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SIMULATION OF FLUCTUATING AIRWAKE VELOCITY OVER THE FLIGHT DECK OF AN FFG-7 FRIGATE

Lincoln P. ERM and Neil E. GILBERT

Air Operations Division, Aeronautical Research Laboratory, DSTO
506 Lorimer St, Fishermens Bend, VIC 3207, AUSTRALIA

ABSTRACT

Using full-scale airwake measurements, deficiencies in a computer simulation model representing the airwake over the flight deck of an FFG-7 class frigate are demonstrated. To improve the representation of the fluctuating velocities, a suitable method is proposed in which an autoregression-moving-average (ARMA) analysis is used. The process, which involves curve fitting the ARMA model to full-scale measured spectra, is shown to give a simulated velocity trace of similar characteristics to the original measurement trace.

1. INTRODUCTION

The Royal Australian Navy (RAN) is currently operating the Seahawk helicopter aboard the FFG-7 class of frigate and is planning to operate the aircraft from the new ANZAC light frigate based on the Meko 200. Considerable uncertainties exist about the flight mechanics problems likely to be experienced, as well as criteria for establishing the take-off and landing flight envelope. Undertaking trials for each aircraft/ship combination and for a large range of take-off and landing conditions is a costly exercise. These practical limitations make the supplementation of information by the use of mathematical representation an attractive proposition. Computer modelling of the helicopter/ship dynamic interface is therefore being undertaken at ARL to provide the RAN with support for operations. The main computer code being used to do this is a Seahawk/FFG-7 simulation code based on one acquired from the US Naval Air Warfare Center Aircraft Division at Patuxent River (previously known as the Naval Air Test Center).

The Seahawk/FFG-7 simulation code is comprised of a number of different modules, each of which deals with a different aspect of the simulation. These have been discussed in detail by Arney *et al.* (1989, 1991).

The helicopter behaviour during approach and landing is strongly influenced by the prevailing flow field in the wake of the FFG-7 superstructure. This flow field is modelled in the code by the Turbulence and Ship Wind Burble (Ship Burble) Module, and to assess whether the module accurately represented the real flow, it was necessary to study it in detail.

2. SHIP BURBLE MODULE

The Ship Burble Module predicts ambient atmospheric turbulent velocities as well as incremental burble velocities resulting from the FFG-7 superstructure, and these velocities are combined to give the total simulation velocities. Velocities are predicted for the longitudinal, lateral, and vertical ship-coordinate directions.

Mean-flow velocities for the atmosphere are determined by simply resolving the chosen atmospheric mean wind velocity into the above three directions. The calculation of turbulent velocities for the atmosphere is not as straightforward due to the difficulty of defining instantaneous turbulent velocities. The problem of incorporating fluctuations into the turbulent velocities is overcome by the use of random-number-dependent noise terms in the equations.

Mean-flow and turbulent incremental burble velocities for the FFG-7 are determined using a data base of tabulated numbers within the code. The data base is obtained from Fortenbaugh's (1978) airwake model, which utilises Garnett's (1976) wind-tunnel measurements taken on a 1/50 scale model of an FF-1052 class frigate. Geometric scaling is used in the Seahawk/FFG-7 code to make the measurements for the FF-1052 applicable to the FFG-7. The validity of applying the geometric-scaling technique is questionable, since the shapes of the FF-1052 and the FFG-7 are markedly different. Once again, random-number-dependent noise terms are used when determining turbulent velocities.

It is important to note that possible fundamental deficiencies exist within the code. The total simulation velocities are only calculated for the centre of gravity of the helicopter and it is assumed that such velocities exist over the entire helicopter. Since the dimensions of the helicopter are not insignificant compared with the ship and burble dimensions, then such a simplification is a major limitation of the simulation procedure. No account is taken of the effects on helicopter behaviour of non-uniform velocity distributions over the rotor blades. In the future it will be desirable to alter the code to take account of variations in velocity over the main rotor disk. It is anticipated that a blade-element type of rotor model will be incorporated into the code to replace the actuator-disk model currently used. It is also noteworthy that the resultant flow field is determined by linearly superimposing predicted velocities with those created by the helicopter.

Although the Seahawk/FFG-7 code contains a number of deficiencies that may have to be addressed, as outlined above, an initial step in developing the code was to assess the accuracy of predicted velocities by comparing them with actual measurements. The experimental programs used to obtain such measurements are first described.

3. FULL-SCALE AND WIND-TUNNEL TESTS

Full-scale velocities have been measured on an FFG-7 frigate (Arney *et al.* 1991) using an array of nine Gill anemometers mounted on a moveable mast. The anemometers were mounted so as to measure the vertical, lateral, and longitudinal ship-coordinate velocities at 3.2 m, 6.4 m, and 9.6 m above the flight deck. The anemometers have a frequency response of about 2.5 Hz at about 16 m/s, enabling them to measure the frequencies of importance in the fluctuating flow field over the flight deck. There were 13 mast positions on the flight deck.

Wind-tunnel measurements have been recorded in the 2.74 m by 2.13 m low-speed wind tunnel at ARL using a 1/64 scale model of an FFG-7 frigate. The measurements were for a free-stream velocity of 50 m/s for seven angles of yaw of the ship, viz. 0^o, 15^o, 30^o, 60^o, 90^o, 135^o, and 180^o, for zero pitch and roll angles of the ship. The atmospheric turbulent boundary layer upstream of the ship was not modelled.

All measurements were based on a rectangular cartesian coordinate system that was fixed with respect to the wind tunnel. The origin for measurements was at the level of the flight deck at the mid point of the plane of the hangar doors. The extent of the burble in the three directions varied depending on the particular angle of yaw of the ship, and the extremities of the measurements in the different cases were chosen to include parts of the burble likely to be encountered by the helicopter during approach and landing.

A rake of yaw probes (Toffoletto, 1992) was used to measure three-dimensional mean-flow velocities at the different locations around the ship model. The rake contains eight similar probes spaced at intervals of 50 mm, and on each probe tip there are five orifices No wind-tunnel turbulence measurements around the ship have been taken.

4. COMPARISON BETWEEN PREDICTED AND FULL-SCALE VELOCITIES

Predicted velocities are compared with full-scale velocities, rather than wind-tunnel velocities, since full-scale velocities contain turbulence components. Predicted and full-scale velocities, U, V, and W, for three coordinate directions, are shown superimposed in Fig. 1 for an 18 m/s (35 kn) relative wind at 30° off the starboard bow and for a height of 6.4 m above the bullseye. The full-scale velocities shown have not been corrected for the effect of ship motion, but this was very small for this flow case.

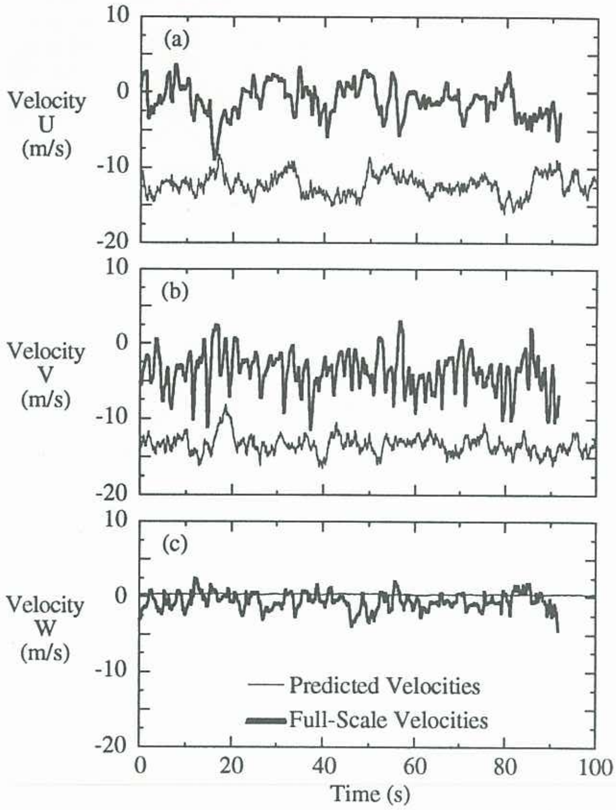

Fig. 1 Comparison between predicted and full-scale velocities 6.4 m above the bullseye for an 18 m/s relative wind at 30° off the starboard bow

From the comparisons it is apparent that there are some large differences between predicted and full-scale horizontal velocities. Other comparisons not included here also indicated large discrepancies. This suggests that the data in the data base in the simulation program are inaccurate. Healy (1992), among others, has also demonstrated the inadequacies of the Fortenbaugh data base, supporting his conclusion with limited three-dimensional hot-wire measurements in wind-tunnel tests on a 1/141 scale model ship in a simulated atmospheric boundary layer. It is likely that further discrepancies have arisen through 'tweaking' of the model for use in a simulator.

Spectra corresponding to the velocities shown in Fig. 1 are shown superimposed in Fig. 2. The spectra for predicted and full-scale velocities are both based upon 1024 data points, but the frequency range covered by the spectra in the two cases is slightly different due to the different time intervals used. The simulation code computes velocities every 0.0666 (1/15) s, whereas full-scale velocities were measured every 0.05 s. The spectra shown have been smoothed using a Blackman (1965) window. Power spectral densities, S_u, S_v, and S_w, are larger for the full-scale velocities, and this is particularly evident for the vertical components of velocity. Since spectra depend upon fluctuating components of velocity, the discrepancies suggest that the method used in the code to compute turbulence velocities is inadequate.

Since the above checks showed some large differences between predicted and full-scale velocities and their corresponding spectra, it was considered necessary to replace the existing model with one that produced velocities in closer agreement with the measurements.

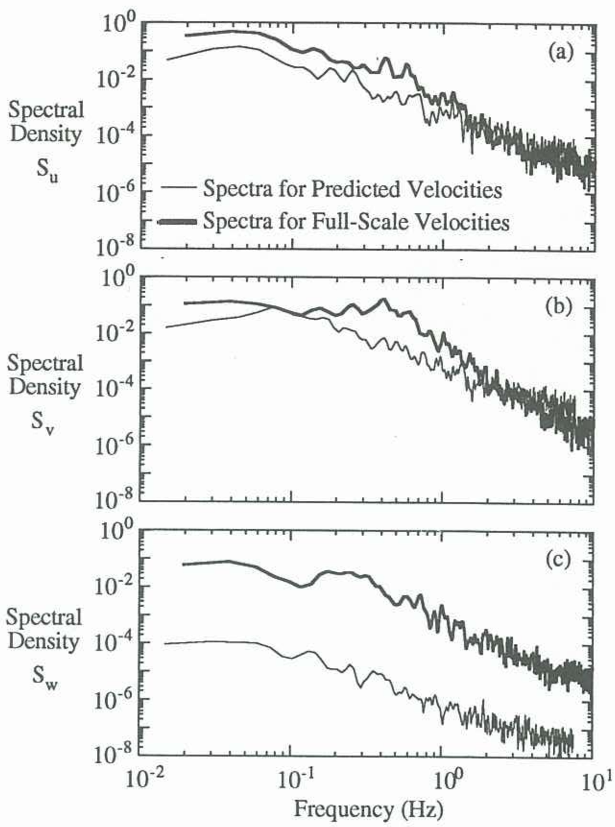

Fig. 2 Comparison between spectra corresponding to velocities shown in Fig. 1

5. AIRWAKE MODEL

In deriving a new airwake model, it is anticipated that the full-scale measurements will be the primary source of data over the flight deck and that the wind-tunnel measurements will be used to model the region outside this area to determine the extent of the burble. Because of likely discrepancies in overlapping areas, the tunnel measurements will need to be merged suitably. The wind-tunnel measurements give only mean-flow velocities and hence only full-scale measurements can be used to determine the fluctuating velocities. Another limitation with the tunnel measurements is that the yaw probe could not be used to measure mean velocities if the incident flow on the probe was outside an angle of about 30° (Toffoletto, 1992). Because there were large variations in the direction of the mean flow (even reversed flow) above the flight deck, there were substantial regions where velocities were not measured by the probe. As part of the model development process, the purpose here is to present the method for determining the fluctuating, or turbulent, component of the burble, and then to apply the method to a representative sample of the data. Only when the method has been applied to a wider range of data samples can possible generalisations be made about how the representation varies with spatial location and free-stream velocity conditions.

5.1 Analysis Method

Turbulent airwake velocities are modelled using an auto-regression-moving-average (ARMA) method of analysis (see Box and Jenkins, 1970; Sherman, 1978). In the method, a fluctuating quantity such as a velocity can be represented by

$$u(t) = -\beta_1 u(t-1) - \beta_2 u(t-2) - \beta_3 u(t-3) - \ldots + \varepsilon(t) + \alpha_1 \varepsilon(t-1) + \alpha_2 \varepsilon(t-2) + \ldots \quad (1)$$

where u is a velocity fluctuation about a mean, t is time, the α and β terms are coefficients having constant values, and the ε terms are Gaussian-distributed random numbers. The velocity at a given time instant depends upon the velocity at previous instants, as well as upon random numbers at the given and previous instants.

According to the ARMA method of analysis, the power spectral density, S, of the fluctuating signal is given by

$$S = \left| \frac{1 + \alpha_1 Z + \alpha_2 Z^2}{1 + \beta_1 Z + \beta_2 Z^2 + \beta_3 Z^3} \right|^2 \frac{\sigma^2}{N} \quad (2)$$

where Z is a complex number given by $Z = e^{-2\Pi in/N}$, N is the number of data points used to define the fluctuating velocity trace (chosen to be 1024), and n is an integer varying between 0 and N/2 - 1. The discrete frequencies, f, defining the spectrum are related to the values of n by the relationship $f = n/(\Delta_t N)$, where Δ_t is the time interval between successive data points on the velocity trace. The variable σ^2 is the variance of the random numbers.

5.2 Practical Application of Method

For a given measured velocity trace, a spectrum is first determined. The ARMA model given by Eq. 2 is then curve fitted to the spectrum. The α and β coefficients of this ARMA spectrum are then used in Eq. 1 to generate an ARMA simulated velocity trace.

The technique used to simulate turbulent velocities is applied here to the longitudinal component of full-scale velocity shown in Fig. 1. The fluctuating component of the velocity and its spectrum are shown in Figs 3 and 4 (spiky spectrum denoted as S1 in Fig. 4). The ARMA spectral equation (Eq. 2) has been curve fitted to this spectrum and the curve-fitted spectrum is also shown in Fig. 4 (smooth spectrum denoted as S2). The curve fitting was limited to frequencies below the anemometer frequency response of 2.5 Hz.

Using the coefficients obtained from the curve fitting, a simulated velocity trace was determined using the ARMA velocity relationship (Eq. 1) and this trace is shown in Fig. 5. This velocity trace is markedly different in character from that shown in Fig. 3 since it contains frequencies greater than 2.5 Hz. To filter out unwanted high-frequency signals, the trace is smoothed using a seven-point triangular smoothing process (Blackman and Tukey, 1958).

The smoothed trace shown in Fig. 6 appears similar in character to the original trace being simulated in Fig. 3. To verify the similarity, a spectrum of the smoothed trace (S4) is compared in Fig. 7 with the spectra shown in Fig. 4 (S1 and S2). The spectrum corresponding to the unsmoothed trace (S3) is also shown. A comparison between S3 and S4 clearly indicates the filtering effect of the seven-point triangular smoothing. For this smoothing, the spectral densities of the different frequencies are not attenuated equally, and the bends in S4 at about 5 Hz and 7 Hz (7 Hz not clearly visible) are expected. Despite the triangular smoothing, S4 still shows reasonably good agreement with S1 and S2 up to 2.5 Hz.

Having demonstrated the process for a measurement trace at a single location, a first step in a generalisation process is to use a mean spectrum to derive a single ARMA model that can be used at a number of locations (for a constant height) above the flight deck. The use of a mean spectrum simplifies the modelling of fluctuating velocities.

Families of full-scale spectra for three coordinate directions for the conditions shown in Fig. 1 for a height of 6.4 m above the flight deck and corresponding to 13 mast locations are shown in Fig. 8. Considering only spectra for the longitudinal components of velocity, shown in Fig. 8a, a mean spectrum was calculated and this is shown in Fig. 9 (spiky spectrum). This spectrum was analysed using the procedure described above for the single trace, and Figs 9, 10, and 11 correspond to Figs 4, 6, and 7 respectively. The unsmoothed velocity trace, corresponding to Fig. 5, is not shown here, but

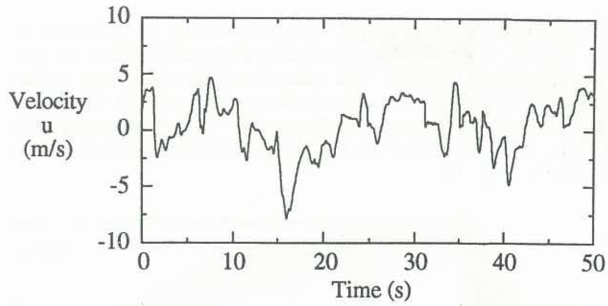

Fig. 3 Turbulent component of longitudinal full-scale velocity for conditions shown in Fig. 1

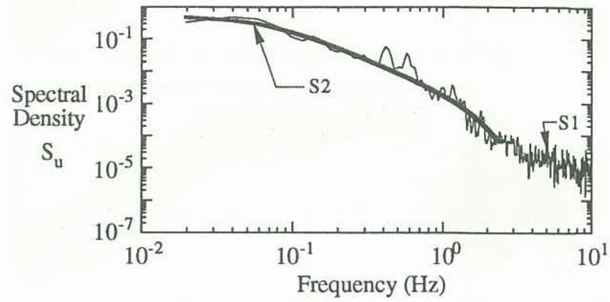

Fig. 4 Spectrum corresponding to velocity trace given in Fig. 3 and curve-fitted ARMA spectrum

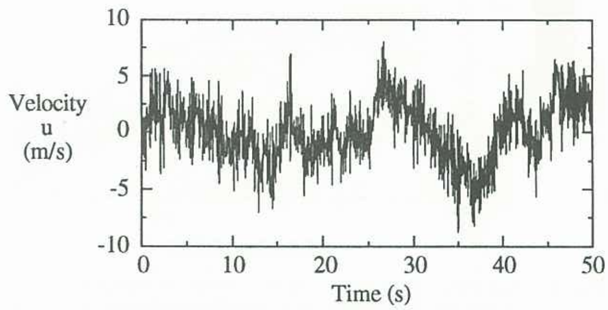

Fig. 5 Unsmoothed velocity trace from ARMA coefficients associated with curve-fitted spectrum in Fig. 4

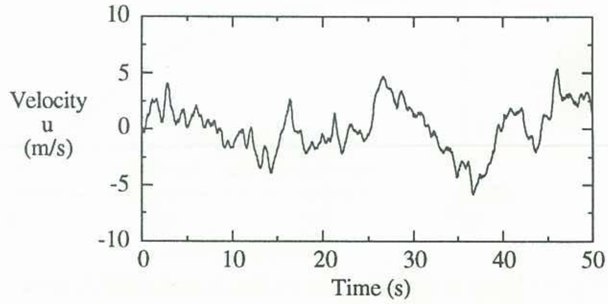

Fig. 6 Velocity trace of Fig. 5 after filtering using seven-point triangular smoothing

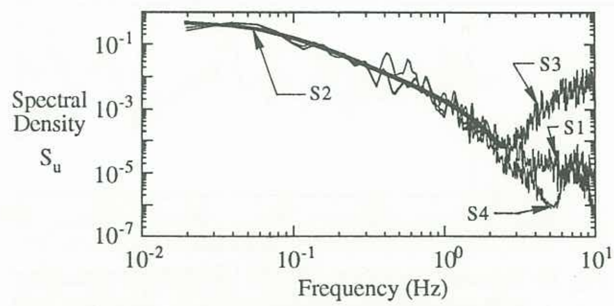

Fig. 7 Spectra shown in Fig. 4 superimposed with spectra corresponding to velocity traces given in Figs 5 and 6

the spectrum associated with it is given in Fig. 11. Discussion on Figs 9, 10, and 11 is similar to that used earlier for the corresponding figures. The use of a mean spectrum in the analysis means that, for the conditions chosen, the simulated longitudinal fluctuating velocities at the 13 mast locations for a height of 6.4 m above the flight deck correspond to the trace shown in Fig. 10.

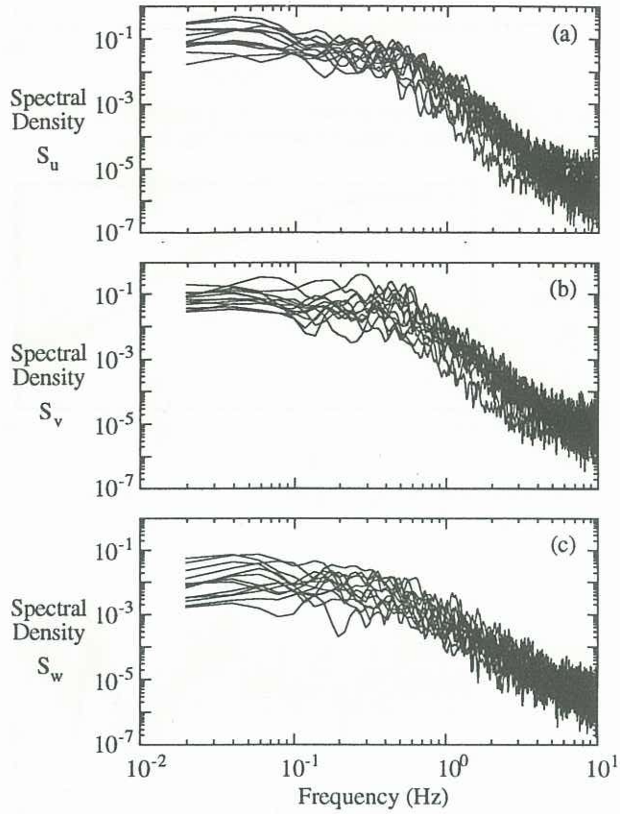

Fig. 8 Families of spectra for full-scale velocities 6.4 m above the flight deck for conditions shown in Fig. 1

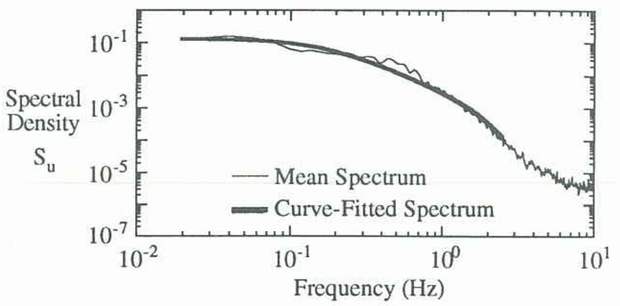

Fig. 9 Mean of spectra given in Fig. 8a and ARMA curve-fitted spectrum

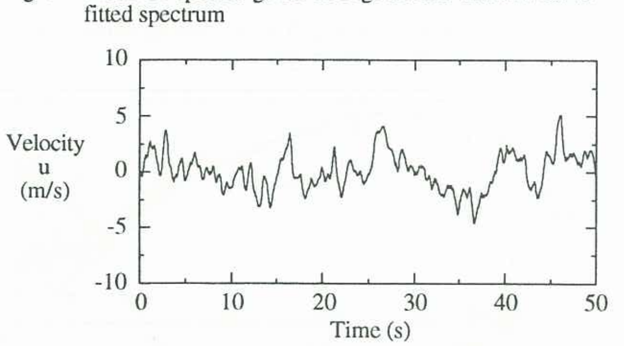

Fig. 10 Velocity trace from ARMA coefficients associated with curve-fitted spectrum in Fig. 9. Trace has been filtered using seven-point triangular smoothing

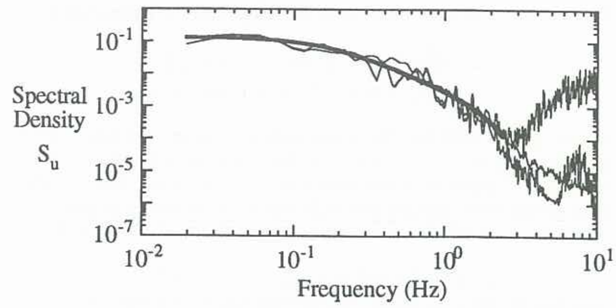

Fig. 11 Spectra shown in Fig. 9 superimposed with spectrum corresponding to the velocity trace given in Fig. 10 and that of the associated unsmoothed trace

6. CONCLUDING REMARKS

Having first demonstrated the deficiencies in the airwake model of an existing Seahawk/FFG-7 simulation code, a suitable method using an ARMA model has been proposed to more accurately represent the fluctuating components of the velocities. As a simplification, fluctuating velocities at a given height above the flight deck at a number of locations and for given operating conditions have been simulated using an ARMA model with a single set of coefficients. More work needs to be done to determine the extent of further generalisation possible, particularly in regard to various wind conditions. Work also needs to be done to determine a suitable representation for mean-flow velocities.

It should be realised that even when a more accurate representation of the airwake is determined, there will still be a number of remaining deficiencies. In particular, an immersed rotor disk will significantly influence the flow field in most commonly encountered flow conditions. Also, the existing actuator-disk model needs to be replaced by a blade-element model so that account is taken of variations in the velocity over the rotor disk.

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