Aerodynamic characteristics prediction of HAWT blade S809 airfoil using coupled potential theory of wing sections and boundary layers calculation

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Abstract:

The industrial development based on the massive use of fossil fuels has led to an ecological imbalance and to a depletion of natural energy resources. This energy and ecological deficit has given the first important start to renewable energy, in particular wind energy. Therefore, many countries have begun their investigation in wind power generators. Also, several National Institutes such as NREL (USA), ECN (Netherlands), and Riso (Denmark) have conducted many studies in this area.

Predicting the HAWT blades loads accurately is one of the most important parts of the wind turbine aerodynamics calculation, and is based on an accurate evaluation of the aerodynamic coefficients and of the upstream velocity field. However, these aerodynamic loads estimations remain a complicated task to perform due to the complex nature of the flow around the blades, and to their cyclical fluctuations, which can be a significant source of fatigue and vibration, resulting from the yaw, stall or turbulent conditions where the HAWT operate mostly.

The main aim of this paper is to develop a sophisticated numerical procedure that can predict aerodynamic coefficients without using great amounts of computer time.

The problem of interest in the first part of the present work is to calculate the air flow around S809 airfoil, the classical assumption of irrotational flow is adopted, the 2-D pressure potential coefficients and the pattern flow calculations, at the surface of the S809 airfoil for any orientation, were made using the potential theory of arbitrary wing sections and Prandtl-Glauert, Karman-Tsien and...
Laitone's compressibility corrections. The two-dimensional aerodynamic coefficients were estimated, for the S809 potential-flow wind-turbine airfoil, from the pressure distribution.

This paper gives an exact solution of the problem of theoretical flow of a frictionless incompressible fluid past S809 airfoil. A numerical method is presented, aimed at determining the velocity of the 2-dimensional flow for any point at the surface of the S809 airfoil. From this pattern flow, the pressure distribution around the airfoil is obtained thanks to the Bernoulli's relation for any orientation and for any Reynolds number. Comparisons of the computed aerodynamic coefficients has been made with wind tunnel data from the Delft University 1.8m×1.25m low turbulence wind tunnel, from the Ohio State University Aeronautical and Astronautical Research Laboratory 3m×5m subsonic wind tunnel and also from the Colorado state university environmental wind tunnel 3.66m×1m.

Aerodynamic coefficients computed from the pressure distribution can not take account of the effects of skin friction, since only the pressure normal to the surface is predicted. Therefore, we found that they differ somewhat from the directly measured aerodynamic coefficients, especially in the case of the drag component, which is mainly due to shearing stresses at the airfoil surface.

The aerodynamics problem of interest in the second part of the present work is to estimate the skin-friction drag component of force acting on an airfoil in a uniform viscous stream. The Navier-Stokes equations were reduced, for analyzing the boundary layer flows, to the continuity equation and to the streamwise momentum balance, which could be used to derive the Von Karman momentum integral equation. This last, is resolved according to the flow regime, laminar or turbulent, for estimating the skin-friction drag coefficient.

Numerical solutions of the momentum integral equation were found by using the Thwaites' method for the laminar boundary layer, and the Head's method for the turbulent boundary layer. The shape factor was evaluated, for laminar and turbulent regions, by the Cebeci and Bradshow semi-empirical formulas. The turbulent closure method required an additional semi-empirical relationship, in this work, the Ludwieg-Tillmann empirical formula for skin-friction coefficient evaluation is used.

The phenomenon of flow transition from laminar to turbulent flow governed by the viscous effects are investigated, the onset of transition was determined by using Cebeci-Smith relation based on the Michel's criterion, and is incorporated into the viscous formulation. And the boundary layer separation point location is determined from the shape factor.

The numerical model developed, for estimating aerodynamic characteristics of Horizontal-axis wind turbine blade S809 airfoil, is based on a strong viscous-inviscid interaction technique using the blowing velocity concept which employs both the displacement thickness and the edge velocity distribution. The numer-
ical results have been benchmarked against experiments for different angle of attack and Reynolds numbers, and generally a good agreement is obtained. A complete computer code package for simulation was developed to obtain accurate numerical values in acceptable computational time.

**Keywords**: Wind turbine, Renewable energy, Potential theory, Boundary layers, Transition prediction, Separation point, Aerodynamic coefficients, S809 airfoil.

**References**


