General momentum theory for wind turbines at low tip speed ratios

General momentum theory is used to study the behaviour of the ‘classical’ free vortex wake model of Joukowsky. This model has recently attained considerable attention as it shows the possibility of achieving a power performance that greatly exceeds the Lanchester-Betz limit for rotors running at low tip speed ratios. This behaviour is confirmed even when including the effect of a centre vortex, allowing azimuthal velocities and the associated radial pressure gradient to be taken into account in the axial momentum balance without any simplifying assumptions. It is shown that the most likely explanation for the anomalous behaviour at small tip speed ratios is that the influence of the lateral component of pressure and friction is neglected in the axial momentum theorem. A refined model is proposed that remedies the problem of using the axial momentum theorem and by which the power coefficient never exceeds the Lanchester-Betz limit and which tends to zero at zero tip speed ratio. Copyright © 2010 John Wiley & Sons, Ltd.