PIV as a complementary tool in aerodynamics studies

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As far as ground vehicles aerodynamics is concerned, consumption reduction is a major issue for reducing the human fingerprint on the Earth. For a car at 100km/h, drag is the major part of resistance to the motion. Since the drag coefficient is closely linked to the flow behavior at the rear of the car, simplified models appeared during the last decades to carry out reference tests. Techniques commonly applied in aerodynamics to study drag and characterize the flow, like balance force measurements, surface visualization, hot-wire anemometry or LDV, are not always enough to deeply understand its nature. The fast growth of the Particle Image Velocimetry technique gives new opportunities for the investigation of the wake mechanism inducing drag.

1. Objectives and methodology

The present study proposes to perform different measurement techniques, including PIV, and to underline their complementarities and their suitabilities to investigate ground vehicle aerodynamics in large wind tunnels.

The study is performed on a simplified car-like model, the Ahmed body. The bluff body was initially used to study the influence of the rear angle on drag coefficient. The model is here studied with a constant rear angle of 40°. In the literature, at this angle, the drag coefficient just passes a very high drag crisis (at 30°) and is back to lower drag coefficients values.

The model is placed in the closed test section of the VKI L1 wind tunnel (2m x 3m) and tested at a speed of 40m/s. Several measurements are realized: aerodynamic drag by multi-component balance, oil visualization and Particle Image Velocimetry. The last two techniques are performed on the rear slant of the model.

2. PIV in a large wind tunnel

The implementation of Particle Image Velocimetry in an aerodynamic wind tunnel implies some efforts for adapting the test section. The seeding is done by a home-made smoke generator creating 1µm oil droplets. As the tunnel is a closed return circuit, the seeding rake can be placed downstream the model to avoid perturbations. After getting the wind tunnel black, a double pulsed Mini-Yag laser is placed on the roof of the test section to light particles from the top. The distance from the exit of the laser to the measurement area on the model is around 2.8 m. That creates losses of light intensity and problems to have a narrow high intensity laser sheet. To ensure a sufficient contrast on the images, the laser sheet is reduced in length, leading to a final effective measurement plane of 150mm x 175mm situated in the middle of the rear slant.

The reduction of the measurement area dimensions is overcome by a concatenation method. Images are taken in four planes and joined together in a larger field. The superposition of the mean quantities over 1000 images does not make any problem, results are continuous and correlated. However, when it comes to instantaneous fields, data cannot be time-correlated (because taken at different moments).

The image post-processing algorithm includes a background noise reduction by the removal of the mean image. The cross-correlation is realized by a house code using window displacement and distortion applied in different steps. The sub-pixel interpolation increases the accuracy of the measurements.

3. Results and discussions

Drag force measurement performed is submitted to blockage correction. The drag coefficient calculation allows the comparison with reference studies. Results obtained are 10% above the literature, this is acceptable giving the uncertainties on the original study conditions and enough to be sure that the flow is completely detached. Indeed, the 30° drag drop is more than 45% in the literature.

Surface oil visualization is performed on the slanted plane of the model. Main information extracted is the reverse flow in the middle of the rear slant. Additionally, no longitudinal vortices are present on the sides. Observations are representatives of a completely detached flow and provide extra arguments for the understanding of the flow behavior.

PIV extracts more information by giving a 2D field in the vertical plane on the rear of the model. First the instantaneous vector field highlights the very strong velocity gradient happening between the free-stream and the quiet zone downstream the rear angle. Going deeper, a vortex detection study brings to the detection of a Kelvin-Helmoltz-like vortex shedding created in the shear layer. Then, the average of 1 000 PIV images shows clearly the recirculation of the flow at the rear of the model. The interpolation of streamlines points out the separation of the flow at the rear edge in a global recirculation bubble. The correlation with oil visualization is direct.

4. Conclusions

Diversified approaches using several measurement techniques converge to a good understanding of the flow behavior at the rear of the model. The combination of techniques has the valuable advantage of giving information in different directions and planes. PIV is especially profitable for providing both time-averaged and instantaneous data.