LDA Measurements of the Flow and Turbulence Structures in the Wake of a Simplified Car Model

by

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ABSTRACT

The aim of the "Models for Vehicle Aerodynamics" (MOVA) Project is to develop, refine, and validate the latest generation of turbulence models for selected examples encountered in vehicle aerodynamics. The validation of turbulence models requires the availability of detailed experimental data. These quantitative data should cover the most critical flow regions around a bluff car-shaped body and they should give physical quantities that can directly be correlated to the results of numerical simulations. Such experimental data were measured in the LSTM low speed wind tunnel using a 2-component laser-Doppler anemometer (LDA) mounted on a traversing system and a simplified model of a car (Ahmed model). Measurements were made for two rear vehicle body slant angles (25° and 35°) at a bulk air velocity of 40 m/s. This paper serves as a synopsis of the major results of this experimental investigation.

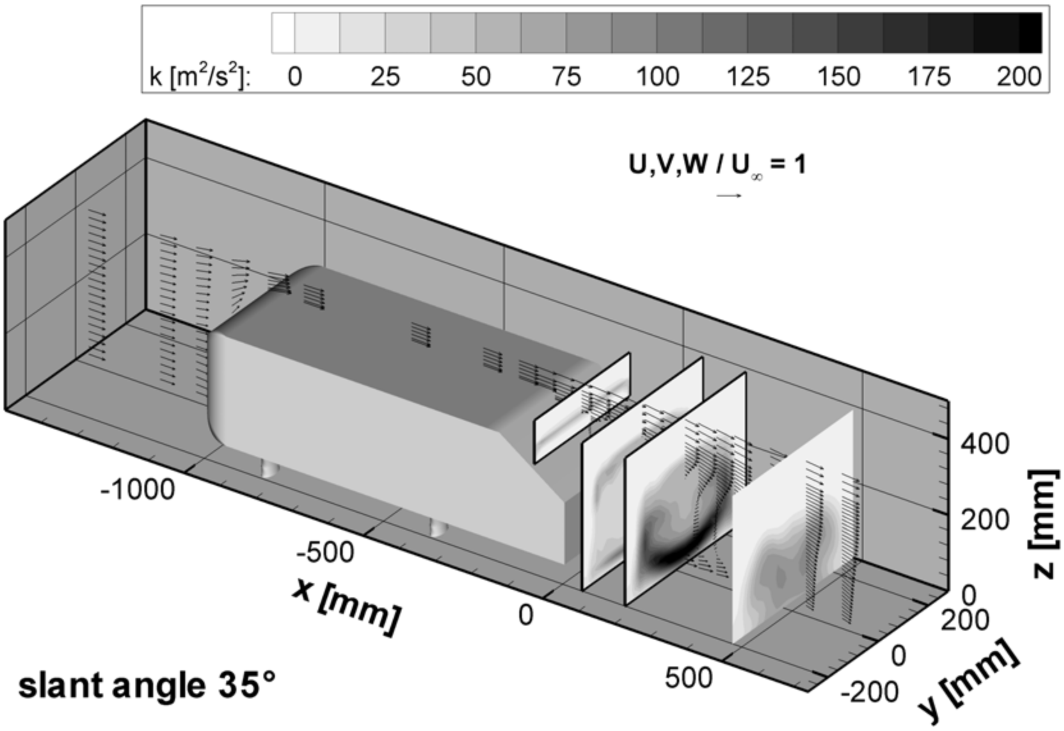

Fig. 1:. Overview of velocity distributions and turbulent energy k around the 35° slant Ahmed model.

INTRODUCTION

The flow region which presents the major contribution to a car's drag, and which poses severe problems to numerical predictions and experimental studies as well, is the wake flow behind the car. The location at which the flow separates determines the size of the separation zone, and consequently the drag force. Clearly, a more exact simulation of the wake flow and of the separation process are essential for the correctness of drag predictions. However, a real-life automobile is a very complex shape to model or to study experimentally. Therefore the MOVA consortium partners (TU Delft, University of Manchester, LSTM, Electricite de France, AVL List, and PSA Peugeot Citroen) agreed to study the vehicle shape employed by Ahmed and Ramm (1983), known as the Ahmed model. Figure 2 is a schematic of the Ahmed model, with actual dimensions in mm included. Two different rear body slant angles (25° and 35°) were considered, which happen to bracket the critical angle of 30° at which separated flow occurs within the wake of the slant (see Figure 3, c_W, c_R, c_K, c_B, c_S represent coefficients of total drag, friction drag, nose pressure drag, slant pressure drag, and base pressure drag, respectively).

The Ahmed model was mounted in the test section of the LSTM wind tunnel (Figure 4) and detailed measurements of velocity profiles were made around this body. The experiments were performed in the LSTM low speed wind tunnel, a closed return facility which can be configured with an open or a closed test section. The present studies were conducted in a ¾ open test section (i.e., floor, but no sides or ceiling) with a blockage ratio of 4%. The wind tunnel can generate flow velocities from 3 to 55 m/s with average turbulence intensities of less than 0.25%. All measurements concerning the Ahmed model were taken at bulk air velocities of 40 m/s. To ensure constancy of the test section bulk velocity and air temperature, a computer-based feedback control system was utilised.

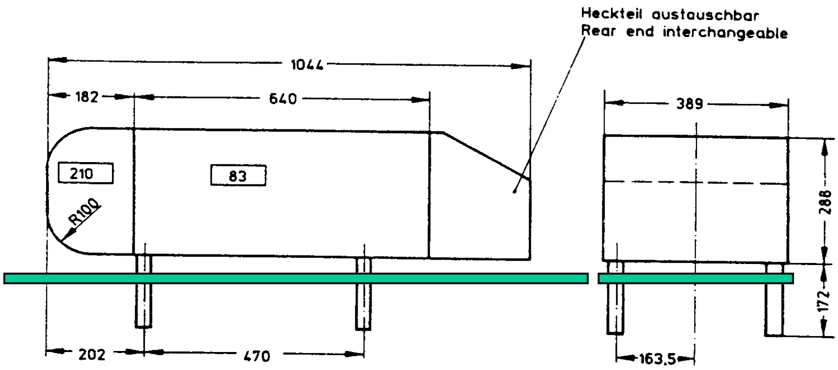

Fig. 2: Schematic of the bluff body (Ahmed and Ramm, 1984) shape.

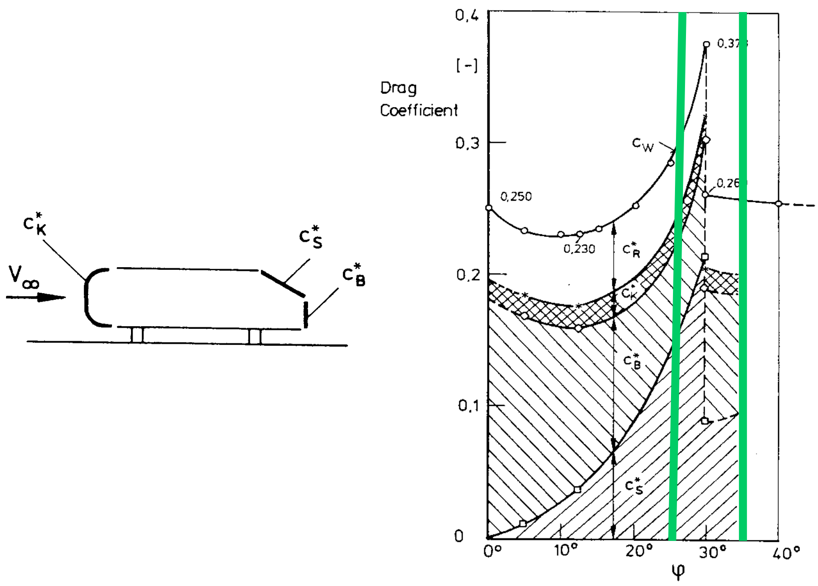

Fig. 3: Drag coefficients for the Ahmed model for various slant angles (Ahmed and Ramm, 1984).

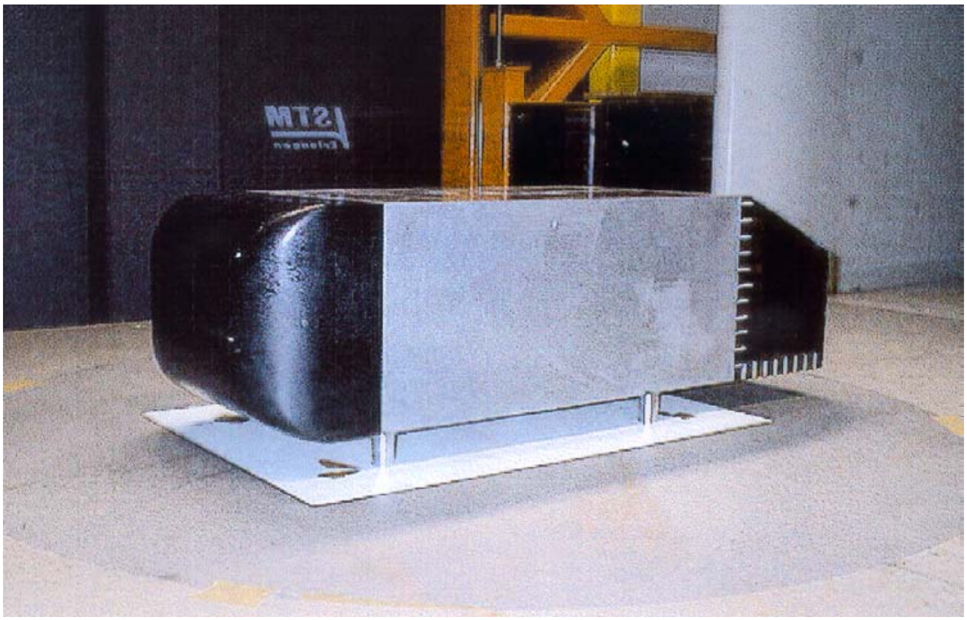

Fig. 4: Photograph of the Ahmed model mounted in the LSTM low-speed wind tunnel.

Hot-wire measurements of the velocity profiles 400 mm upstream of the Ahmed model were obtained to serve as a inlet condition for the numerical simulations. The measurements were performed by a two-component hot-wire system, which was rotated to obtain the third component. The results showed that the test section inlet velocity profile was well defined and controlled, which guaranteed reliable measurements for the model validation database. Flow visualization using oil streaks was performed for both model shape angles. The visualization showed complex three-dimensional flow patterns and confirmed earlier findings that a small change in the slant angle around the critical 30° causes a dramatic change in the flow pattern. Comparison of Figures 5 and 6 illustrate these changes. The formation of clinging vortices and flow reversal for a slant angle of 25° is evident in the photograph of oil streaks in Figure 5. Attached flow is maintained in this case while at a slant angle of 35° (Figure 6) detached flow is obvious.

Fig. 5: Oil / soot streak flow visualisation of the Ahmed model rear for a 25° slant angle.

Fig. 6: Oil / soot streak flow visualisation of the Ahmed model rear for a 35° slant angle.

A two-component laser-Doppler anemometer (LDA) was installed on an existing three-dimensional computer controlled traversing system (rotation of the sending/receiving optics offer an additional axis of traversing). The LDA was composed of DANTEC fiberoptic-based optics and electronics. Two different laser wavelengths were used: 514.5 nm (green) and 488 nm (blue). The system was of backscatter orientation, the only optical configuration possible for these measurements due to the proximity of the measurement grid to the body surface. The laser was a water-cooled, 5 watt argon-ion Spectra Physics Model 2060. Beam splitting and frequency shifting were provided by DANTEC FiberFlow optics. Signal analysis and signal processing were accomplished via a DANTEC Model 57N20 Burst Spectrum Analyzers (BSA) and DANTEC BSA Flow software. A PC computer provided measurement control and data acquisition / storage. LDA measurements were made for all three components of velocity in the symmetry plane from upstream of the Ahmed model to some distance downstream behind the closure of the wake. LDA measurements were also made in several transverse planes in the wake.

LDA MEASUREMENT RESULTS

Figure 7 attempts to show the different measurement positions employed in this effort. In summary, there were 7,500 discrete measurement positions located in 13 unique planes. Because higher order statistical moments (i.e., Reynolds stresses, , etc.) were of interest, each measurement location had to be sampled twice -- first for the U and V components of velocity, then for the U and W components. Preliminary statistical analysis indicated that approximately 40,000 measurement realisations were necessary at each location for statistically significant results. This translates to a maximum measurement time of approximately 5 minutes at each location. Following the procedure outlined in Bendat and Piersol (1986), for a 95% confidence interval the statistical uncertainty in the outer flow (far from the Ahmed model) mean velocity was less than 0.005% of the local mean velocity. Within the wake of the Ahmed model, where mean velocities can approach zero and turbulence intensities are very high, an estimate of mean velocity measurement uncertainty is rather arbitrary. An order of magnitude estimate for the calculated 95% confidence interval was 1% for mean and 1.5% for rms quantities. The LDA system measured turbulence intensities as small as 0.8% in the outer flow region. This value represents a LDA lower threshold for measured turbulence intensity and includes inaccuracies due to measurement technique, wind tunnel fluctuations, traverse system vibrations, etc..

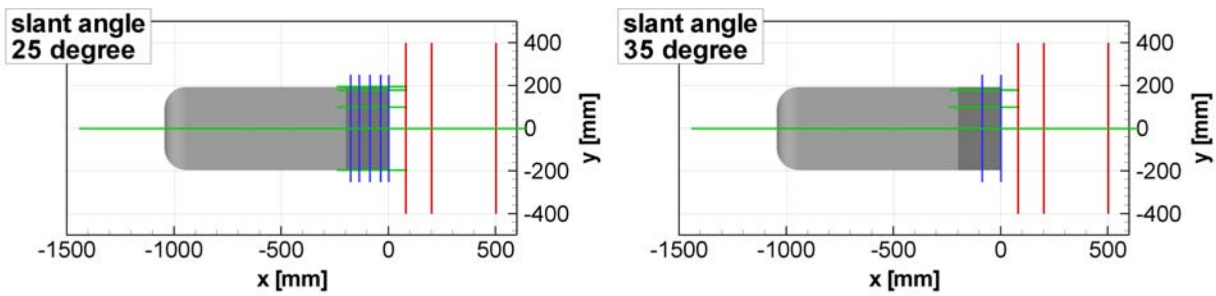

Fig.7: Measurement planes utilised to characterise the velocity distribution.

Figure 8 serves as a good overview of typical velocity distributions around the 25° slant Ahmed model. The mean velocity vectors along the line of symmetry of the rear slant indicate that no separation of the flow is occurring. The two counter-rotating trailing vortices are shown in the three transverse planes of turbulent kinetic energy (k) contour plots. Peaks in k occur in the centres of the vortices. These vortices are responsible for maintaining attached flow at the slant up to a slant angle of approximately 30°. Vortical structures extend more than 500 mm beyond the end of the Ahmed model.

Figure 9 is a direct comparison of the region of attachment / detachment and recirculation at the rear of the Ahmed model for the two slant angles of interest. These measurements were made along the plane of symmetry of the Ahmed model. The intention of this figure is to indicate the major differences in the near-wake flow fields for the two slant angles studied.

More detailed near-wake measurements were made but omitted from this figure to avoid obscuring the wake structures. The only additional information provided by the more detailed measurements concerns a very small recirculation region in the upper part of the 25° slant surface. Beyond this region, the flow then reattaches to the slanted surface, then develops a second, larger recirculation region along the lowermost part of the rear. Observations for the 35° case are quite different, however. The flow detaches along the slanted surface and develops a single, significantly larger recirculation region within the wake.

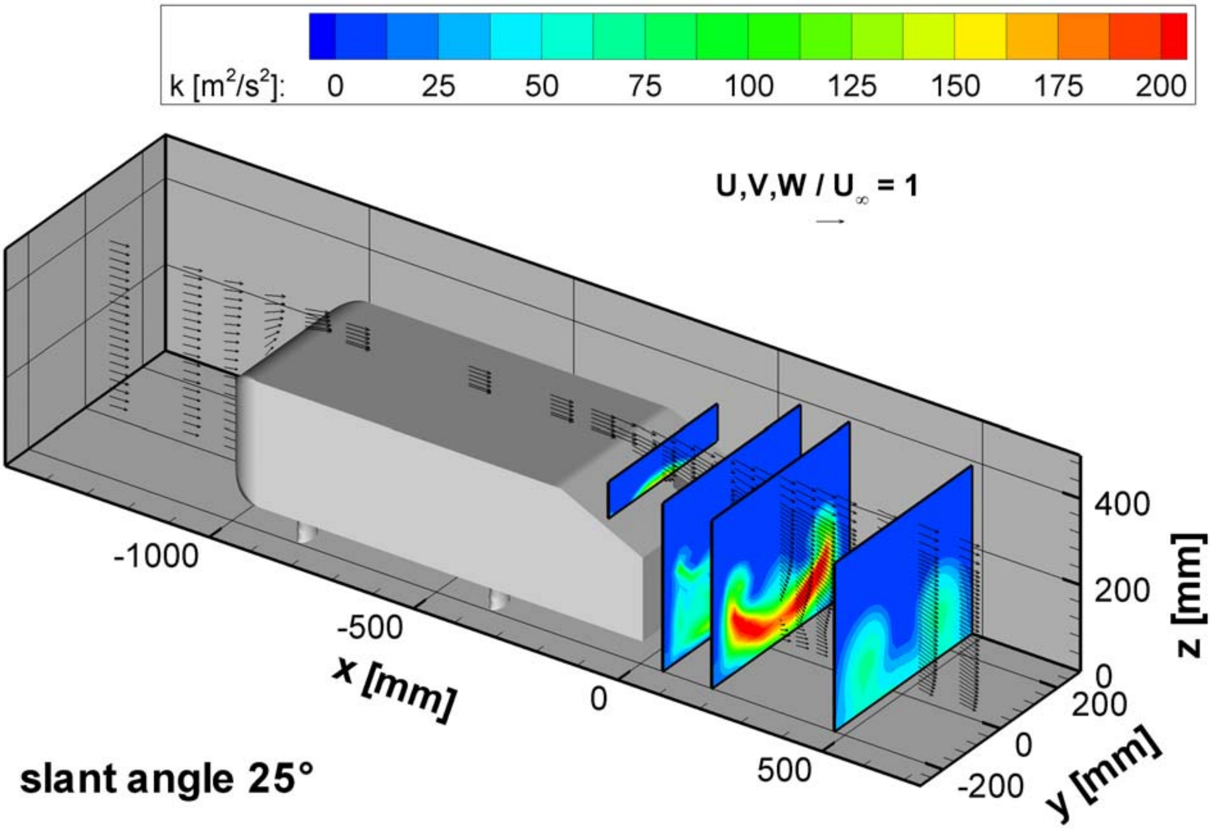

Fig. 8: Overview of velocity distributions and k around the 25° slant Ahmed model.

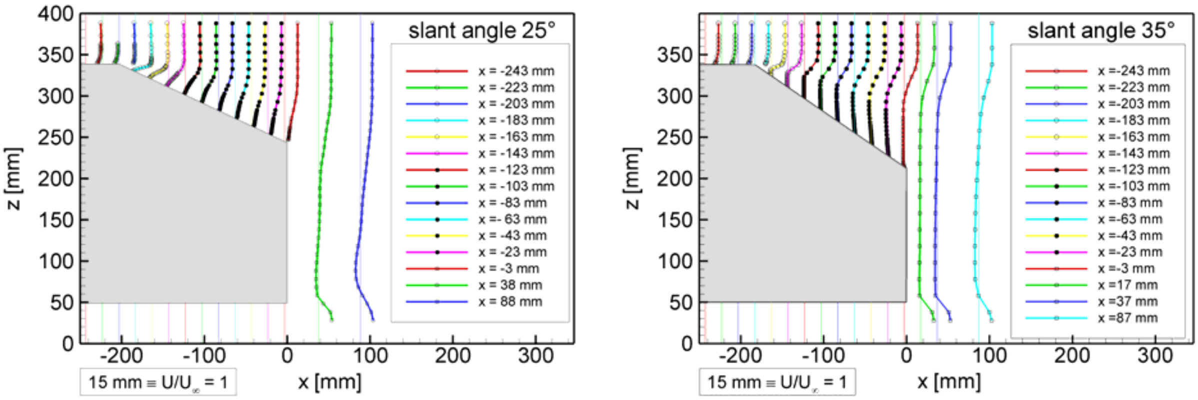

Fig. 9: Comparison of the recirculating wake region and attached / detached flow for the two different rear slant angles.

Mean velocity vectors and profiles of turbulent kinetic energy (k) for the symmetry plane of the Ahmed 25° and 35° degree slant angle models are displayed in Figure 10. Peak k values are within the small recirculation zone at the rear of the body. Note that the Ahmed model only disturbs the outer flow for a relatively small distance from its surface.

Finally, Figure 11 shows the downstream development of the counter-rotating trailing vortex system produced by the 25° slant Ahmed model. The contours represent regions of constant magnitude downstream velocity. At 80 mm downstream from the trailing edge of the Ahmed model, there is a large and strong region of recirculation back towards the surface. Although the recirculation has disappeared by x = 200 mm, there is still a large streamwise velocity deficit. At x = 500 mm the location of the cores of the trailing vortices can still be distinguished by deficits in streamwise velocity.

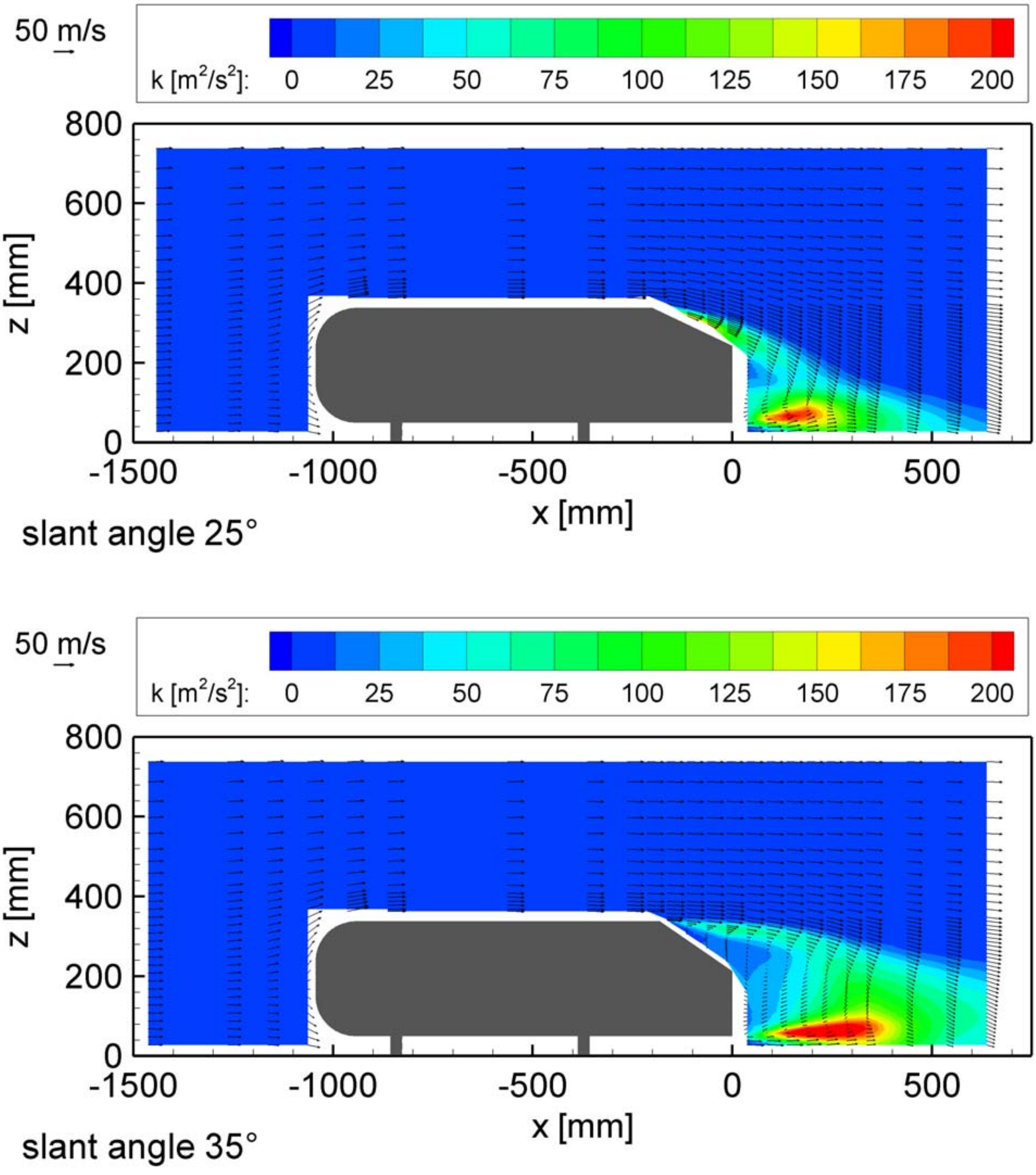

Fig 10: Contours of turbulent energy k along the symmetry plane of the 25° and 35° slant Ahmed model

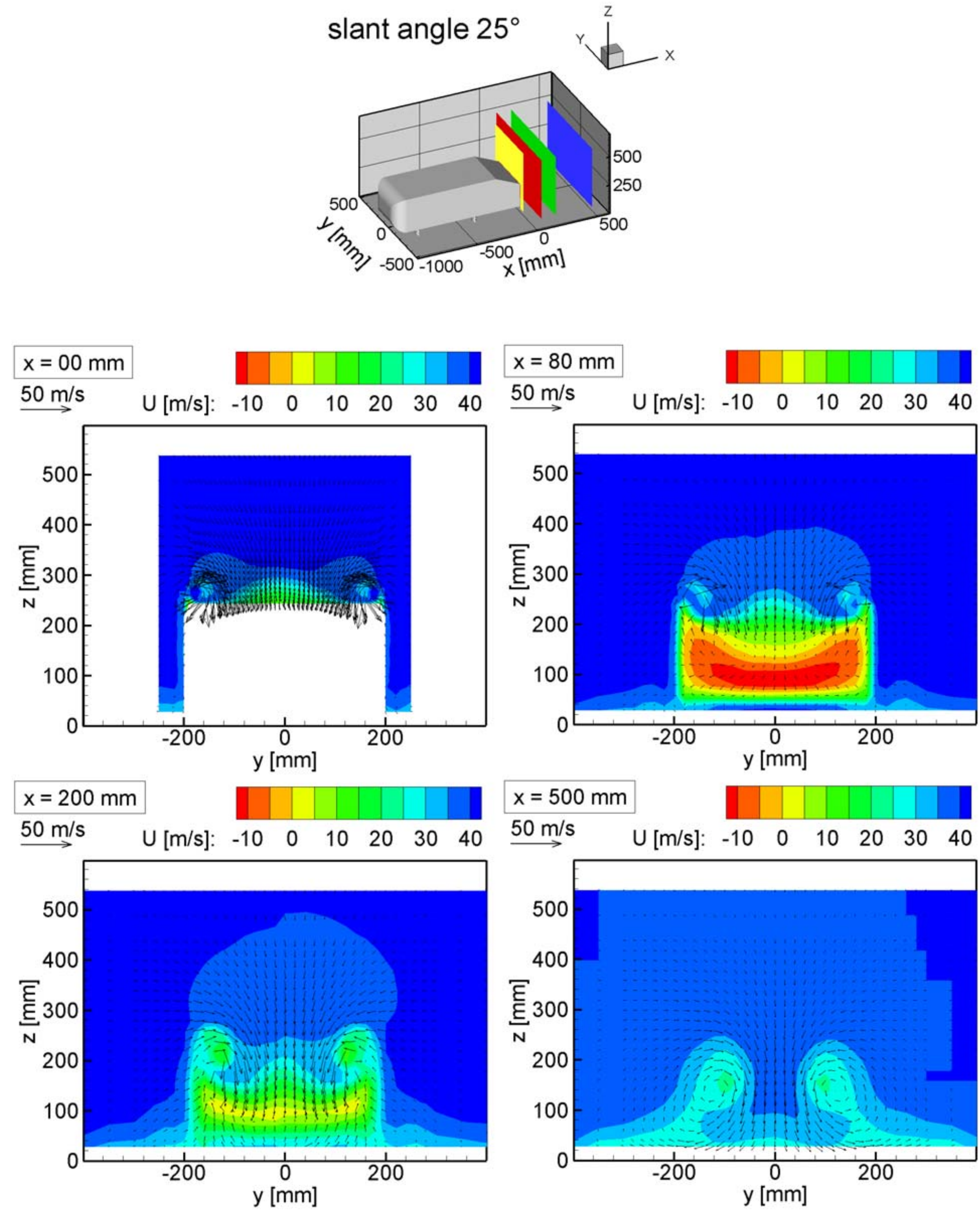

Fig. 11: Development of the counter-rotating trailing vortex system within the wake of the 25° slant Ahmed model.

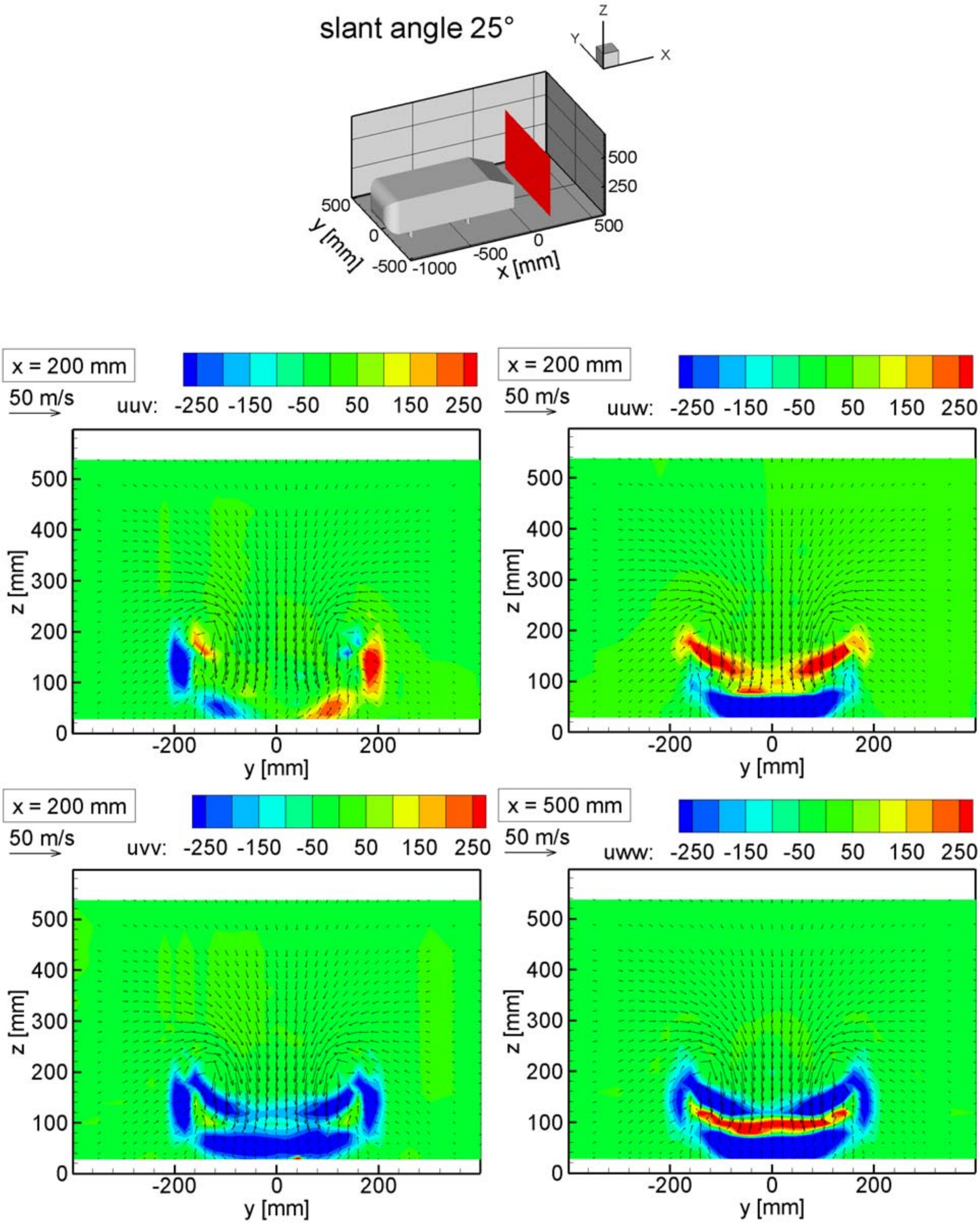

Fig. 12: Profiles of higher-order statistical moments within the wake of the 25° Ahmed model.

Figure 12 is an example of profiles of second - and third - order moments for the wake region of the Ahmed model. The contours of various moments display very good symmetry.

CONCLUSIONS

Flow visualization, hot wire, and LDA measurements have been performed around an Ahmed model for two different rear slant angles: 25° and 35°. These two slant angles bracket a critical instability when the flow detaches from the slanted surface. LDA measurements include all three components of mean and RMS velocity as well as most second (Reynolds stresses) and third order moments. The measurements clearly show the differences in flow attachment and recirculation for the two different slant angles considered. The quantitative information provided by these measurements should prove invaluable for developing, testing, and validating computer models of the aerodynamics of vehicular wake regions

ACKNOWLEDGEMENTS

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