H01

STUDY OF A TRUCK AND BUS MODEL IN WIND TUNNEL

1. Aim of measurement

Determination of drag coefficient c_D for different configurations of a modular vehicle model in wind tunnel.

3. Theoretical background

Ground vehicles act as so called bluff bodies in the flow, which means that the flow is separated at certain areas of the vehicle's surface. This is the opposite way streamlined bodies, like airfoils, behave in a flow: the flow remains on them attached to the body surface. Flow separations (separation bubbles) on bluff bodies are the source of their higher drag coefficient. However, there are many possibilities to reduce this higher aerodynamic drag with optimizing the details of a vehicle (e.g., changing fillet radii of the front surfaces). In this measurement you will be able to check the effectiveness of some of those optimizations.

During the measurement, one has to determine the drag coefficient c_D at various wind speeds. Wind speed is measured using a Pitot-static tube, the drag force is measured using a one-component aerodynamic balance.

$$c_D = \frac{F_D}{\frac{\rho}{2} \cdot v^2 \cdot A} = \frac{F_D}{p_{din} \cdot A}$$

and

$$v = \sqrt{\frac{2 \cdot p_{din}}{\rho}} \; ; \; \rho = \frac{p_{st}}{R \cdot T}$$

with:

F_D: drag force

ρ: density of air

p_{st}: static pressure inside the wind tunnel (which is lower than the static pressure outside!)

p_{din}: dynamic pressure measured using Pitot-static tube

A: frontal area (cross-section perpendicular to the flow direction) of the model

2. Measurement facility

The wind tunnel

The measurement can be performed in the ÉMI (a.k.a. boundary layer-) wind tunnel.
The test section is accessible through an openable window. As during the measurement (when the wind tunnel is running) the static pressure is lower in the wind tunnel than the atmospheric pressure, the window must be closed. Static pressure inside the tunnel can be measured using the static hole of the Pitot-static tube. Use a podium or platform to reach the test section safely.

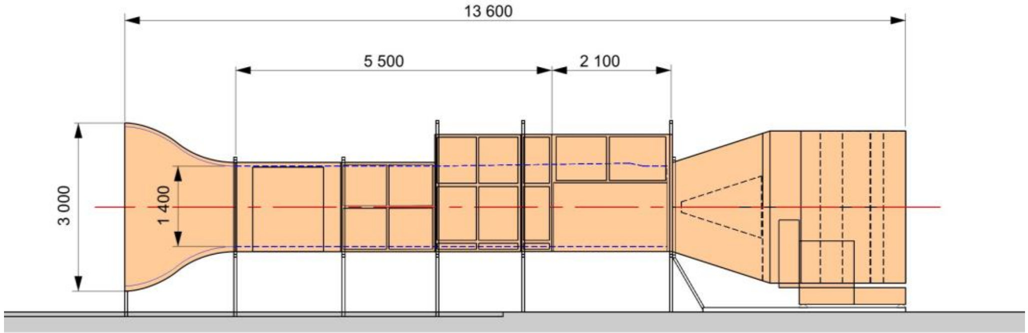


Fig. 1. The ÉMI wind tunnel

Table 1. ÉMI wind tunnel parameters

Type	boundary-layer
test section	closed
Length of test section [m]	2.1
Width of test section [m]	2.2
Height of test section [m]	1.6
Maximum velocity[m/s]	19
Maximum turbulence intensity[%]	0.5

Fig. 2. The wind tunnel controller with a 10-turn potentiometer.

Wind tunnel speed can be controlled using a 10-turn potentiometer (Fig. 2) between 0-100%. The switch on the left turns the control on or off. The actual potentiometer setting can be fixed ('rögzit') or released ('old') using the tiny arm on the lower right side of the potentiometer.
In case the wind tunnel must be stopped rapidly, use the left switch to set speed immediately to 0%.

One-component force measurement platform
The platform is a aluminium mounting plate, stiffened by a steel frame, which hangs on steel springs. The steel springs are needed to allow a small movement of the platform without internal friction. (A hanging on roller or gliding bearings would cause friction, and in consequence, hysteresis during the force measurement)
The platform is supported from the side by the force measurement device, an EMALOG CZL 608 load cell (with 30 N load capacity). The load cell will measure the total force acting on the platform's load side in horizontal streamwise direction.

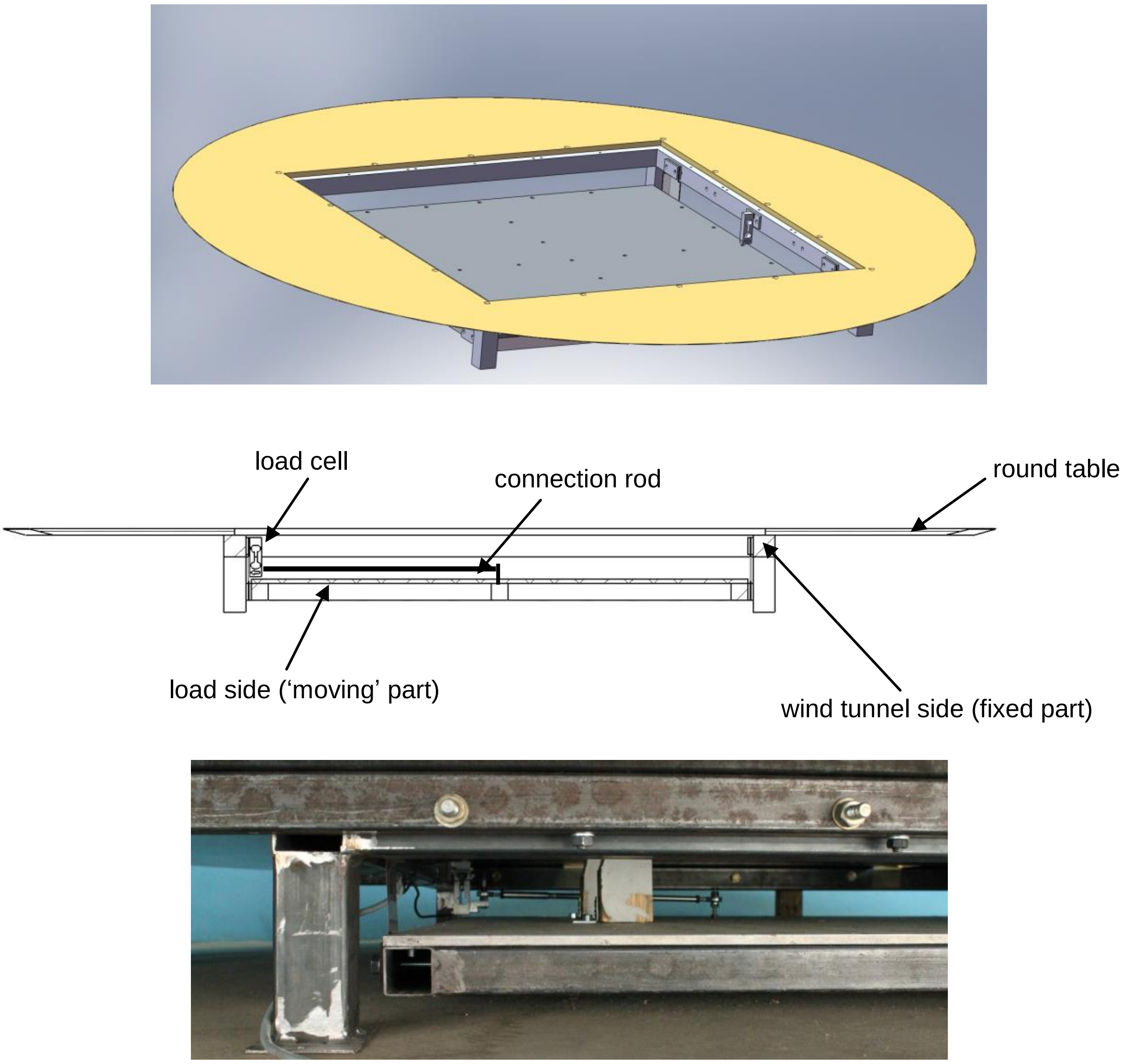


Fig. 3. The force measurement platform

Due to the length of the wind tunnel, thick boundary layers develop on the bottom, top and side internal surfaces. To place the vehicle model outside the wind tunnel, the platform is raised by 150mm from the bottom surface of the test section.

The hole plate is covered by 3 brown wooden plates, which provide a smooth, flat surface for the flow. The central plate has 4 openings. The vehicle model itself is placed on 4 wooden columns on the aluminium hole plate. The wooden columns cannot reach the edge of the openings in the central brown wooden cover plate, there must be a gap of few mms between them.

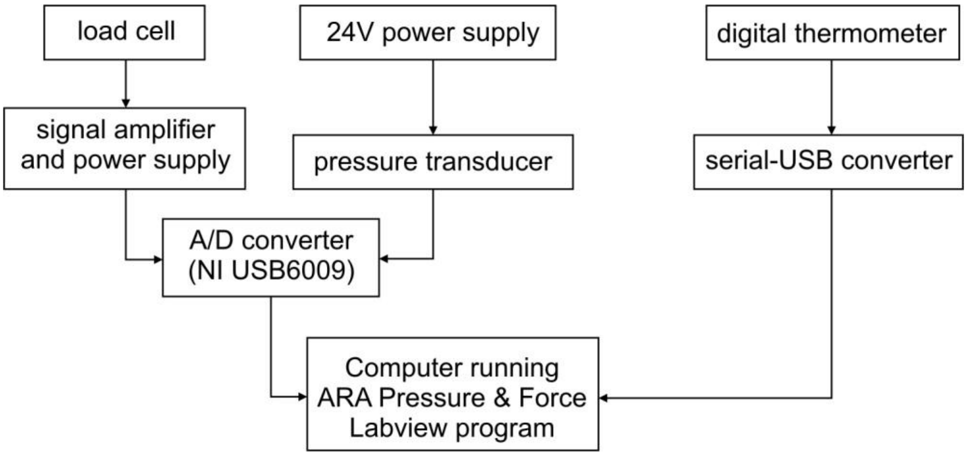
When placing the model on the wooden columns, on should be careful

- to maintain a gap between the brown cover plate and the wheels of the model
- not to overload the load cell (only gentle push or pull in any direction)

When replacing modules on the vehicle model, first lift the model off the columns, place it on the side of the platform, replace parts/modules and then put the model back onto the columns!

The data acquisition system

The analogue electric signals of the load cell and of the pressure transducer are conncted through an A/D converter to the computer (**Fig. 4**). The measurement program ARA Pressure & Force is described in detail in [2]. During the measurement session the program will be set up and running, you only need to know how to use the calibration module (Linear transducer calibration) because the load cell must be calibrated.



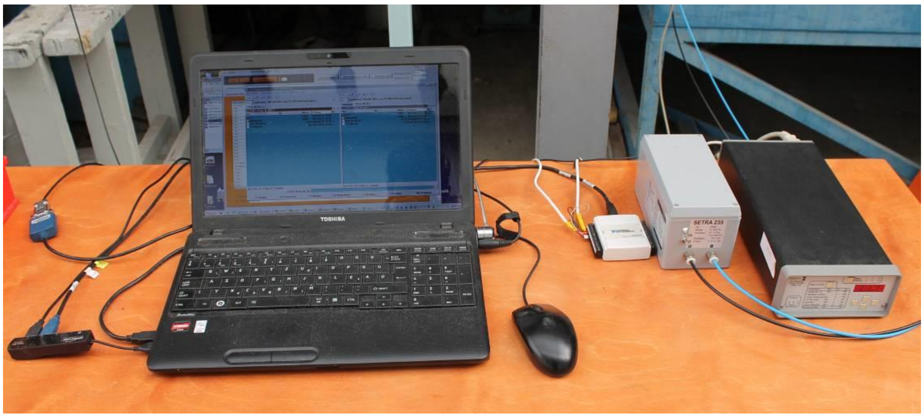


Fig. 4. Scheme and actual photograph of the data acquisition system

The vehicle model

The model is made of wood and steel plates. Several modules can be fixed on the frame using screws or magnets. **Be careful with your fingers, magnets are unusually strong!** This way one can change front curvature radius, shape and height of the model. Some extension elements are mad partly of polistyrol foam. **Be careful not to damage these during mounting or removing. Use a thin steel plate to snap tehese elements off the magnet!**

The width of the model is 250 mm, its scale is 1:10.

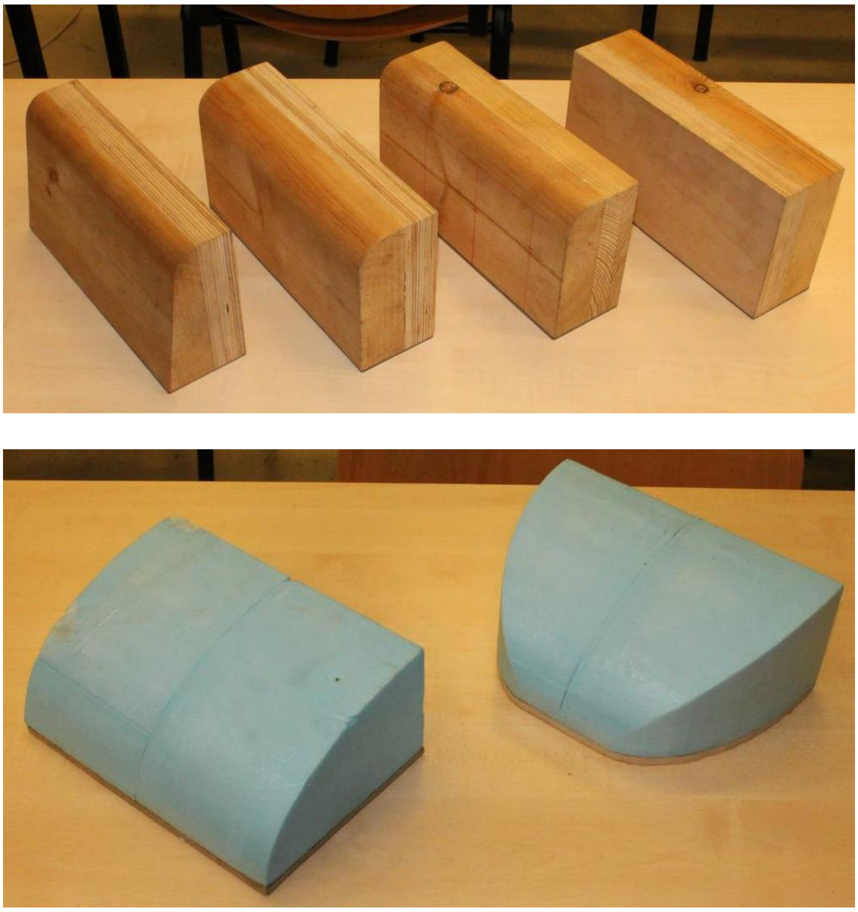


Fig. 5. Cab fronts (top) and spoilers (bottom) to be mounted using magnets

3. Measurement process

1. Calibration of pressure transducer or check of the calibration performed earlier, using a Betz-type micro-manometer.
2. Place the model into the wind tunnel. Determine the actual frontal area of the model, and make photographs and/ or sketches to document the geometry measured.
3. Calibration of the load cell using calibration weights, a wire and guide pulleys. Connect the wire to the hook in the back of the model. Calibrate at least in 5 points with increasing and then in decreasing order. (to check hysteresis)
4. Before starting the wind tunnel, perform zero measurements (measuring the output of the load cell and the pressure transducer at zero wind velocity). The values will have to be subtracted later from the measured values.
5. Perform measurements in at least 6-8 wind speeds (30% -> 100%). At each wind speed, take two 20-sec averaging time measurements. If difference between the two is less than 0.2-0.3 N, you can accept the measurement, if not, take a third one. Another option is to take measurements between 70-100% in 5% steps.
6. Stop the wind tunnel, wait until wind speed is zero and then perform zero measurement again.

7. Configure the vehicle model to another configuration. Point (2) and then repeat (4)-(6).
8. (optional) Measure one of the configurations repeatedly, to estimate the repetition error of the whole measurement.

Fig. 5. The guide pulleys and the calibration basket. (Weight: 0.7527kg).

Fig. 6. Ensure that there is a gap between wheels and the cover plate, when placing the model onto the platform

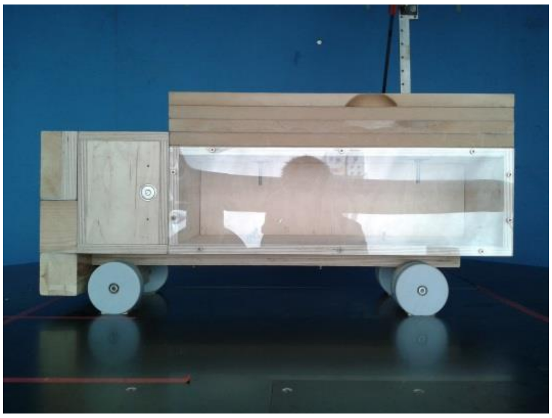
4. Measurement tasks

Task 'A'

Investigate the influence of front surface fillet radius of a bus model. (3 versions: sharp edges; curved on top and bottom, sharp on the side, curved on all sides)

Task 'B'

Investigation of a truck model with elevated cargo hold (3 versions: curved cab geometry without spoiler; with 2D spoiler; with 3D spoiler)



Task 'C'

Investigation of the influence of the gap between cab and cargo hold. Use rounded cab geometry. Configurations:

1) without gap
2) gap 100 mm
3) gap covered with steel side plates

Task 'D'

Investigation of the cab top rounding radius with elevated cargo hold.
Configurations:

(1) Sharp cab top edge, sharp side edges elevated cargo hold.
(2) slanted, rounded cab top edge
(3) vertical, rounded cab top edge

Task 'E'

Investigation of drag reduction using tail contraction.

Configurations:

(1) basic truck model with elevated cargo hold, bottom plate and rounded cab;
(2) with tail contraction.

Task 'F' (not available yet)

Investigation of truck behind truck and truck with trailer configurations.

Configurations:
(1) Basic truck model with flat cargo hold, rounded cab
(2) Placement of foam „truck" dummy in front of the model on the platform at 75mm distance. Trailer = Config (1) with sharp cab edges.
(3) Distance between front truck dummy and 'trailer': 150 mm
(4) Automatic road train: Placement of foam „truck" dummy in front of the model at 300 mm distance. Follower truck: Configuration (1)

6. Contents of the measurement protocol

Include all measured data in tables, properly rounded. Give all calculation formulae, and calculated values with error estimation. Draw diagrams of c_D as a function of Reynolds-number. Reynolds number can be calculated based on the model's width, 250 mm.

Calculate average drag coefficients for the configurations investigated, and compare them. Try to find literature data (give sources) for drag coefficients of real trucks and busses

Give explanations on the measured c_D values.

7. Error calculation

Estimate the error of the drag coefficient. The error of the force measurement can be taken from the hysteresis experienced during measurement. The pressure transducer's error is indicated on its casing. Then use the Gaussian error propagation formula.

If you performed the repeated measurement of a configuration, you might give the repeatability error of that as the error of c_D.

Literature

[1] Lajos Tamás: Áramlástan alapjai (2004)
11.3 fejezet: Közúti járművek áramlástanának alapjai

[2] Balczó Márton (2014): ARA Pressure & Force help.