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An ideal limit for the performance of a large, fully-developed wind farm P. LUZZATTO-FEGIZ, C.P. CAULFIELD, University of Cambridge — Wind turbines are often deployed in arrays of hundreds of units, where interactions lead to drastic losses in power output. Remarkably, while the theoretical "Betz" maximum has long been established for the output of a single turbine, no corresponding theory appears to exist for a generic, large-scale energy extraction system, although models exist for specific turbine designs and layouts. Recent work with vertical-axis turbines indicates that large performance gains may be achievable (Dabiri 2011), making the search for a theoretical upper bound even more compelling. We develop a model for an array of energy-extraction devices of arbitrary design and layout, first focusing on the fully-developed regime. When tailoring the model to reflect current designs, the predicted power output is in good agreement with field measurements. Furthermore, by considering a suitable ideal limit, we establish an upper bound on the performance of a large wind farm. This is found to be several times larger than the output of existing arrays, thus supporting the notion that performance improvements may be possible. Finally, we extend our model to include spatially developing flows, as well as to account for the effect of atmospheric stability, finding good agreement with laboratory and field data.

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