Wind tunnel project instructions

MTF236 - Road Vehicle Aerodynamics

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1. General information about the project

In this project students will study one specific area within Road Vehicle Aerodynamics. The students will work in groups of around five and the available areas are:

1. Aerodynamics of racing cars
2. Aerodynamics of passenger vehicles
3. Aerodynamics of commercial vehicles (trucks and buses)

The project includes several important parts:

1. The students should familiarize themselves with the models and tasks that they can work with and choose a group accordingly (keep the time slots in mind!);
2. A post-processing seminar will be given when students analyses the CFD solution data for the chosen vehicle and come up with the suggested designs to test in the wind tunnel;
3. The first two steps should be summarizes in a short pre-study report that is going to be discussed with the course assistants during the separate study session;
4. After the pre-study report is approved, the group should build the add-ons for the models (separate 2 hour session);
5. Next comes the main part of the project: the wind tunnel session itself;
6. After the lab the group should present the results in a form of 20 pages technical report;
7. Finally, an oral presentation is made when each group is also asked to raise question for one other group.

For further information about each part of the project, see specific topics in this project instructions.

2. Intended learning outcomes

After this project work you should be able to:

- Describe aerodynamic phenomena that occur around various vehicles;
- Explain operating principles of the wind tunnel and various equipment used in the lab;
- Describe and evaluate the changes that can be made to the vehicle to affect the downforce or aerodynamic resistance;

3. Pre-study

A pre-study is the first thing you do for the project. During the pre-study you are expected to sign up for the group and come up with the add-ons you are going to build in order to achieve the goals given for your group. To help you with it, a separate CFD post-processing session is going to be organized when you will work with the pre-computed air flow around your model. The pre-study ends with a short report and building of the add-ons that are going to be tested in the wind tunnel.

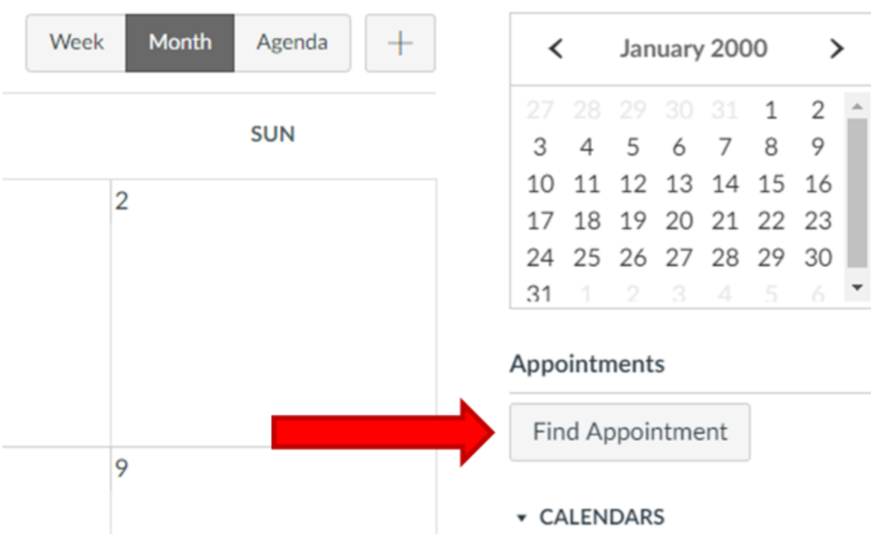
a. Group selection and signing up

All students in the course are going to be divided into 7-9 groups with up to 5 students in every group depending on the amount of student taking the course. The vehicle that you are going to work with and specific goals to achieve with add-ons depend on your group number:

- groups 1 and 2: Bus;
- groups 3 and 4: Truck;
- groups 5 and 6: Passenger vehicle (SAAB 9-5 Estate);
- groups 7 and 8: Racing car (Koenigsegg LMP 900).

For the common and group specific tasks, please see the section 4.c. When selecting the group, please also take into account that different groups have different wind tunnel time slots available for them to choose from.

Use Canvas course page to sign up for the group you want and then, together with the rest of the group, decide on the time slot, when the entire group can come to the wind tunnel. Signing up for the Wind Tunnel Lab time slot is also done via the Canvas page (use the Find Appointment button to see the available slots).



Note! Both group slots and wind tunnel slots are assigned on first come - first served basis, so do not wait too long.

b. Post-processing workshop

Before the pre-study presentation each group will work with post-processing of a given CFD solution of the chosen vehicle. This is performed by using the Siemens Star-CCM+ software. The students will investigate e.g. the pressure and velocity magnitude around the vehicle to be able to find problem areas. This information should thereafter be used to decide what geometrical changes will be added to the vehicle for the wind tunnel lab session.

A separate document with the specific instructions for the software usage and data post-processing is going to be provided.

c. Pre-study report (presentation)

As a result of the pre-study each group will produce a short report describing relevant materials and methods that you intend to use in the aerodynamic optimization of your vehicle. The results from the CFD post-processing should be included in the pre-study and must be used as a central source of data, based on which you will make an evaluation of the current aerodynamic state of the vehicle and suggest improvements concerning your specific group task. You should also add expected results due to the modifications and a clarification of why you think you will obtain these results. Together with this, there should be a test plan of how, what and in what order the group will measure during the lab session to evaluate the design of the vehicle from an aerodynamic point of view.

You do not have to make a PowerPoint presentation, the 3-5 page Word document is enough. You will discuss your finding and ideas with course assistants during a separate study session during study week 3. The pre-study is mandatory in order to get access to the wind tunnel laboratory.

d. Building session

After the pre-study report is approved, you are supposed to build the add-on parts for your models. A separate 2 hour session is organized for it in the course laboratory (M-kurslab). You will be provided with materials and tools e.g. paper, cardboard, duct tape, knives and scissors, but you are definitely encouraged to bring your own materials, if you want to try building something more sophisticated.

4. Wind tunnel laboratory

The wind tunnel lab session is mandatory to attend. Each group will have supervised access to the laboratory for 3 hours. When the students arrive the reference vehicle model will be prepared for measurements and flow visualization. Tools available are an external balance for force measurements, smoke and tufts for visualization. With these tools the groups are expected to draw their own conclusions regarding the design of the vehicle due to the flow behavior. It is recommended to bring a camera to take photos or record movies that can be used afterwards for evaluating the flow behavior and it could be used during the final presentation. It is also recommended to make approximately 4 configurations to the vehicle for the additional task.

Note! The most important part of this project is to be able to explain the changes in forces and flow behavior for different configurations, so try to think in advance what you are going to test and how to visualize the flow in the area you are applying the changes to.

a. Safety

Safety should always come first. There are a lot of things in the lab that have a possibility to hurt you or your groupmates, so be attentive and think before you do anything. If you are not sure about anything, ask the technicians or supervisors who are present at the time in the lab.

The most important things to remember:

- Lock the clamps fixing the wind tunnel panels until it clicks, you do not want them to fall and break or heart someone;
- Do not touch the shaft of the smoke machine, even if it is not being used in the moment: the shaft can become seriously hot, since it is needed for creating a smoke from the liquid;
- Do not exceed the maximum allowed wind speed limit given for your model: currently 30-35 m/s. The model behavior can become unstable at higher velocities;
- If working inside the test section of the wind tunnel, make sure you step on the parts of the floor that has structural support under it;
- The wind tunnel hall contains a lot of expensive equipment, which we are not going to use. You do not want to be the person damaging any of it.

b. Common task

Your task is to measure the forces and calculate aerodynamic drag and lift coefficients C_D and C_L, as well as separating lift coefficients for front and rear axles (C_{LF} and C_{LR}) in case of passenger and racing vehicles. You should do it for at least 10 different velocities in a so-called Reynolds sweep to investigate the dependency of these coefficients on the vehicle velocity.

When the force measurements are finished the students should evaluate the aerodynamic design of the vehicle by using different visualization techniques.

c. Group specific tasks

Groups 1-2: Your task is to optimize the general shape of the vehicle for low drag and investigate how these optimization affect force coefficients at yaw angles (±10 degrees);

Groups 3-4: Your task is to evaluate tractor(and/or trailer) mounted drag reducing devices and investigate how these optimization affect force coefficients at yaw angles (±10 degrees);

Groups 5-6: Your task is to optimize the general shape of the vehicle for low drag;

Groups 7-8: Your task is to evaluate the different downforce generating devices.

d. Relevant model data

Vehicle model	Scale	Frontal area*	Reference length**
Racing car (Koenigsegg LMP 900)	1/5	0.0576 m^2	0.510 m
Passenger vehicle (SAAB 9-5 Estate)	1/5	0.0848 m^2	0.550 m
Truck	1/18	0.0310 m^2	0.789 m
Bus	1/18	0.0262 m2	0.465 m

*Note that the dimensions of the actual models can be slightly different compared to the CAD representation used in the numerical pre-study.

**For the reference length it is common to use a wheelbase if the vehicle that has two axles. For the vehicles with more axles the total length for the vehicle is usually taken.

5. Report

After the lab session the students should present their results and conclusions together with theory and references to support the results in a written **technical report that does not exceed 20 pages**. The recommended report layout should include: front page (including Title, course, group number, group members), table of contents, introduction, theoretical background, methodology, results and discussions, conclusions, references.

In the report, the students are encouraged to revise their pre-study work and comment on their hypotheses, theories and methodology discussed earlier. Compare your results and theories with those found in other references and discuss differences and similarities. It is of GREAT IMPORTANCE that you explain the phenomena and the measured values by using theory and knowledge obtained during the project. Hence, all results MUST be explained, which means that you have to explain WHY you obtain the results you get, from an aerodynamic point of view. You only have to briefly cover the theory part about the wind tunnel and the scale. Also, you should describe why the Reynolds sweep graph looks like it does.

Once the report is handed in you will NOT get any additional chance to add parts or change it. Hence, the grading of the report will be based on what you hand in! Therefore, you have to make sure that every part is correct and expressed in a way that is understandable! Handwritten reports will not be accepted. Submit your report no later than the end of a last study week (week when you have final presentations).

Note! In accordance with Chalmers policy against plagiarism all of the reports are going to be send to URKUND system for checking. Please, make sure to handle quotation and references properly if you cite other people's work. More information is available at https://student.portal.chalmers.se/en/chalmersstudies/policy-documents/Documents/20090920_Academic_Honesty.pdf

6. Presentation

The project work should also be presented orally to the other groups during study week 8, see the course schedule. Each group is given 20 minutes to present their results and conclusions and 10 minutes for questions and opposition. A recommendation is that two persons make the presentation. The focus of the presentation should be on the results, including what phenomena you observed in the wind tunnel and why they occurred, connect the results from the post processing and the wind tunnel.

The presentation should be brought on a USB flash drive on the presentation day. Additionally, the presentation slides should be submitted through the course homepage.

In addition to presenting your results every group is going to be assigned with another group to oppose and ask questions. This opposition is only done for the oral presentation and not the final written report.

7. Assessment and grading

A student group can obtain up to 20 points for the project work. The distribution of point is done in the following way:

Pre-Study, Lab. session & Report	-	10 points
Project presentation and defense	-	7 points
Opposition	-	3 points

The main criteria for assessment of the reports are format/layout, structure, interplay between figures and text, and most importantly the discussions and conclusions that the group makes from the experimental results.

For the presentation, the same criteria are being used with additional assessment of the presentation style used and the way information is delivered. Answering the questions is also considered to be part of the presentation and will affect the point obtained for it.

Lastly, the group opposing (asking questions) is also getting points for scrutinizing the results and conclusions of the group presenting.

8. Recommended literature

Basic aerodynamics: Barnard Chapter 1-3;

Wind tunnel theory: Barnard Chapter 11;

Passenger car aerodynamics: Barnard Chapter 4;

Race car aerodynamics: Barnard Chapter 6, Mulsanne's Corner (www.mulsannescorner.com);

Commercial vehicle aerodynamics: Barnard Chapter 5;

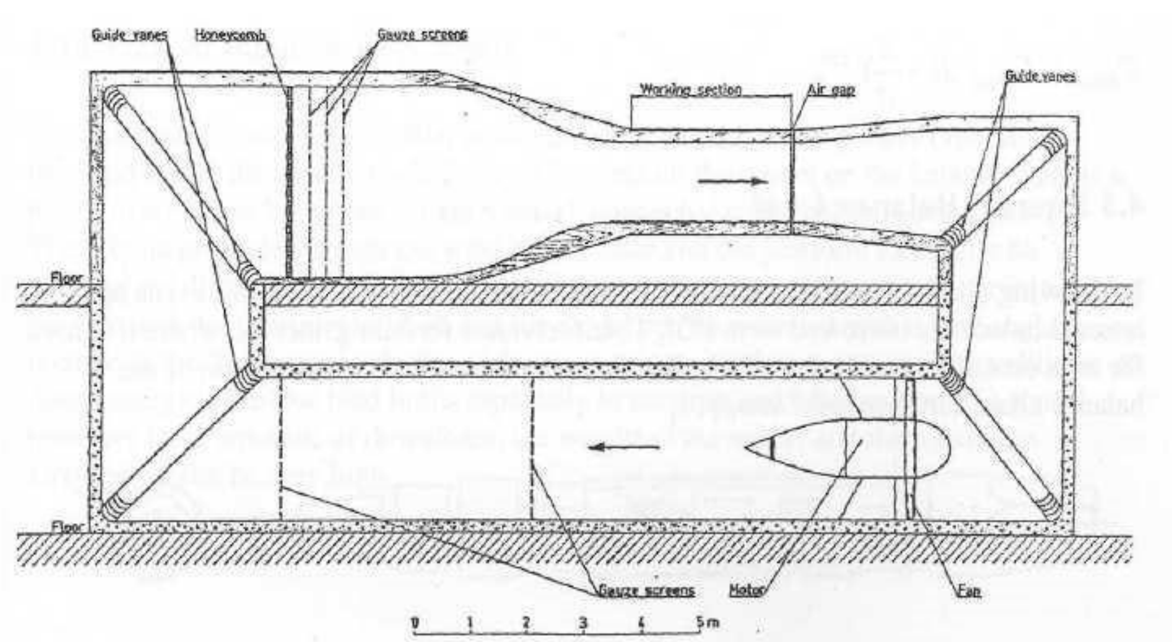
Cooling air flows: Barnard Chapter 7;

Other relevant sources: SAE-papers available via Chalmers library.

9. Appendices

a. Wind tunnel L2 description and blockage correction

Chalmers wind tunnel L2 is a closed circuit, low speed tunnel with a maximum free stream velocity of 63 m/s and a free stream turbulence intensity of 0.1%. The test section is 1.25x1.8x3.0 m and it has a contraction ratio of 6. A schematic description is given in the figure below.



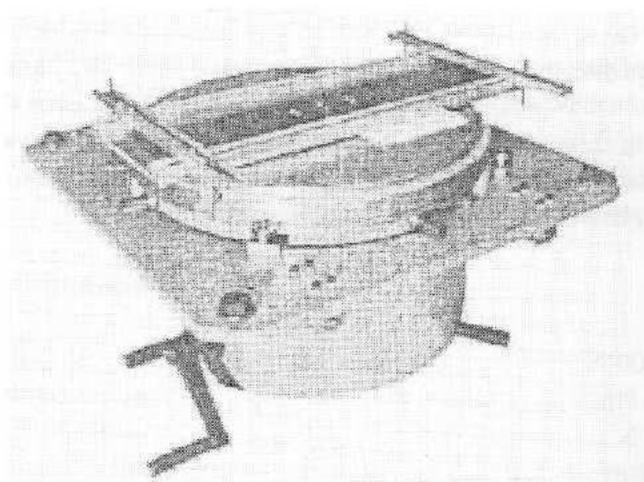
The fan has six fixed blades made of wood and is driven by an electrical motor mounted in the wind tunnel and its cooling air is vented out of the tunnel via the motor. There is another small motor that compensates for lost flow through the slot and due to cooling. Right after the main fan, there is a climatic unit that is used to maintain a constant air temperature in the tunnel. A Prandtl tube, connected to a manometer is used to measure the free stream velocity. The manometer also measures ambient pressure and temperature.

Due to blockage, the flow pattern and velocity distribution are altered when a model is placed in the tunnel. Blockage is the ratio of the model frontal (A) area to the cross sectional area of the test section (S). In order to get appropriate results, it is needed to compensate for the blockage according to the equation below. Remember, that this correction needs to be applied to all measured coefficients/forces.

$$C_{D\_true} = C_{D\_ind}\left(1 - \frac{A}{S}\right)^{1.288} \tag{1}$$

b. External Balance (FFA Y-603)

The external balance is of six component strain gauges type and it is mounted below the test section. To be able to fix the model on the balance there is a platform with four mounting points, one for each wheel, connected to the balance. See the following figure.



Knowing the distance between the struts (same as wheelbase), the pitching moment and the total lift force, the distribution of lift forces between front and rear wheels can be calculated.

An advantage with the external balance is that it can be rotated so that the model can be mounted with a yaw angle relative to the free stream, simulating cross-wind conditions. A disadvantage is the low load limits especially in the lift direction.

Some specifications for the balance FFA Y-603:

Max force	300 N
Max moment	60 Nm