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The Effect of Rotor Blade Shape on the Performance of the Wells Turbine

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ABSTRACT

This paper presents an experimental investigation into the effect of blade section on the performance of the Wells turbine. The blades tested included 2 sets of symmetrical constant chord blades: one set had standard NACA 0015 blades, whilst the other had optimized blades. The aim of the experiments was to investigate and compare the aerodynamic performance of the NACA 0015 and the optimized blades for 2 different rotor solidities.

INTRODUCTION

The Wells turbine is an axial-flow self-rectifying air turbine designed to extract energy in ocean-wave energy devices, particularly the oscillating water column. Like most other turbines, the Wells turbine is sensitive to the angle of the relative airflow approaching the blades. For high flow rates, the operational range of all fixed-pitch configurations is limited by the flow stalling around the rotor blades, culminating in a loss of torque in the turbine rotor (Raghunathan, 1995).

When designing a Wells turbine rotor for wave energy applications, then, one of the main points to consider is the maximization of the range of sea conditions during which the turbine can operate efficiently (Curran et al., 1997). A numerical method for optimizing symmetrical profiles was proposed (Gato and Henriques, 1996) aiming at the extension of the Wells turbine's operating range for large flow rates. The basic idea behind the method is to control the shape of the pressure distribution around the turbine rotor blade sections, so as to postpone blade stall. This study indicated that optimization of the blade profiles could significantly delay the onset of separation. A Computational Fluid Dynamics (CFD) study of numerically optimized 2-dimensional Wells turbine blade profiles (Thakker et al., 1997) reached the same conclusion. Fig. 1 shows the NACA 0015 section and the optimized HSIM 15-262123-1576 profile. This figure shows how the design method moves the maximum thickness position of the modified profile towards the leading edge, with a consequent leading-edge radius increase when compared with the NACA 0015 airfoil. The theoretical performance of the optimized blade and the resultant blade shape are fully described in Gato and Henriques (1996).

This paper presents an experimental investigation into the effect of rotor-blade section optimization on the performance of the Wells turbine. The model tested included 1 set of 8 symmetrical constant chord NACA 0015 blades, 1 set of 8 symmetrical HSIM 15-262123-1576 blades, and 2 rotor solidities. The tests were conducted under unidirectional steady flow in a test facility that had previously been utilized for investigation of the Wells turbine's aerodynamic performance (Gato et al., 1996; Gato and Curran, 1997; Webster and Gato, 1999).

The aim of the present experiments was to investigate and compare the aerodynamic performance of the NACA 0015 and the optimized blades for 2 different rotor solidities. The measurements included flow rate, pressure drop, torque and rotor speed. Traversing work with the aid of a directional total-static pressure probe yielded more detailed information on the performance of each set of rotor blades.

EXPERIMENTAL RESULTS

A detailed description of the test rig, the instrumentation and the experimental technique is given in Webster and Gato (1999). The geometric data for the rotors and blades used are as follows: outer casing diameter $2R = 590$ mm; inner to outer diameter ratio of 0.68; number of blades (solidity) 8(0.64) and 4(0.32); blade profile NACA 0015 and HSIM 15-262123-1576; blade sweep of 0°; blade stagger equal to 90° and blade chord $c = 125$ mm.

All performance tests were carried out at constant rotational speeds of 2500 rpm, 2000 rpm and 1500 rpm, under steady state conditions, i.e. Reynolds number $(\rho \omega R c)/\mu = 6.5 \times 10^5$, 5.2×10^5, and 3.9×10^5, and Mach number $(\omega R)/a = 0.23$, 0.18 and 0.13, respectively, based on a tip blade radius, R. Here ρ is the fluid density, μ the viscosity, ω the rotor angular speed, c the blade chord and a the speed of sound.

A comparison between the NACA 0015 and optimized HSIM 15-262123-1576 bladed rotor performances (both without guide vanes) is presented in Figs. 2 and 3. The figures show dimensionless plots of the experimental obtained values for efficiency, $\eta = T\omega / (Q \Delta p_0)$, and torque, $T^* = T / (\rho \omega^2 R^5)$, against flow rate coefficient, $U^* = U / (\omega R)$, for high and low solidity rotors. Here Q is the volume flow rate and U the inlet flow (average) velocity.

As predicted from wing theory, for stall-free flow conditions the damping ratio $(\Delta p_0^* / U^*)_{\eta = \eta_{\max}}$ (of the approximately rectilinear characteristic of $\Delta p_0^* = \Delta p_0 / (\rho \omega^2 R^2)$ versus U^*) achieved by HSIM bladed rotor is similar to that obtained with the NACA 0015 rotor turbine (Fig. 2). Whilst the NACA 0015 blades start having a positive value of efficiency and thus produce power at a

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