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# Developments in Blade Element/Momentum Theory for Horizontal-axis Wind and Hydrokinetic Turbines

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## Abstract:

Blade element/momentum theory (BEMT) is the basic tool of turbine aerodynamics that is used extensively in multidimensional blade optimization and aeroelastic codes for complete turbine analysis. BEMT balances the lift and drag exerted on a section of a blade – called a blade element – and the axial and angular momentum changes to the streamtube flowing over the element. All applications of BEMT thus require the relationship between the velocities at the blades and the streamtube averages. This relationship is often computed via Prandtl's "tip loss function" which is accurate only for straight, unconed, equispaced and aerodynamically equal blades operating at high tip speed ratio (TSR). This presentation will describe recent, mostly unpublished, work to extend the applicability of BEMT to cases including:

1. Swept and coned rotors. Sweep is the displacement of the blade's aerodynamic centre in the plane of rotation. Coning is the movement of the blade out of the radial plane of rotation which is becoming an important issue as blades become larger and more flexible.

2. Optimal blade design at low TSR. The optimal loading on a rotor changes significantly with TSR making the optimization of blade design more challenging at low TSR. This work is an extension of Wood & Hammam (2022).

3. Rotors with unequally-loaded blades. Blade erosion, and the effects of wind shear etc make the loading on the blades unequal but the proper aerodynamic characterization of this inequality has only recently been addressed.

4. Turbines in their high-thrust region where an additional term for the thrust equation has been identified and tested against wind tunnel measurements. The extended BEMT has the potential to be a significant improvement on the current ad hoc modifications to BEMT in the high-thrust region, Wood& Golmirzaee (2023).

## References:

Wood DH and Hammam MM (2022), Optimal performance of actuator disc models for horizontal-axis turbines. *Front. Energy Res.* 10:971177.
Wood, D H, & Golmirzaee, N A, (2023) Revision of Blade Element/Momentum Theory for Wind Turbines in their High-Thrust Region. *Front. Energy Res*, 11, 1256308.