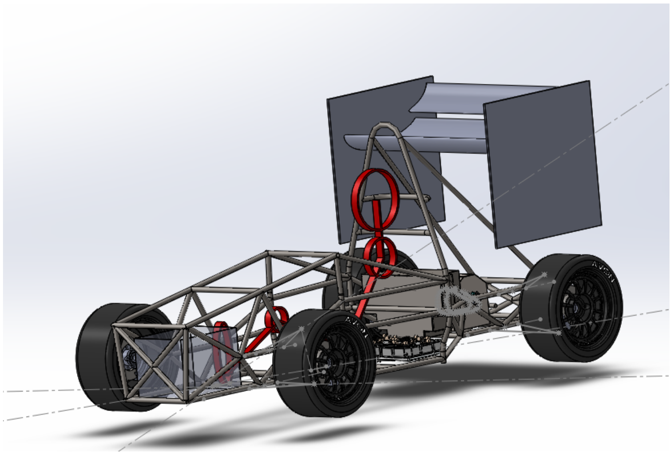
DESIGN OF REAR WING OF AN ELECTRIC RACE CAR



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Furthermore, a big thanks to Rasmus from Philips Lighting, for helping us machine the 1/4 scale wing used in the windtunnel tests.

Abstract

Race cars wooo! Formula studee3333nt

Contents

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Introduction

Vermilion Racing is a newly started Electric race car team building their first vehicle: The Eevee [1]. The teams' purpose is competing against other Universities at the Silverstone race track from the 11^{th} to the 16^{th}. As members of the team, the purpose of this report is to document the design process of the rear wing of the first car, the Eevee, and provide an aerodynamic package documenting drag and downforce. The intent is to start a student organization, passing on the teachings of racecar mechanics for many years to come.

Aerodynamics is a major decider in racing today. Cornering, not top speed is the deciding factor amongst the teams, and aerodynamics is the key. Drag, lift and side force are the three cornerstones to vehicle aerodynamics. A car's ability to handle depends on the grip of the tyres, and downforce directly increases grip by increasing the downwards load on the tyres without adding a weight penalty. Additionally, drag directly decreases the speed of a vehicle by increasing air resistance, but is of less importance as the car's in this class have far more accelerative power than the tyres can handle [2]. Designing the bodyworks of Eevee is therefore a dance of downforce.

1.1 Motivation

- Why are we designing this to begin with

1.2 Design Philosophy

Designing a car with hundreds, if not thousands different factors is incredibly difficult. Therefore, analyzing which things matters and which don't is crucial to the teams' success. First, the deadline for finishing the wing is soon. This sets a limit on the complexity of the wing's dimensions. Secondly, this is the first iteration of the car, thus no decision can be based on prior experience, and optimization has to wait for the next iteration. Finally, the finances of the car is tight. This forces us to go with a low-cost solution. We therefore have to go for a simple, low cost wing, basing the design solely on litterature and experience other teams have done.

The wing has to have as low weight as possible, in order to ensure optimum acceleration of the car. Thereto, drag has to be kept low, but the effect from drag is near negligible, which will be explained in section 2.2.1. Lastly, we have to maximize the downforce provided by the wing, but also ensure that the center of pressure is kept as constant as possible. If the frontwing, undertray and rear wing's downforce don't scale equally with speed, the center of pressure will move during acceleration. This will make the car's handling unpredictable, and potentially limit the driver's confidence in the car.

1.3 Design restrictions

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Theory

2.1 Aerodynamics

2.2 Vehicle Performance

2.2.1 Evaluating Top Speed

First, let's explain what makes a car fast, and what parameters we can change to improve the speed of our car. The car's acceleration can be described by Newton's second law as:

FiXme Note: stort D eller lille d i ligningen?

$$\sum F_x = m\ddot{x} = F \tag{2.1}$$

Where the sum of forces in the x-direction (the direction of travel) can be expressed as the force already pertained by the vehicle, minus the drag force:

$$F - C_D\left(\frac{1}{2}\rho\dot{x}^2 A\right) = m\ddot{x} \tag{2.2}$$

Assuming we're moving at a steady speed, the acceleration is 0, hence

$$F = C_D\left(\frac{1}{2}\rho\dot{x}^2 A\right) \tag{2.3}$$

As we were interested in the speed of the car, let's solve for the velocity. The force is given by $F = \frac{P}{\dot{x}}$, where P is the power of the car, which gives:

$$\dot{x} = \left(\frac{2P}{C_D\left(\rho A\right)}\right)^{\frac{1}{3}} \tag{2.4}$$

This is assuming we're traveling at terminal velocity – that is, the point where the Driving Force = Friction Force. The terminal velocity of the

FiXme Note: Muligvis uddyb her

racer is then easily calculated, as the competition restricts the maximum amount of power:

$$\dot{x}_{\max} = \left(\frac{2 \cdot 80\,\mathrm{kW}}{0.85\left(1.225\,\mathrm{kg\,m^{-3}}\ 1.2\,\mathrm{m^2}\right)} \right)^{\frac{1}{3}} = 50\,\mathrm{m\,s^{-1}} = 181.4\,\mathrm{km\,h^{-1}} \tag{2.5}$$

however, given the ruleset a forecasted maximum of $110\,\mathrm{km\,h^{-1}}$ allows a much larger drag coefficient C_D:

$$C_D = \frac{2P}{\dot{x}^3\left(\rho A\right)} = \frac{2 \cdot 80\,\mathrm{kW}}{(120\,\mathrm{km\,h^{-1}})^3\left(1.225\,\mathrm{kg\,m^{-3}}\ 1.2\,\mathrm{m^2}\right)} = 2.82 \tag{2.6}$$

Thus, the car's top speed will only be limited by a drag factor > 2.82, which is far above the drag introduced by the aerodynamic devices.

From this derivation, it's clear that the car's abilities at maximum speeds far exceed the requirement of the track. Therefore, the next step is to improve cornering speeds which depend strongly on the tyre's grip on the surface of the road [2].

2.2.2 Cornering performance

2.2.3 Load Distribution

2.3 Similarity of Flows

In order to perform tests on the rear wing, it has to be scaled down to fit inside the wind tunnel. This reduces the physical size of the wing, which under equal circumstances changes the flow around it. In order to correctly emulate the simulated flow inside a wind tunnel, the Reynolds number and Euler number have to be the same, assuming incompressible flows:

$$\mathrm{Re_m} = \mathrm{Re} \tag{2.7}$$

$$\mathrm{Eu_m} = \mathrm{Eu} \tag{2.8}$$

Mathematically, the Reynolds- and Euler number are defined as:

$$\mathrm{Eu} = \frac{p_u - p_d}{p v^2} \tag{2.9}$$

where v is the characteristic velocity of the flow, p_u denotes upstream pressure, and p_d denotes downstream pressure, and:

$$\mathrm{Re} = \frac{uL}{\nu} \tag{2.10}$$

where u is the velocity relative to the object, L is the characteristic length and ν is the kinematic viscosity of the fluid.

For a down-scaled model, matching Reynolds- and Euler number requires an increase in velocity, inversely proportional to the increase in length

FiXme Note: skriv det her ud plx.

$$\begin{aligned} \frac{u_\mathrm{m} L_\mathrm{m}}{\nu} &= \frac{uL}{\nu} \\ \Rightarrow u_\mathrm{m} &= \frac{L}{L_\mathrm{m}} u \end{aligned} \tag{2.11}$$

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Experiment

Verifying the simulated aerodynamic effects is crucial to ensuring the correctness of the numerical analysis. In order to assess the reliability of the previouisly conducted simulations, a physical measurement of the pressure along the down-scaled wing.

In figure **??** the down-scaled wing can be seen with pressure-taps along the centerpiece.

3.1 Equipment

3.2 Experimental Procedure

Given the nature of the competition, the average cornering speeds are around $55\,\mathrm{km\,h^{-1}} = 15.28\,\mathrm{m\,s^{-1}}$, which is where downforce is of most importance. As shown in section 2.3, the desired velocity in the wind tunnel for the scale model can be found from equation 2.11

$$u_\mathrm{m} = \frac{0.6\,\mathrm{m}}{0.15\,\mathrm{m}} 15.28\,\mathrm{m\,s^{-1}} = 61.12\,\mathrm{m\,s^{-1}}$$

3.3 Results

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Simulation

The simulation will run in several parts. First, the wings relative placement between eachother will be optimized in a 2-dimensional environment. This involves, size, x- and y-distance between the multi-element wings, angle of attack and height relative to the chassis to give a good estimate of the wings placement range. Secondly, a 3-dimensional analysis of the entire wing with endplates will be performed. Endplate dimensions will be optimized, and further optimization of the height relative to the entire chassis to finalize the design and placement. Lastly, a complete computational solution to the entire car will finalize the aerodynamical package, and yield the total amount of drag and downforce.

4.1 Star-CCM+

4.2 Finite Volume method

Star-CCM+ employs the finite volume method, which will be covered briefly in this report.

4.3 Mesh Generation

The mesh has to be structured in accordance to best practice. Areas with high velocity and pressure gradiants have to be dissolved in acceptable resolutions, in order to ensure correct results. Running an initial test on a generic mesh shows us where the wing requires greater resolution. Gradiants are easily visible around the wing's leading edge, and generally around the solid bodies. Furthermore, aligning the meshg with the flow improves accuracy and rate of convergence. .

FiXme Note: Noget med konvergens undersøgelse. Måske også grid sensitivity test.

4.4 The Wing

4.4.1 Multi-Element Wing Optimization

Wing was moved around to optimize lift. Here's the results changing the variables.

4.5 The Aerodynamics Package

4.5.1 Undertray, Diffuser, Front Wing and Driver

4.5.2 Everything Together Now

4.6 Results

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Construction

In order to verify the computational fluid dynamics used, a 1/4 scale wing was constructed. This miniature wing is constructed for performing windtunnel tests, and comparing results with the simulations. If the two are in accordance, the simulated results of the full scale wing can be used with confidence.

5.1 1/4 Scale Wing

The small scale rear wing is constructed in 6 pieces. The large wing is dissected into three parts. Two regular wings, and a central part with 15 pressure taps.

Material selection is based on the ease of machinability - a CNC-miller was provided to us, along with ample amounts of aluminium. This scale wing is not to be used in the actual race car, so weight is not a concern.

5.2 Requirements

FiXme Note: Hvad kræves af styrke fra konkurrencens side? Hvad ønsker holdet?

5.3 Prototyping

5.4 Material Selection

FiXme Note: Overvej CES (for flair jo)

5.5 Molds

The molds for the wings were chosen as positive molds, meaning polystyrene molds of the actual wings were cut out and overlaid with resin coated carbon fiber. In order to do this, we devised a hotwire-based specialized tool for the job. This can be seen in figure **??**, and the name of the job is to do it slowly in order to receive a clean surface.

5.6 Assembly

5.7 Finish

6

Discussion

7

Conclusion

bla

Perspective

Bibliography

[1] Bulbapedia. http://bulbapedia.bulbagarden.net/wiki/Team_Rocket, may 2016.

[2] Joseph Katz. *Race Car Aerodynamics*. BentleyPublishers, 2nd edition, 2003.

[3] George P. Sutton and Oscar Biblarz. *Rocket Propulsion Elements*. Wiley, 8th edition, 2010.

[4] John D. Clark. *Ignition!: An informal history of liquid rocket propellants*. Rutgers University Press, 1st edition, 1972.

[5] Seppo A. Korpela. *Principles of Turbomachinery*. Wiley, 1st edition, 2012.

[6] James G. Quintiere. *Principles of Fire Behaviour*. Delmar, 1st edition, 1997.

[7] Julio de Paula Peter Atkins. *Atkin's Physical Chemistry*. Oxford University Press, 10th edition, 2014.

[8] Nancy Hall. Compressible Area Ratio. https://www.grc.nasa.gov/www/k-12/airplane/astar.html, May, 2015.

[9] Nancy Hall. Isentropic Flow. https://www.grc.nasa.gov/www/k-12/airplane/isentrop.html, May, 2015.

[10] SierraPine. *MDF Material safety data sheet*, January 2005.

[11] Thermocouples: Using Thermocouples to Measure Temperature. http://www.omega.com/prodinfo/thermocouples.html, 2016.

[12] Richard Nakka. Propellant Grain. http://www.nakka-rocketry.net/th_grain.html, july 2001.

[13] Richard Nakka. Nozzle Theory. http://www.nakka-rocketry.net/th_nozz.html, April 2014.

[14] Robert A. Braeunig. Nozzle. http://www.braeunig.us/space/propuls.htm, 2012.

[15] E659-78. Standard test method for autoignition temperature of chemicals. *ASTM*, 14(5), 2000.

[16] Anders Hjort-Degenkolv Kristensen Alex Nørgaard, Martin Gosvig Jensen. Undersøgelse af regressionsrater i en hybrid raketmotor, 2015.

[17] HorsePunchKid. De laval nozzle. https://en.wikipedia.org/wiki/Rocket_engine_nozzle#/media/File:De_laval_nozzle.svg.

[18] Philip-J. Pritchard Robert W. Fox, Alan T. McDonald. *Introduction to Fluid Mechanics*. Wiley, 6th edition.

[19] Frank M. White. *Fluid Mechanics*. McGraw-Hill Higher Education, 4th edition.

[20] Steven S. Zumdahl. *Chemistry*. Houghton Mifflin, 7th edition.

[21] Enthalpy. http://fchart.com/ees/eeshelp/eeshelp.htm.

[22] Merle C. Potter. *Mechanics of Fluids*. Cengage Learning, 4th edition.

[23] Industrial Measurements Systems Inc IMS. http://imsysinc.com/Knowledgebase/ultratherm.htm.

[24] The Engineering ToolBox. Wood-combustion heat.