Synthetic Turbulence Generation for Turbine Modelling with BEMT

Michael Togneri, Ian Masters
School of Engineering, Swansea University, Swansea

Summary: This presentation examines methods of generating synthetic turbulence for use in blade element momentum theory simulations of tidal stream turbines. Two techniques are employed, both based on data gathered from field measurements. The first is a 'single-point' method, which generates a spatially-uniform but temporally-varying field, and the second is the synthetic eddy method (SEM) of Jarrin *et al*. [1,2], which generates a flowfield that varies in both space and time. This work is intended to help determine the best way to incorporate turbulence into BEMT models in order to capture its effects on turbine loads.

Methods

The single point method takes a large set of ADCP data, and for each bin of each beam breaks all the available data into several ten-minute subsets. From the spectra of these subsets, we determine average properties for each frequency and then randomly generate a synthetic spectrum based on these properties, which can be inversely transformed to obtain a synthetic time series for each bin. This can be repeated until the time series is as long as is desired.

This is a fairly straightforward procedure, but the principle drawback is that since the time series for each bin is generated individually, there is no correlation between neighbouring bins. Furthermore, since this effectively generates a synthetic ADCP record, we still have the usual problems of using an ADCP record i.e., we do not have a complete picture of the instantaneous velocity field at any point in space. To get a flowfield that is usable in a BEMT model we take a zero-averaged along-beam record and superimpose it on a mean longitudinal velocity to get a flowfield that varies in the longitudinal direction (equivalent to varying in time with the frozen turbulence hypothesis) but not in the lateral or vertical.

For the synthetic eddy method, we start by defining the region of space on which we want to generate a turbulent flowfield; for this study, this is taken to be the rotor plane. This is enclosed by a second, larger region we will call the 'eddy volume', a box whose limits are equal to those of the first region with the addition of a margin equal in size to the largest eddy we will simulate.

We generate N eddies to fill the eddy volume; eddy k has an associated position $\boldsymbol{x}^k$ and an intensity $\boldsymbol{c}^k$. The initial value of $\boldsymbol{x}^k$ is generated as a uniformly random point in the eddy volume. Each component of $\boldsymbol{c}^k$ is generated from the Cholesky decomposition of the Reynolds stress tensor, whose elements we denote a_{ij}, as $c_i^k = a_{ij}\varepsilon_j^k$ (using repeated index summation). ε_j^k here is a random variable whose value is distributed uniformly to ±1. With all positions and intensities defined, we can calculate each component of fluctuation velocity at a given point in space $\boldsymbol{x}$ by:

$$u_i'(\boldsymbol{x}) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N} c_i^k f_\sigma(\boldsymbol{x} - \boldsymbol{x}^k)$$

f_σ is the shape function of the eddy, which is compactly supported on $[-\sigma, \sigma]$ in all dimensions and is chosen such that its norm satisfies certain constraints. Once all eddies are generated and the resultant velocities evaluated for all desired points, we increment the time by convecting all eddies in the longitudinal direction according to the frozen turbulence hypothesis. Any eddies that are convected out of the downstream face box are recycled through the upstream face, with their lateral and vertical positions and ε_j^k-values randomly regenerated. With this scheme, we generate a turbulent flowfield whose autocorrelations and cross-correlations match the provided Reynolds stress tensor (or rather, would match for a simulation of infinite duration).

Sample results

In figure 1, we compare a real along-beam measurement with a synthetic one generated in a single-point fashion. It is clear that the behaviour of the synthetic data is very similar to that of the real data. When we extend this to bulk properties of the fluid, we see the same thing, as illustrated in the right-hand panel of figure 1 which compares real TKE density profiles with one obtained from a synthetic ADCP data set generated in the manner described above. Figure 2 illustrates results obtained using the SEM method to generate a turbulent flowfield by comparing the input profiles of R11, R22 etc., with the resultant mean profiles from 25 different synthetic flowfields.

Acknowledgements:

This work was undertaken as part of the Low Carbon Research Institute Marine Consortium (www.lcrimarine.org.uk), and as part of SuperGen UK Centre for Marine Energy Research (UKCMER). The authors wish to acknowledge the financial support of the Welsh Assembly Government, the Higher Education Funding Council for Wales, the Welsh European Funding Office and the European Regional Development Fund Convergence Programme. The authors would also like to acknowledge the support of EPSRC through grant EP/J010200/1, which funds the UKCMER project.

References:

[1] Jarrin, N., Benhamadouche, S., Laurence, D., Prosser, R. (2006). A synthetic-eddy method for generating inflow conditions for large-eddy simulations. *Int. J. Heat and Fluid Flow*. **27** 585-593

[2] Jarrin, N. (2008). Synthetic Inflow Boundary Conditions for the Numerical Simulation of Turbulence. Ph.D. thesis, University of Manchester.

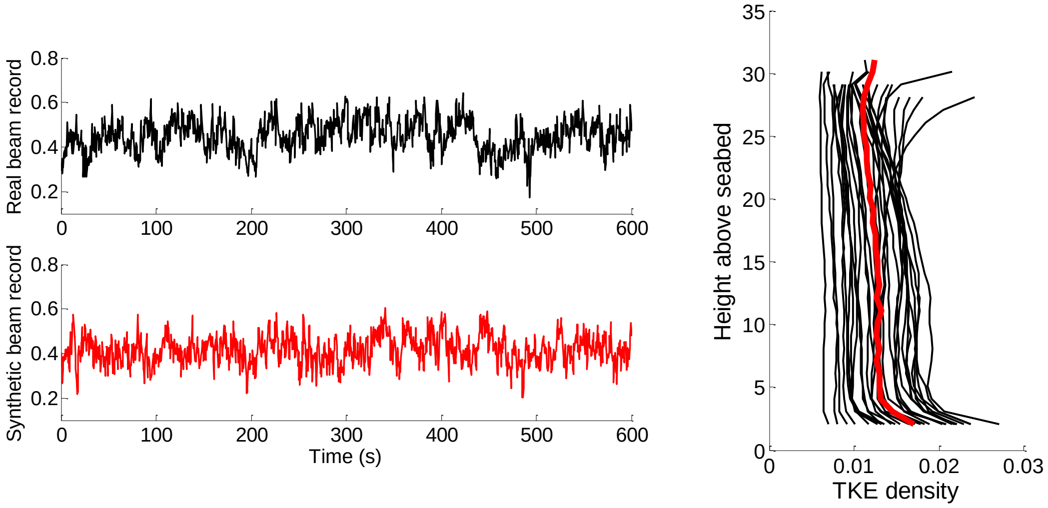

Fig. 1: Left-hand panel shows sample real along-beam velocity record (top, black) and sample synthetic record (bottom, red). Right-hand panel compares real TKE density profiles (black) with synthetic profile generated based on the same data. All real data taken from EMEC test site.

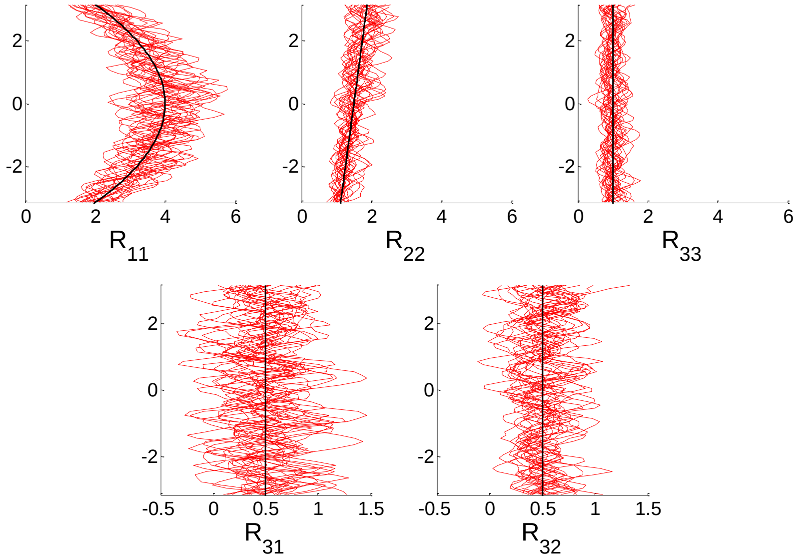

Fig. 2: Comparison of mean profiles of synthetic autocovariances and cross-covariances for 25 different flowfields (in red) generated using the SEM with the input covariance profiles (in black)