NPL Wind tunnel

N1. Car front surface: Investigation on the flow past a simplified, mirrored car front surface model, with special regard to the drag force, for various chassis geometries

No drag force acts on bodies exposed to flow of ideal fluids. In the case of accelerating flow, e.g. developing in the vicinity of the front wall of a personal car, the boundary layer is thin. For this reason, the flow in the vicinity of the front wall is similar to the ideal, inviscid flow. As a result, the front wall drag coefficient of the car (being nearly equal to the mean pressure coefficient) is nearly zero. The total pressure slightly away from the front wall is nearly constant.

Assignment: justification of the above assumptions and gathering experiences about the flow in the vicinity of the car front wall. In order to model the ground (impermeable boundary), two symmetrically arranged front wall models are available. Pressure taps are installed inside the model as well as in the symmetry plane related to one of the two part-models. By this means, the pressure distribution can be measured on the front wall and in the separation bubble. The drag force can also be measured by means of a balance. The depression inside the model (i.e. in the separation bubble), multiplied by the maximum cross-section of the model, is to be subtracted from the drag force. By this means, the front wall drag can be estimated.

In the 45 min of the measurement,

a) The balance is to be calibrated (by means of weights, in 2 or 3 points),
b) The flow characteristics are to be examined by oil smoke flow visualization,
c) The drag force acting on the balance arm w/o the model is to be determined,
d) For 3 different velocities, the drag force acting on the models as well as the static pressure inside the models (relative to the pressure in the measurement section) is to be determined,
e) For the same velocities, the static pressure is to be measured on the front wall,
f) Repetition of b) and measurement of the static pressure inside the model [in d)] for modified front wall geometry: e.g. sharp inlet edge above the windscreen, spoiler below the front wall.

Availabilities:

- Balance protruding into the measurement section of the wind tunnel, by means of which the drag force being parallel to the flow direction can be measured, and by means of which the static pressure inside the model can be tapped,
- 2 symmetrical car front wall models, one is equipped with static pressure taps,
- Oil smoke generator,
- Pipe and probe for introduction of the oil smoke,
- Manometer.

A camera is to be provided by the measurement group.

Expected background information (chapters from Lajos, T.: Fundamentals of Fluid Mechanics, 2004, <u>3rd Edition</u>):
2.1.1. Pathline, streakline, streamline, 2.1.3. Flow visualization, 3.3.3. Static, dynamic, total pressure, 3.4.1. Euler component equations in the natural coordinate system, 3.4.2. Applications, 6.2.4. Instruments based on the deformation of a flexible body, 6.2.5. Practical pressure measurement problems, 6.3.1. Determination of velocity based on the measurement of dynamic pressure, 8.5.2. Preconditions for similarity of flows, 9.1.1. Characteristics of boundary layers, 9.2.2. Development of the boundary layer in streamwise direction, 9.3.1. Development of shear stresses in the boundary layer, 9.3.2. Boundary layer separation, 9.3.3. Flow past a cylinder, 9.3.5. Control and elimination of boundary layer separation, 10.1.2. Dimensional analysis, 10.1.3. Application of dimensional analysis, 11.1.1. Development of aerodynamic forces, 11.1.2. Aerodynamic force acting on a cylinder, 11.2.2. Aerodynamic force acting on bluff bodies.
Further recommendations: From <u>4th Edition</u>: 6.4.1. The aim of application of wind tunnels, 6.4.2. Types of wind tunnels, considering velocity and layout, 6.4.3. Structural elements of wind tunnels, layouts for measurement sections, 6.4.4. Practice of wind tunnel measurements, and/or Bradshaw, P., Mehta, R.: Wind tunnel design www-htgl.stanford.edu/bradshaw/tunnel/

Expected further background information –
For measurements regarding vehicle models:
<u>3rd Edition</u>, CD appendix: M.11.2.4. Vehicle aerodynamics PP presentation (**<u>4th Edition</u>**: DVD appendix M.11.3.1 presentation).
Further recommendations: <u>4th Edition</u>:
11.3.1. Aims and approaches in vehicle aerodynamics, 11.3.2. Structure of the flow field past vehicles, the front wall drag and its reduction, 11.3.3. Rear wall, under-chassis and side-wall drag, 11.3.4. Flow past buses and trucks

NPL Wind tunnel
N2. Race car wheel: Drag force acting on the front wheel of a Forma1 race car, and its reduction by means of shear layer conditioning

A significant portion of aerodynamic drag acting on Forma 1 race cars is the force acting on the two front wheels. versenyautók áramlási ellenállásának nagy részét a két első kerékre ható erő teszi ki. The boundary layer is separated from the plate being normal to the flow and located upstream of the wheel near the ground. Downstream of the plate, a separation bubble develops, in which depression occurs. This depression moderates the overpressure on the lower part of the wheel, and thus, the force acting on the wheel decreases (shear layer conditioning).

Assignment: Investigation on the possibilities of modification of flow field, serving as basis for drag reduction. In order to model the ground (impermeable boundary), two symmetrically arranged wheel models are available. Deflector plates of various size and position can be tested.

In the 45 min of the measurement,

1. The balance is to be calibrated (by means of weights, in 2 or 3 points),
2. The drag force acting on the balance arm is to be determined,
3. The flow characteristics are to be examined by oil smoke flow visualization,
4. For 3 different velocities, the drag force acting on the models is to be determined,
5. The drag force is to be measured again when installing plates: 2 plate sizes, 2-2 distances measured from the wheel.
6. For the same velocities, the static pressure is to be measured on the front wall,

Availabilities:

- Balance protruding into the measurement section of the wind tunnel, by means of which the drag force being parallel to the flow direction can be measured,
- 2 F1 wheel models,
- Deflector plate, attachable on the wheels, interchangeable, adjustable
- Oil smoke generator,
- Pipe and probe for introduction of the oil smoke,
- Manometer.

A camera is to be provided by the measurement group.

Expected background information (chapters from Lajos, T.: Fundamentals of Fluid Mechanics, 2004, 3rd Edition):
2.1.1. Pathline, streakline, streamline, 2.1.3. Flow visualization, 3.3.3. Static, dynamic, total pressure, 3.4.1. Euler component equations in the natural coordinate system, 3.4.2. Applications, 6.2.4. Instruments based on the deformation of a flexible body, 6.2.5. Practical pressure measurement problems, 6.3.1. Determination of velocity based on the measurement of dynamic pressure, 8.5.2. Preconditions for similarity of flows, 9.1.1. Characteristics of boundary layers, 9.2.2. Development of the boundary layer in streamwise direction, 9.3.1. Development of shear stresses in the boundary layer, 9.3.2. Boundary layer separation, 9.3.3. Flow past a cylinder, 9.3.5. Control and elimination of boundary layer separation, 10.1.2. Dimensional analysis, 10.1.3. Application of dimensional analysis, 11.1.1. Development of aerodynamic forces, 11.1.2. Aerodynamic force acting on a cylinder, 11.2.2. Aerodynamic force acting on bluff bodies.
Further recommendations: From 4th Edition: 6.4.1. The aim of application of wind tunnels, 6.4.2. Types of wind tunnels, considering velocity and layout, 6.4.3. Structural elements of wind tunnels, layouts for measurement sections, 6.4.4. Practice of wind tunnel measurements, and/or Bradshaw, P., Mehta, R.: Wind tunnel design www-htgl.stanford.edu/bradshaw/tunnel/

Expected further background information –
For measurements regarding vehicle models:
3rd Edition, CD appendix: M.11.2.4. Vehicle aerodynamics PP presentation (**4th Edition**: DVD appendix M.11.3.1 presentation).
Further recommendations: 4th Edition:
11.3.1. Aims and approaches in vehicle aerodynamics, 11.3.2. Structure of the flow field past vehicles, the front wall drag and its reduction, 11.3.3. Rear wall, under-chassis and side-wall drag, 11.3.4. Flow past buses and trucks

Trolley 1

K.1.1. Free jet: Measurement on the velocity distribution in a planar free jet

Planar free jets are frequently applied e.g. for air curtains, or in drying, cooling processes. Therefore, the knowledge on their characteristics is of practical importance.

Assignment: determination of velocity distribution in a planar free jet, at least in 4 sections. To be determined: maximum velocity, momentum flux, flow rate transported in the free jet as function of distance from the outlet. Study on the Coanda effect is also an assignment (attachment of the jet to a plate being parallel to the jet: at what distance?). Investigation on the effect of outlet geometry (sharp or rounded slot) in another measurement series, and on the turbulent diffusion (and, analogously, heat transfer), by means of oil smoke flow visualization.

In the 45 min of the measurement,

1. The velocity distribution is to be determined in 4 sections at various distances from the outlet,
2. The previous phase is to be repeated using a sharp slot,
3. It is to be observed at what distance should the plate be located for attachment of the free jet onto it,
4. The mass transport is to be examined by means of oil smoke introduction and photography.

Availabilities:

- Equipment for generation of a planar free jet,
- Pitot and Pitot-static probes for velocity measurements,
- Probe traverse,
- Oil smoke generator,
- Pipe and probe for introduction of the oil smoke,
- Manometer.

A camera is to be provided by the measurement group.

Expected background information (chapters from Lajos, T.: Fundamentals of Fluid Mechanics, 2004, 3rd Edition):
2.1.1. Pathline, streakline, streamline, 2.1.3. Flow visualization, 3.3.3. Static, dynamic, total pressure, 3.4.1. Euler component equations in the natural coordinate system, 3.4.2. Applications, 6.2.4. Instruments based on the deformation of a flexible body, 6.2.5. Practical pressure measurement problems, 6.3.1. Determination of velocity based on the measurement of dynamic pressure, 8.5.2. Preconditions for similarity of flows, 9.1.1. Characteristics of boundary layers, 9.2.2. Development of the boundary layer in streamwise direction, 9.3.1. Development of shear stresses in the boundary layer, 9.3.2. Boundary layer separation, 9.3.3. Flow past a cylinder, 9.3.5. Control and elimination of boundary layer separation, 10.1.2. Dimensional analysis, 10.1.3. Application of dimensional analysis, 11.1.1. Development of aerodynamic forces, 11.1.2. Aerodynamic force acting on a cylinder, 11.2.2. Aerodynamic force acting on bluff bodies.
Further recommendations: From 4th Edition: 6.4.1. The aim of application of wind tunnels, 6.4.2. Types of wind tunnels, considering velocity and layout, 6.4.3. Structural elements of wind tunnels, layouts for measurement sections, 6.4.4. Practice of wind tunnel measurements, and/or Bradshaw, P., Mehta, R.: Wind tunnel design www-htgl.stanford.edu/bradshaw/tunnel/

Expected further background information –
For measurements regarding free jets:
3rd Edition, or 4th Edition: 7.5. Free jets

Trolley 1

K.1.2. Air curtain: Curvature of a planar free jet due to pressure difference; investigation on an air curtain applied to an industrial hall

For "non-contact closing" a door of an industrial hall that is otherwise to be open because of transportation reasons, i.e. for moderation of heat and mass transfer between the hall and the surroundings, cold air curtain is used. The difference between the internal and ambient pressure is balanced by means of the curvature of the vertical, planar free jet introduced on one side of the door.

Assignment: investigation on the behavior of the air curtain model, as function of outlet velocity, outlet slot width, outlet angle, door width, and pressure difference. The air volume flow rate entering the protected enclosure is also to be determined as function of pressure difference. The mass and heat transfer is to be observed on the basis of oil smoke flow visualization.

In the 45 min of the measurement,

a) The entering flow rate is to be determined, for a given rounded outlet slot geometry, outlet velocity and angle, and depression. The parameters of operating state related to zero inflow are also to be determined.
b) Assignment a) is to be repeated for another outlet angle and outlet velocity.
c) At a given outlet angle, the effect of door width is to be examined.
d) By means of introduction of oil smoke and carrying out photography, the shape of the curved jet and the mass transfer through the jet are to be studied.

Availabilities:

- Equipment for generation of an air curtain,
- Industrial hall model, with variable free jet outlet angle, door width, and depression (using a fan of variable speed), and with an inlet element calibrated for flow rate measurements,
- Pitot and Pitot-static probes for velocity measurements,
- Oil smoke generator,
- Pipe and probe for introduction of the oil smoke,
- Manometer.

A camera is to be provided by the measurement group.

Expected background information (chapters from Lajos, T.: Fundamentals of Fluid Mechanics, 2004, 3rd Edition):
2.1.1. Pathline, streakline, streamline, 2.1.3. Flow visualization, 3.3.3. Static, dynamic, total pressure, 3.4.1. Euler component equations in the natural coordinate system, 3.4.2. Applications, 6.2.4. Instruments based on the deformation of a flexible body, 6.2.5. Practical pressure measurement problems, 6.3.1. Determination of velocity based on the measurement of dynamic pressure, 8.5.2. Preconditions for similarity of flows, 9.1.1. Characteristics of boundary layers, 9.2.2. Development of the boundary layer in streamwise direction, 9.3.1. Development of shear stresses in the boundary layer, 9.3.2. Boundary layer separation, 9.3.3. Flow past a cylinder, 9.3.5. Control and elimination of boundary layer separation, 10.1.2. Dimensional analysis, 10.1.3. Application of dimensional analysis, 11.1.1. Development of aerodynamic forces, 11.1.2. Aerodynamic force acting on a cylinder, 11.2.2. Aerodynamic force acting on bluff bodies.
Further recommendations: From 4th Edition: 6.4.1. The aim of application of wind tunnels, 6.4.2. Types of wind tunnels, considering velocity and layout, 6.4.3. Structural elements of wind tunnels, layouts for measurement sections, 6.4.4. Practice of wind tunnel measurements, and/or Bradshaw, P., Mehta, R.: Wind tunnel design www-htgl.stanford.edu/bradshaw/tunnel/

Expected further background information –
For measurements regarding air curtains:
3rd Edition, or 4th Edition: 7.5. Free jets, Air curtains

Laboratory report

The report **MUST** contain the following data, in well-organized and easy-to-read format, providing a basis for reproducing the measurements if necessary:

- Title, names of measurement personnel, date and location.
- Measured air temperature and barometric pressure data, and the resultant air density.
- Schematic view of the experimental facility; dimensions.
- Instruments applied, type numbers, serial numbers, measurement uncertainties.
- Description of determination (measurement, calculation) of characteristics (with equations as appropriate).
- The measurement data, represented in Excel diagrams as appropriate.
- Experimental uncertainty, indicated by error bars in the diagrams as appropriate.
- Detailed report on the experimental uncertainty, summarized in table format; accompanied by the details of the uncertainty calculation.
- Evaluation of results, conclusions.