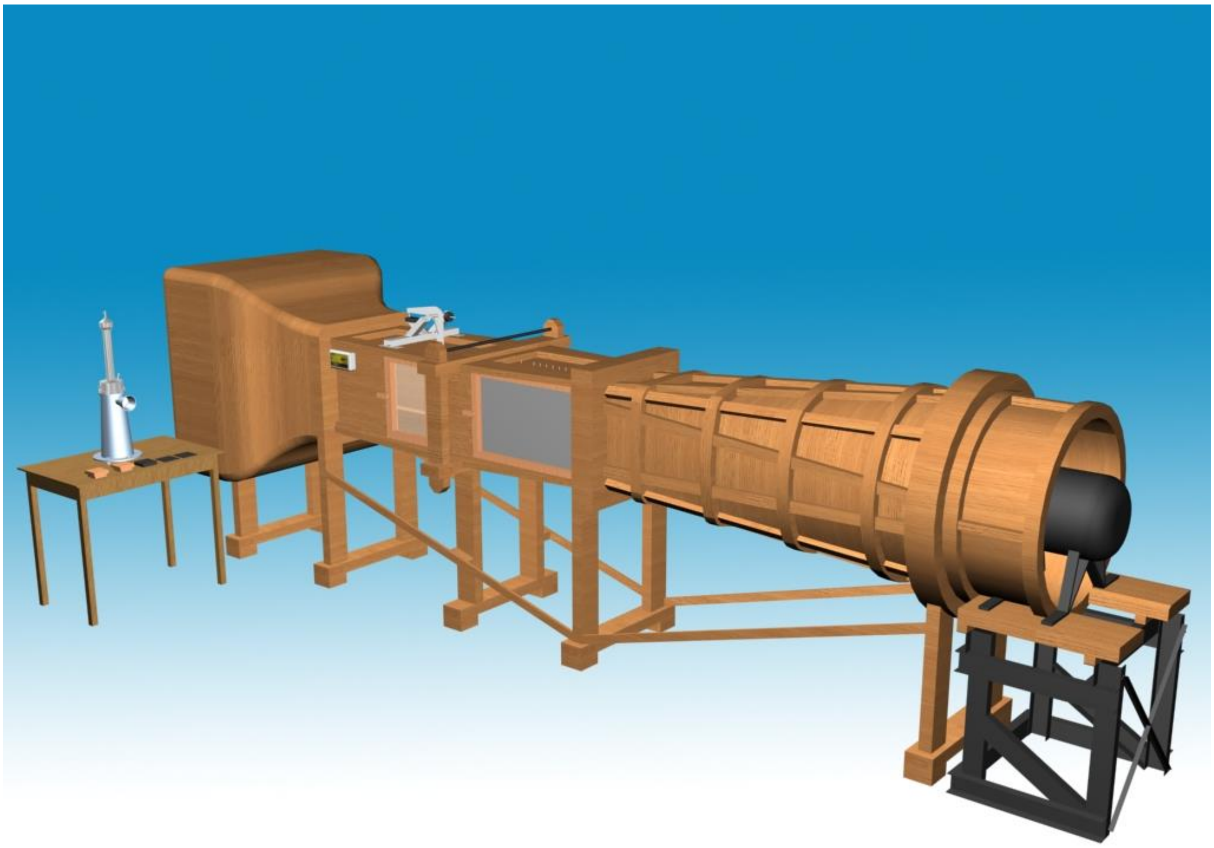


H4

INVESTIGATION OF FORMULA-1 RACING CAR ELEMENTS AND CYLINDER IN NPL WIND TUNNEL

1. Aim of the measurement

The forces acting on a body placed in a flow, as well as the definition of the drag coefficient can be found in many textbooks. The frictional force of aerodynamic drag increases significantly with vehicle speed. Also, the characteristic shape of a road vehicle is much less streamlined compared to an aircraft. Drag coefficient is a commonly published rating of a car's aerodynamic smoothness, related to the shape of the car.

2. Description of the measurement equipment

The smallest wind tunnel of our department is NPL (*National Physical Laboratory*)-type, the cross section of its test section is 0.5x0.5 m. It is completely made of wood and is mainly used for calibration of anemometers and for educational goals, but it is also suitable for scientific measurements. The maximum velocity of the wind tunnel is 15 m/s. [*Varga, 2013*]. Further information about the drag and lift force can be found in the Lajos Tamás: Az áramlástan alapjai course book's Chapter 11. [*Lajos, 2009*].

The pressure difference will be measured with digital handheld manometer. After the measurement section of the wind tunnel, there is a diffuser, which is followed by the fan which sucks the air through the wind tunnel. The fan is spun using a dc motor, the speed of which can be set to any value between 0-1500 1/min using a potentiometer. In this way, the velocity in the wind tunnel can be set between 0-15 m/s. The body, which is to be examined, is to be attached to the arm, which extends into the measurement section from the top of the wind tunnel. Here the forces acting on the arm in the tunnel are measured using a load cell.

There are three different tasks, which can be examined in a NPL type wind tunnel. Task A and B are typical vehicle aerodynamics problems and relate to the Formula-1 racing cars. Task C investigates the shear stress arising when placing different bodies in the wind tunnel.

3. Principles of the measurement, evaluating the results

Task „A"

Determine the drag and lift force which occur at the front wheels and reduce the forces with modifying the shear layer. The change of the drag and lift coefficient is to be investigated with respect to the changed bodies in the flow.

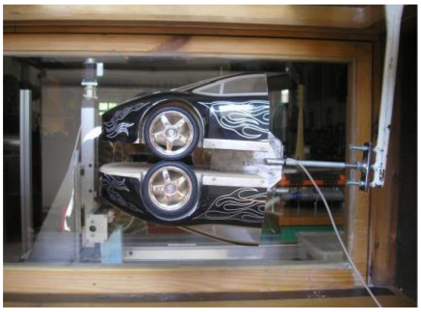
Task „B"

In this task a simplified, mirrored car face-wall model is to be placed in the wind tunnel. The change of the drag coefficient is to be investigated with respect to the changed car-body elements.

Task „C"

In this task cylinder is to be placed in the wind tunnel parallel to the flow. The shear layer is to be investigated with the respect to change the front area of the body.

Task „A"
[Gali et al, 2010]



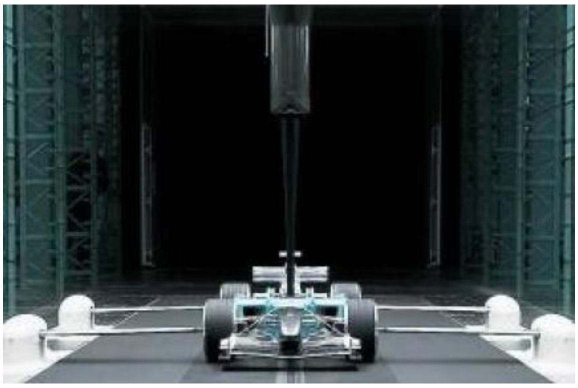
Task „B"
[Major et al., 2010]

Task „C"

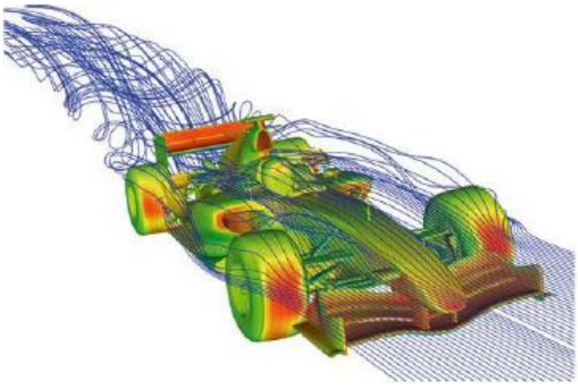
Vehicle aerodynamics is studied using both computer modeling and wind tunnel testing. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows. With CFD modeling, there is no need to actually create the components; the flow around the car can be investigated with simulation. [*Papp, 2012*]. The numerical simulation (CFD [*Kristóf, 2014*]) has a high appreciation, since it's a compromise solution to find the best aerodynamic shape to the highest downforce and lowest drag force. However it's important not to accept the results implicitly. Another relevant issue is the number of the numerical cells within the computational domain. It's recommended to use high-speed computers that work together (cluster, *Nagy et al, 2014*). The Department of Fluid Mechanics has used a 100 core system since 2005.

For the most accurate results from a wind tunnel test, the tunnel is sometimes equipped with a rolling road made of steel or nowadays composite material. This is a movable floor for the working section, which moves at the same speed as the air flow [Balczó et al., 2014]. The Department also investigates the effects of the movable floor and tests one in the NPL wind tunnel [Lajos et al., 2002]. Flow visualization in fluid dynamics is used to make the flow patterns around bodies visible, in order to get qualitative or quantitative information on them [Hári, 2013]. The flow visualization is equally important in computational as in experimental fluid dynamics. For appropriate documentation the following methods are available:

- The human eye; we can see in three dimensions but the information don't last forever.
- Camera/video camera which gives 2D pictures (Mahmood, 2011). 3D visualization can be possible with holography.
- Possible ways of flow visualization:
  - surface: with colored oil or staple
  - around the body: fume, optical methods.



Formula-1 wind tunnel measurement



BMW Sauber F1, CFD test

Lots of articles, thesis, and final project attend with vehicle aerodynamics at the Department of Fluid Dynamics. Our Department's homepage presents some of them.

[Publikáció_tanszék][Régert et al.,2007][Ivady, 2013][Kurdi és Ivády 2012].

4. Useful references

Useful references on vehicle aerodynamics, CFD, wind tunnel testing: [Lajos, 2009]

- **M.11.2.4.** Vehicle aerodynamics PP presentation found in the áramlástan alapjai course book 3. Edition's CD, resp. DVD enclosure.
- **M.11.3.1** presentation found in the 4. Edition course book's DVD enclosure.
- **11.3.1**. Basics of vehicle aerodynamics.
- **11.3.2.** Characteristics of flow past vehicle bodies and reduction of fore body drag,
- **11.3.3.** Reduction of base, side wall, roof and underbody drag,
- **11.3.4.** Aerodynamic drag of buses and trucks.

Useful references on flow around different bodies (cylinders):

- **11.1.2**. Force acting on cylinder,
- **11.1.3.** Force acting on non-circle cross-sectioned cylinders, plates, spheres.

Useful references from the course book's 4. Edition:

- **6.4.1.** Using wind tunnels,

- **6.4.2.** Different types of wind tunnels
- **6.4.3.** Elements of wind tunnels, measurement sections,
- **6.4.4.** Wind tunnel measurements,
- and *[Mehta, 1979].*

Public databases:

- Journals', universities' web pages,
- Scopus database http://www.scopus.com/,
- Web of Science http://apps.webofknowledge.com
- BME Publication database http://mycite.omikk.bme.hu/www/
- MATARKA - http://www.matarka.hu/

5. Measurement procedure

5.1. Task „A": Determine the drag and lift force which occur at the front wheels and reduce the forces with modifying the shear layer. The change of the drag and lift coefficient is to be investigated with respect to the changed bodies in the flow.

The Formula-1 racing cars' drag coefficient is somewhat large, especially on the front wheel. If a plate is placed near the ground in front of the wheel, the air will separate and results in pockets of low and high pressure. The gauge-pressure at the front wheel will be decreased and so the drag forces (*shear layer conditioning*).

Task „A", empty case *(Gali et al., 2010)*

Task „A", with spoiler *(Gali et al., 2010)*

The change of the drag and lift coefficient on two, symmetrical wheels is to be investigated with modifying the shear layer respect to the changed bodies in the flow. The symmetrical formation ensures the moving floor effect. Determine the pressure distribution around the circumference of the wheel with the help of the pressure hole.

Assignments: investigate the flow field around the body, calculate the drag coefficient and decrease the drag coefficient with shear layer conditioning.

Tasks:

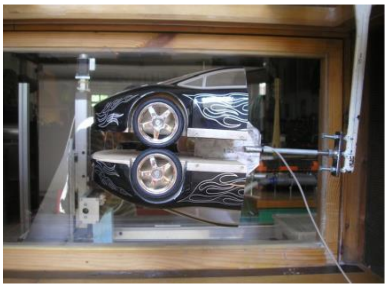
- first step is to check the calibration of the load cell (with different loads in 2-3 points),
- The forces acting on the arm are need to be measured
- flow visualization with cotton tapes and colored oil,
- The drag coefficient is needed to be measured at 3 different velocities; the pressure distribution around the wheel is needed to be measured at 1 velocity.
- The drag force acting on the wheel is needed to be measured at two different plate sizes and two different distances.
- The pressure distribution around the wheel is needed to be measured at one formation and the drag and lift force are need to be calculated.

In the lab you can found:

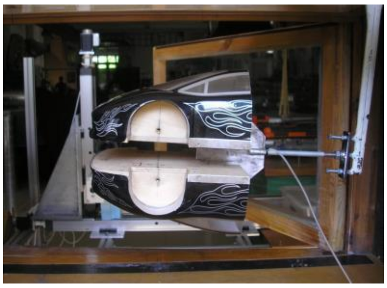
- the arm which is supporting the body can be found at the measure section, parallel to the flow
- two F1 wheels, one with static pressure taps
- fixable, changeable plates
- oil mist generator, pipe
- cotton tape
- digital handheld manometer
- Please bring camera to the measurement.

5.2. Task „B": In this task a simplified, mirrored car face-wall model is to be placed in the wind tunnel. The change of the drag coefficient is to be investigated with respect to the changed car-body elements.

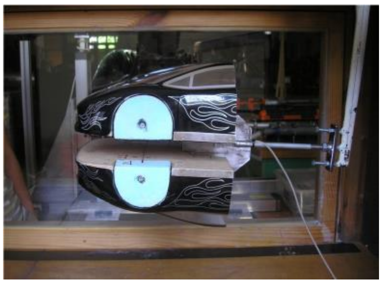
Drag force does not act on bodies placed into ideal flow. The boundary layer on the fore body of the cars is thin, so in this case the flow is similar to the frictionless flow. The drag of the fore body is near to zero, the total pressure away from the wall is constant.



With wheels
[Major et al., 2010]



With empty wheelhouse
[Major et al., 2010]



Without wheels, enclosed wheelhouse
[Major et al., 2010]

Assignment A: Verify the assumptions and investigate the fluid flow around the face-wall model. The symmetrical formation ensures the moving floor effect (the models are being cut by the B-pillar). One of the models has pressure taps on the symmetry line and inside, so the fore-body pressure distribution and the pressure inside the separation bubble. The total pressure can be measured with Pitot-tube and the drag force with the load cell. The fore body drag (with wheels and with empty wheelhouse) can be estimated if the product of the pressure inside the separation bubble and the area of the model are available (with the subtraction of the measured drag force on the load cell).

Assignment B: Measure the pressure difference (Δp_{seb}) between the wind tunnel and the atmospheric pressure. The pressure tap can be found behind the wind tunnel's confuser and measured with digital handheld manometer. With the measured pressure the flow velocity in the wind tunnel can be calculated.

Tasks:

- first step is to check the calibration of the load cell (with different loads in 2-3 points),
- The forces acting on the arm are need to be measured
- flow visualization with cotton tapes and colored oil,
- The drag force and the static pressure are needed to be measured at 3 different velocities with wheels, without wheels and with filled wheelhouse,

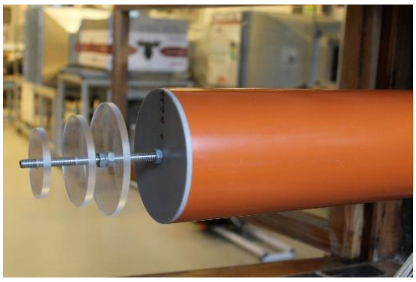
- The drag force and the static pressure are needed to be measured with different elements in front of the model (e.g. spoilers), assignment B is needed to be done.

In the lab you can found:

- the arm which is supporting the body can be found at the measure section, parallel to the flow
- two mirrored, face-wall car model
- oil mist generator, pipe
- digital handheld manometer

5.3. Task „C": In this task cylinder is to be placed in the wind tunnel parallel to the flow. The shear layer is to be investigated with the respect to change the front area of the body.

The drag coefficient of the cylinder placed parallel to the flow can be reduced by shear layer conditioning.



Different cylinders

Rear end pressure

Measurement configuration

Assignments: Investigate the shear layer conditioning, and reduce the drag coefficient of a cylinder placed parallel to the flow with circle plates which have different sizes. The circles' distance can be modified.

Tasks:

- first step is to check the calibration of the load cell (with different loads in 2-3 points),
- The forces acting on the arm are need to be measured
- flow visualization with cotton tapes and colored oil,
- Drag force is needed be be measured without shear layer conditioning and with 2 different circle plates at 3-3 different distances from the front wall.
- At the lowest drag force the flow is need to be visualized with colored oil and the pressure distribution is need to be measured.

In the lab you can found:

- the arm which is supporting the body can be found at the measure section, parallel to the flow
- Cylinder with different circle plates and static pressure taps on the front end.
- oil mist generator, pipe
- digital handheld manometer

6. Evaluation of the results and error calculation

The absolute and relative errors need to be calculated for the drag coefficients. This can be done using the following equations and values:

The measured quantities and the measurement errors:

- F the measured force, and the error: dF= 0,02 [N]
- p_o the measured ambient pressure and the error: dp_o=100 [Pa]
- T_o the measured temperature and the error: dT_o=1 [K]
- p_k the measured pressure and the error: dp_k= 2 [Pa].

For further details see: Áramlástan BMEGEATAG11.

Remember that during the labs:

- ❖ Before turning any measurement device on, or in general during the lab, make sure that safe working conditions are ensured. The other participants have to be warned of the starting of the machines and of any changes that could endanger the members of the lab.
- ❖ The atmospheric pressure and room temperature should be recorded before and after every measurement.
- ❖ The measurement units and other important factors (e.g. data sampling frequency, data of calibration) of every recorded value of the applied measurement devices should be recorded.
- ❖ Type and construction number of the applied measuring instrument should be included in the final report.
- ❖ Checking and harmonizing of the units of the recorded values with those used in further calculations.
- ❖ The digital manometer must be calibrated.
- ❖ The measurement ports of the pressure meter should be carefully connected to the correct pressure ports of the instrument.
- ❖ If inlet or outlet tubes are to be assembled with fans, connections should be airtight as escaping/entering air can significantly modify the measurement results
- ❖ The students should consult with their instructor before submitting the report.

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