paragraph 4)

We felt like this was an appropriate direction to choose because of our lack of experience working on a project like this. It seemed a good idea to have flexibility.

Using Agile worked well for the most part. The project faced several situations where change was necessary. As the project evolved, we took note of some things that did not work so well.
This method relies on good communication between group members. And the most important thing is to make sure all members are working towards the same goal and that all members understand what is required to achieve this goal.
A good progress mapping tool is important. We did not track our progress until February 2020 and did not set progress targets. The project can quickly fall behind when you do not have a reference to your progress. And that is part of what happened to us.
Also, the flexibility is good when it comes to responding to change but can be an excuse to change the plan rather than working harder to achieve the original deadline.

6.2 Project Follow-up

6.2.1 Timetable and progress

Our original goal, in short, was to have a build a working product by the end of march. The first deadline was made under the circumstances that we would have gotten the necessary workshop courses and have full access by January, the original deadline was February 14. However, we did not get any courses in 2019 and realized in January 2020 that we would not get any courses until February. This pushed our deadline; our first timetable had a buffer for such a scenario, so the new deadline was now March 1.
Ordering parts took a long time and ultimately, we underestimated how much time was needed for orders and production, resulting in us pushing the deadline further, to March 23. By March 8. 72 % of the build was completed, this includes design, purchasing, production

and testing. We looked on track to making the deadline, but on March 12. The government announced the lock down of the country due to the COVID-19 pandemic and as a result NTNU campuses were closed. At that point, the build was at 78 %.
We made a made a new plan shortly after. The best-case scenario was that the campus opened April 13. And we could finish the workstation by May 1. In this the period, Shell Eco-marathon cancelled all their events and the Fuel Fighter board decided to stop all production and announce this year's project as cancelled as well. By the end of Easter, we knew the earliest return date was April 27. With limitations. We therefore decided to abort all plans to finish the product and use the remaining time to focus on writing the bachelor thesis.

6.2.2 Cost

We estimated the mechanical parts of the workstation would cost 28 650 kr. As of March 12. We had spent 33 % of our "budget". Most of the essential parts had been ordered, what remains is mostly plywood, LED lights, speakers and miscellaneous.

Item	Price per unit	Quantity	Price
"mini løfter"	kr 599,00	2	kr 1 198
Air rubber, 75kg swivel with brakes	kr 363,00	4	kr 1 452
Belts	kr 64,90	2	kr 130
Steel frame	kr 193,62	7	kr 1 355
Aluminum bolt Ø200mm, L800mm	kr 4 609,00	1	kr 4 609
chain	kr 449,00	1	kr 449
sprockets	kr 159,00	2	kr 318
Total price			kr 9 511

Table 17 Cost

6.3 Learning Outcome

"Knowledge:

- *The candidate should have in-depth knowledge of a selected problem within the subject area.*
- *The candidate should have knowledge of project management and documentation.*

Skills:

- *The candidate must be able to identify, formulate and solve a relevant problem.*
- *Utilize knowledge and skills from several disciplines in the study, as well as do independent study where necessary.*
- *Acquire project management skills by completing and documenting project work.*
- *Be able to find, evaluate and refer to information and subject matter and present it so that it highlights an issue.*

General competence:

- *The candidate should be able to identify, formulate and solve relevant problems in the field of mechanical engineering, and thus be able to function well as an engineer in the working world.*
- *The candidate can disseminate knowledge within his / her field of study to various target groups both in writing and orally."*

(TMAS3001, 2019)

Our experience:
Through our studies we have acquired most of the knowledge needed within the subject area, although some aspect needed more research. Our knowledge of project management at the start of the project was limited. The subject "Prosjektledelse" was taught in the fall semester of 2019. And "Ingeniørfaglig systemtenking" was taught in January and February 2020. This meant that our knowledge of project management and documentation increased as the project progressed. Our level of documentation increased in 2020, as we started with progress mapping, more regular scheduled meetings, and revised time schedules.

At the start of the project in late September 2019 we made a time schedule and agreed on a general plan on how to approach the problem. We have documented every activity in the project. Most times with a basic draft during the time of the activity and later written a detailed version. We used project management tools such as Gantt, AHP, stakeholder analysis, risk analysis, WBS, goal analysis and more.
Regular group meetings were a big part of our plan to achieve good group synergy. We used the meetings to make sure every member was on the same page regarding the project, but also as a platform to express our thoughts on the process and potential problems we might have had.
Because of the sudden stop due to the pandemic, we learned that ongoing documentation can be smart. The workshop was closed with just one day notice, and when writing the thesis, we realized that we were lacking good photos and details of certain parts.

The project has given us valuable experience with both teamwork and project management. An added bonus is the experience we gained from working within a larger organization. Having to cooperate and communicate with more people and giving us regular practice in oral presentation.

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8 Abbreviations

WBS	Work breakdown structure
PU-journal	Journal containing relevant project documentation
AHP	Analytical hierarchy process
SEM	Shell Eco-marathon
Rpm	Revolutions per minute
MIG	Metal inert gas
MAG	Metal active gas
TIG	Tungsten inert gas
CNC	Computer numerical control
PVC	Polyvinyl chloride
NTNU	Norges teknisk- naturvitenskapelige universitet
CAD	Computer- aided design
LED	Light- emitting diode
DNV GL	Det Norske Veritas Germanischer Lloyd
CFD	Computational fluid dynamics
SW	SolidWorks

9 Appendix

9.1 Address List
9.2 Intern samarbeidsavtale
9.3 NTNU Standardavtale Bachelor
9.4 Technical Data Sheet
9.5 CAD-Model
9.6 AHP
9.7 Workshop Risk Analysis
9.8 Backbone
9.9 Gearing input

NTNU

Kunnskap for en bedre verden