Turbulent energy budgets of a ground vortex flow

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The turbulent kinetic energy budgets are presented for a highly curved flow generated by the collision of plane wall turbulent jet with a low-velocity boundary layer. Turbulent kinetic energy balances are obtained in vertical plane of symmetry by quadratic interpolation of the LDV measurements, for a wall jet-to-boundary layer velocity ratio of 2. The results, which have relevance to flows encountered by powered-lift aircraft operating in ground effect, quantify the structure of the complex ground vortex flow resulting from the collision of a wall jet with a boundary layer.

The analysis of turbulent kinetic energy resulting from the collision of wall jet with a boundary layer were presented and discussed with horizontal and vertical profiles together with contours for a wall jet-to-boundary layer velocity ratio of 2.

Fig. 1 Representation of the ground vortex flow phenomena on the underside of V/STOL aircrafts (Joint Strike Fighter F-35 Variant B).

The turbulent kinetic energy balances revealed that in the collision zone of the wall jet with the boundary layer there is a local gain of energy by convection. In the region of the deflected flow the convective term not presents any significant contribution to the loss or gain of turbulent kinetic energy.

The results revealed that in the collision zone the diffusive and dissipative term and the production by shear stresses term become predominant and the production of turbulent kinetic energy tends to be balanced by the loss by diffusion and dissipation. In the same zone near to the wall, the production of turbulent kinetic energy is by convection, by normal and shear stresses. The small contribution of convective term to the production of turbulent kinetic energy is less than the production due to the normal stresses and shear stresses.

The collision zone between the wall jet and the boundary layer presents a behavior similar to a wall jet. In general the results indicate that the modeling of turbulence of this flow may require an adequate treatment of production by normal stresses, which is important in the collision zone.

Experimental setup

The wind tunnel facility designed and constructed for the present work is schematically shown in Fig. 2. With this facility the three-dimensional effects created by skewing of pre-existing spanwise vorticity are eliminated, and makes our data particularly interesting to assess the turbulent or transient effects near the separation point of the ground vortex where the transverse velocity component is null.

The recommendations of Metha and Bradshaw (1979) for open circuit wind tunnels were followed throughout all the design process especially for the boundary layer part of the flow. A fan of 15KW nominal power drives a maximum flow of 3000 m³/h through the boundary layer and the wall jet tunnels of 300 x 400mm and 40 x 400 mm exit sections, respectively. The facility was built to allow variable heights of the wall jet exit from 15 up to 40mm, but in the present study a constant value of 16mm was used.

The origin of the horizontal, X, and vertical, Y, coordinates is taken near the visual maximum penetration point. The X coordinate is positive in the wall jet flow direction and Y is positive upwards.

The present results were obtained at the vertical plane of symmetry for a wall jet mean velocities of \( U_j = 13.7 \text{ m/s} \) and mean boundary layer velocity of \( U_o = 6.9 \text{ m/s} \) corresponding to a velocity ratio, \( V_R \), of 2.0.

Fig. 2 Diagram of the experimental facility and Laser Doppler velocimeter system.

References