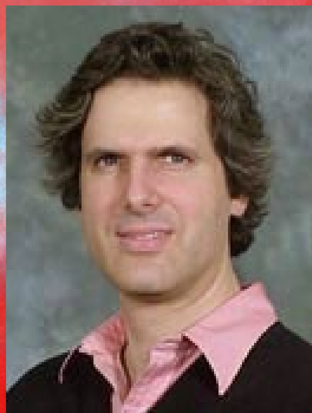
Aerospace Seminar



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Near Wall Turbulence Structure

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Abstract: Some of the most important properties of turbulent boundary layers are its mean flow and turbulence kinetic energy profiles. Townsend (1976) introduced the concept of wall-attached eddies which predicts a logarithmic decrease of the streamwise turbulence velocity variance as a function of distance from the wall. However, this model also predicts that the streamwise integral lengthscale varies very slowly with distance to the wall in the intermediate layer. The only way for the integral length scale's variation to be more realistic while keeping with the Townsend attached eddy concept is to add a new wavenumber range to the model at wavenumbers smaller than the Townsend-Perry original wall-attached spectrum. It turns out that this addition can also account for the recently observed high Reynolds number outer peak of the turbulent kinetic energy in the intermediate layer. An analytic expression is obtained for this outer peak in agreement with extremely high Reynolds number superpipe data by Hultmark, Vallikivi, Bailey & Smits (2012, 2013). Townsend's (1976) local production-dissipation balance and the finding of Dallas, Vassilicos & Hewitt (2009) that, in the intermediate layer, the eddy turnover time scales with skin friction velocity and distance to the wall implies that the mean flow gradient has an outer peak at the same location as the turbulent kinetic energy. This is seen in the superpipe data of Hultmark, Vallikivi, Bailey & Smits (2012, 2013). The same approach also predicts that the mean flow gradient has a logarithmic decay at distances to the wall larger than the position of the outer peak, a qualitative prediction that is also supported by the aforementioned data.

These results have been obtained by the addition of a new wavenumber range, but it also turns out that the spectrum in the original Townsend-Perry wavenumber range may not have the exact -1 spectral scaling that is responsible for Townsend's log law. On the basis of (i) Particle Image Velocimetry data of a Turbulent Boundary Layer with large field of view and good spatial resolution and (ii) a mathematical relation between the energy spectrum and specifically modeled flow structures, we show that the scalings of the streamwise energy spectrum in a Townsend-Perry wavenumber range directly affected by the wall are determined by wall-attached eddies but are not given by the Townsend-Perry attached eddy model's prediction of these spectra, at least at the Reynolds numbers considered here which are such that the ratio of the turbulent boundary layer thickness to the viscous sublayer thickness is or the order of 10,000. Instead we find a power law streamwise energy spectrum with exponent -1-p where p varies smoothly with distance to the wall from negative values in the buffer layer to positive values in the inertial layer. The exponent p characterises the turbulence levels inside wall-attached streaky structures conditional on the length of these structures. A particular consequence is that the skin friction velocity is not sufficient to scale the streamwise energy spectrum for wavenumbers directly affected by the wall.