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THE AERODYNAMIC CONTROL OF THE 'V' TYPE VERTICAL AXIS WIND TURBINE BY BLADE TIP CONTROL

SYNOPSIS

This paper presents results of wind tunnel tests carried out on a small V-type Vertical Axis Wind Turbine (V-VAWT). This model wind turbine was specifically designed to study the effect of tip area and tip pitch on the performance of this novel vawt. The results have demonstrated that tip pitch is highly suitable for overall control of the V-VAWT and that tip areas as little as 5% of the total blade area could provide both power regulation and overspeed control. While it has not been possible to match the predicted performance data directly to these tests results, the computer model VAWTTAY6 can be used with some confidence to predict the performance of larger sized V-VAWTs.

1 INTRODUCTION

The V-type Vertical Axis Wind Turbine, conceived by Derek Taylor at The Open University, has been described at a number of international wind energy and solar energy conferences [1-4].

The development of the V-VAWT concept has concentrated on the enhancement of Sharpe's aerodynamic performance prediction model VAWTTAY6, the verification of this model with data from wind tunnel tests of small V-VAWTs and the design and construction of a 5kW free-air wind turbine. The 5kW V-VAWT has recently been erected on the Appropriate Technology Group's field test facility at The Open University, but only preliminary evaluation of the performance of this machine has been conducted.

This paper will consider the aerodynamic control methods that have been perceived as suitable for rotor power control and overspeed protection of a medium sized V-VAWT, and will compare the predicted performance and measured performance of a small V-VAWT with pitchable blade tips, Fig 1.

2 AERODYNAMIC PERFORMANCE PREDICTION

The aerodynamic performance of the V-VAWT is modelled using the computer program VAWTTAY6, which embodies Sharpe's extended multiple streamtube theory [5]. The predictions using VAWTTAY6 have been verified by wind tunnel tests with model V-VAWTs undertaken at Queen Mary College, London [2].

3 POWER REGULATION AND OVERSPEED CONTROL

All wind turbines, whether they be of horizontal axis or vertical axis configuration, require some form of power regulation and overspeed protection, either actively or passively activated and the V-VAWT is no exception.

Blade tip control has been extensively used on horizontal axis wind turbines of all sizes and has proven to provide power regulation and overspeed control. However the only vertical axis machine known to the authors employing such control is the recently developed Westwind 75kW wind turbine; an 'H'-type VAWT with two blades of fixed pitch but with moveable tips at both ends of each blade.

Blade tip control is also considered highly suitable for the V-VAWT, but the tip device known as the T-brake [4] has a number of structural advantages and because of its simplicity is favoured for the 5kW free-air V-VAWT. However, in order to assess the potential of tip pitch control, a wind tunnel sized V-VAWT with moveable tip portions was constructed and its performance evaluated at Queen Mary College.

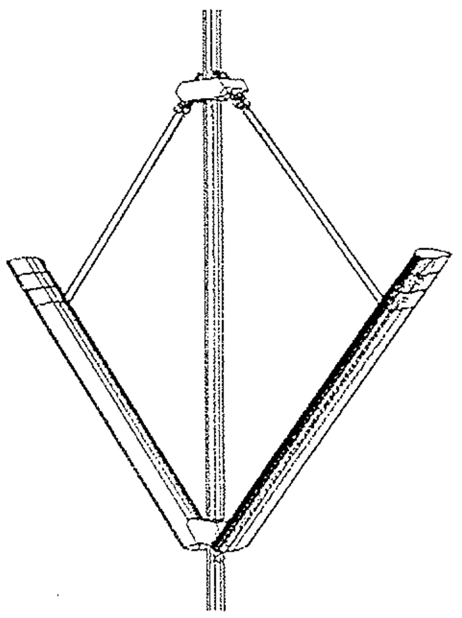

Figure 1: General view of model V-VAWT with pitching tips

3.1 Wind tunnel test model and testing technique

A two-bladed model V-VAWT of tip diameter 940mm was constructed to assess the potential of tip pitch control. Each blade was 615mm in length, with a uniform chord of 80mm. For strength the blades were of a NACA0025 aerofoil cross section and were made from English Ash encapuslating a high tensile aluminium spar for rigidity. Each blade was held to the hub at the 30% chord, inclined at 45 degrees to the vertical and supported by a pair of cables attached 115mm from the tip.

Additionally, each blade had three moveable tip portions, the area of each measuring 5% of the total blade area. The pitch angle of each tip portion was adjustable and could be pre-set with either positive, 'nose-in' pitch or negative, 'nose-out' pitch. The position of each tip portion was locked by two grubscrews that were accessible through the leading edge. During tests, the access holes were filled with plasticene and covered with vinyl tape to restore the leading edge profile. Using this model, the effect of variation of tip pitch on overall performance for tip areas of 5%, 10% and 15% of the total blade area on overall turbine performance has been studied.

The model V-VAWT was tested in the blowdown wind tunnel at Queen Mary College using the acceleration method [6], which is a simple and quick method for determining the complete Cp-lamda characteristic of the turbine.

The test results have been corrected for cable drag and bearing friction, both of which were measured separately. Cable drag is the most significant of these parasitic losses and was measured in a manner previously described [2]. Corrections for wind tunnel blockage have not been included because the experiments were conducted in an open jet tunnel.

The rotor would only accelerate to a rotational speed where the torque being developed by the turbine was equal in magnitude to the parasitic drag losses from the cables and the bearings. In order to obtain performance data for rotational speeds greater than this equilibrium speed, it was necessary to drive the turbine via a friction contact with an electric motor. When the motive power was released, the deceleration of the turbine was measured. This technique allowed measurement of rotor torque over a greater range of tip speed ratios and tip pitch settings.

All tests were conducted at an average Reynold's Number of approximately 2-300000 which is much lower than the operating Reynold's Numbers of larger-sized, free-air machines. The consequence of testing at such low Reynold's Numbers is discussed below.

3.2 Wind tunnel test results

Some of the results from this series of tests are presented in figures 2-6. Figures 2-4 show

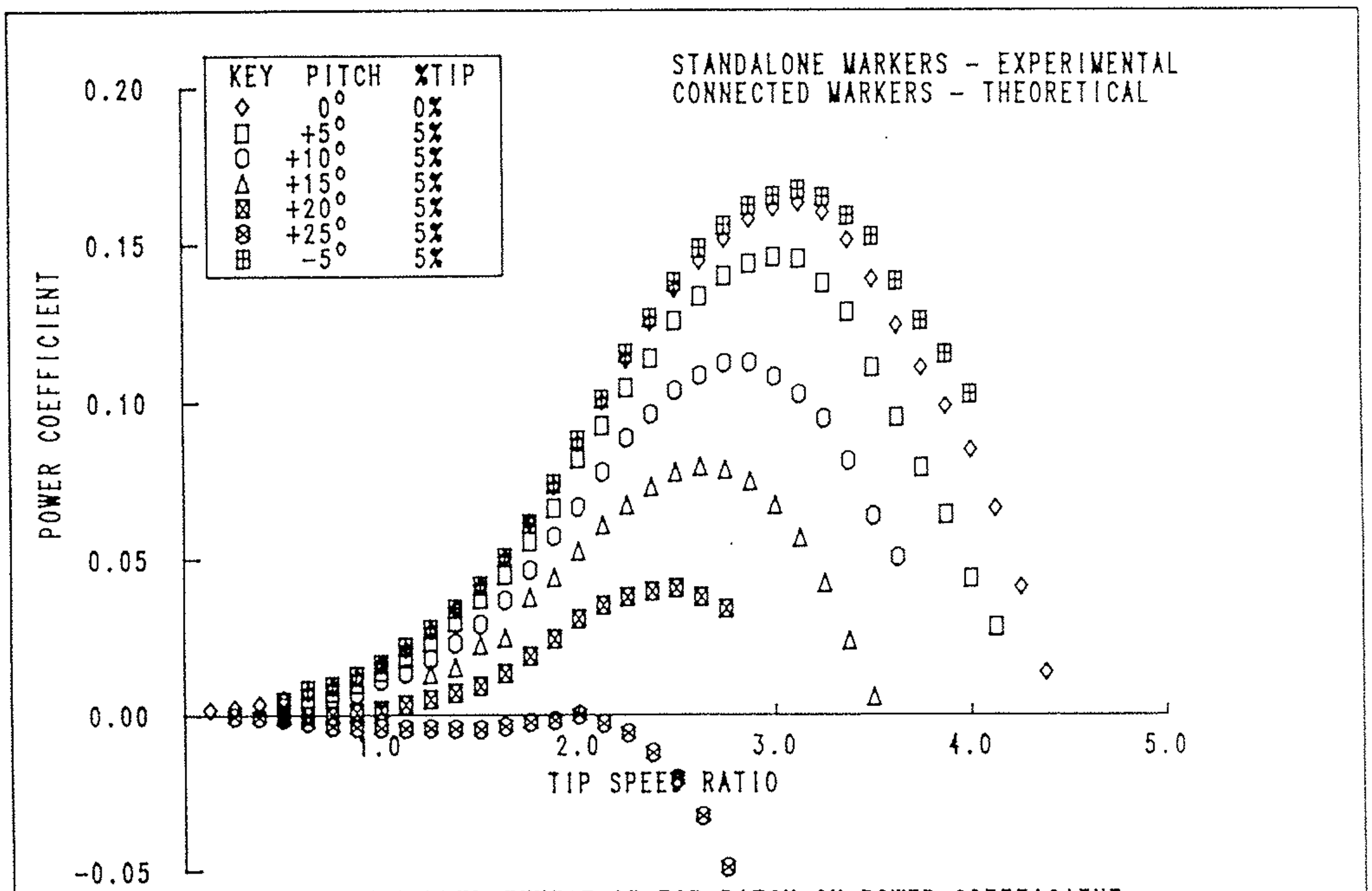

FIG. 2 MEASURED EFFECT OF TIP PITCH ON POWER COEFFICIENT FOR MODEL V-VAWT WITH 5% TIP AREA

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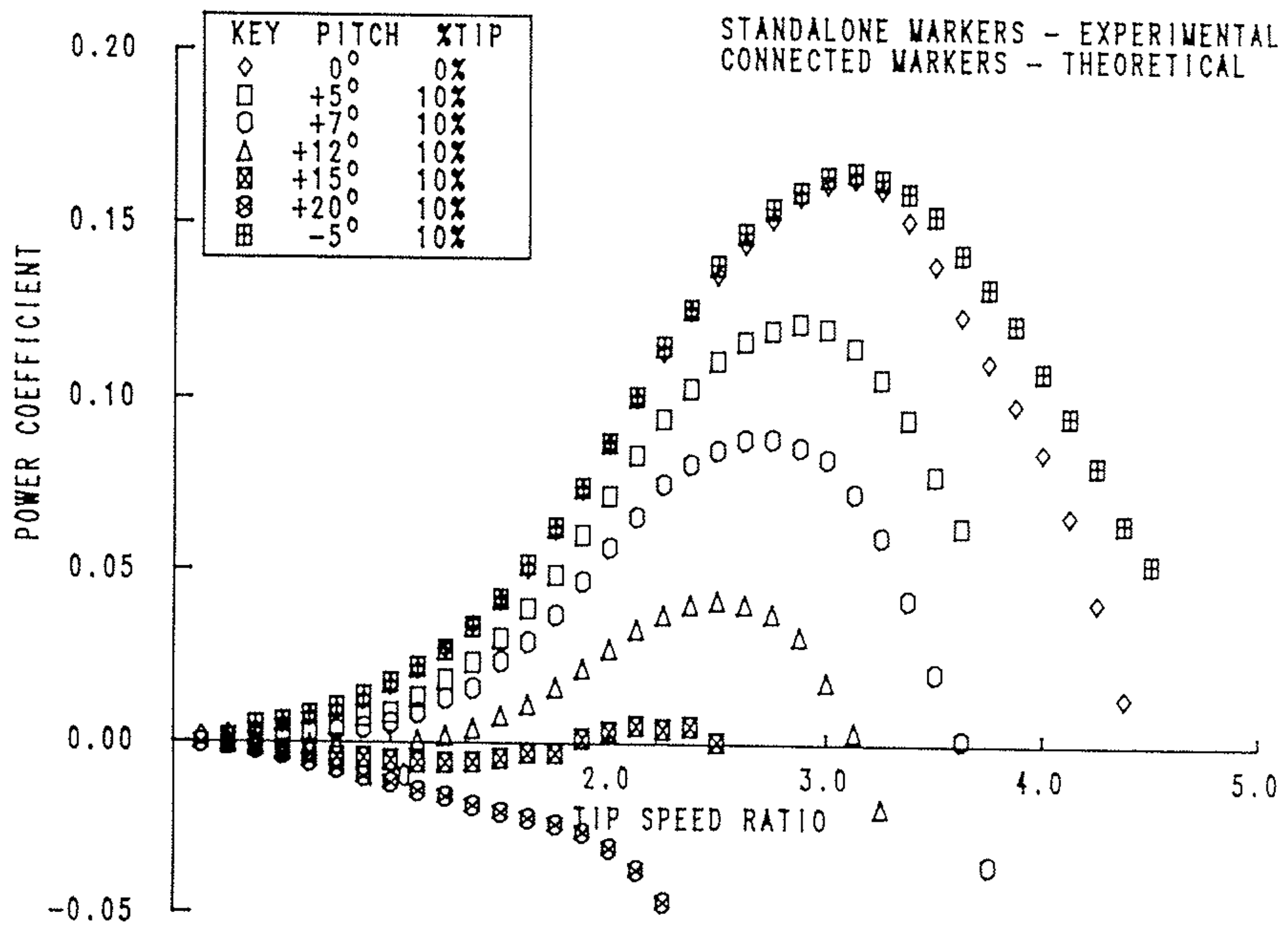

FIG. 3 MEASURED EFFECT OF TIP PITCH ON POWER COEFFICIENT FOR MODEL V-VAWT WITH 10% TIP AREA

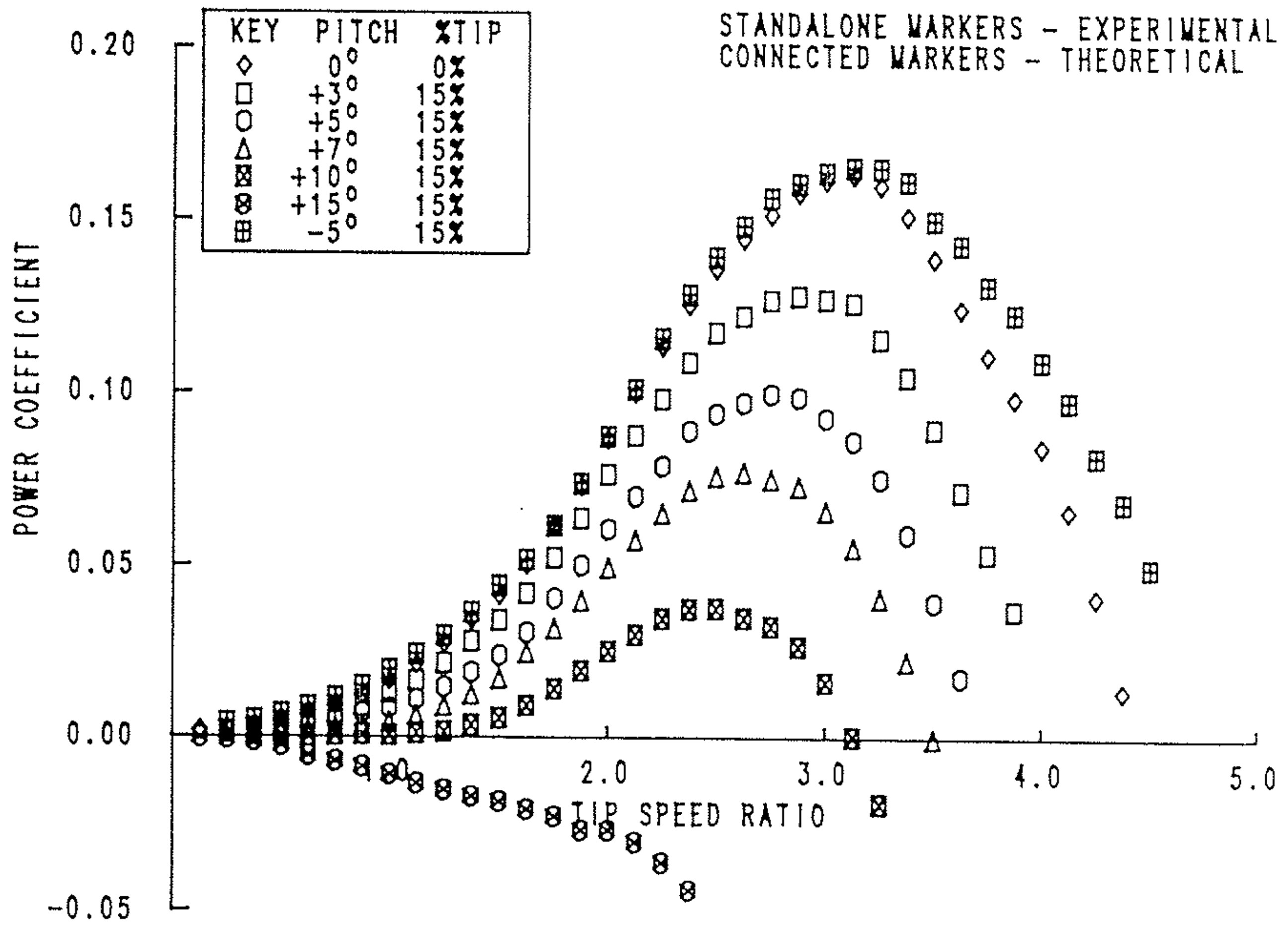

FIG. 4 MEASURED EFFECT OF TIP PITCH ON POWER COEFFICIENT FOR MODEL V-VAWT WITH 15% TIP AREA

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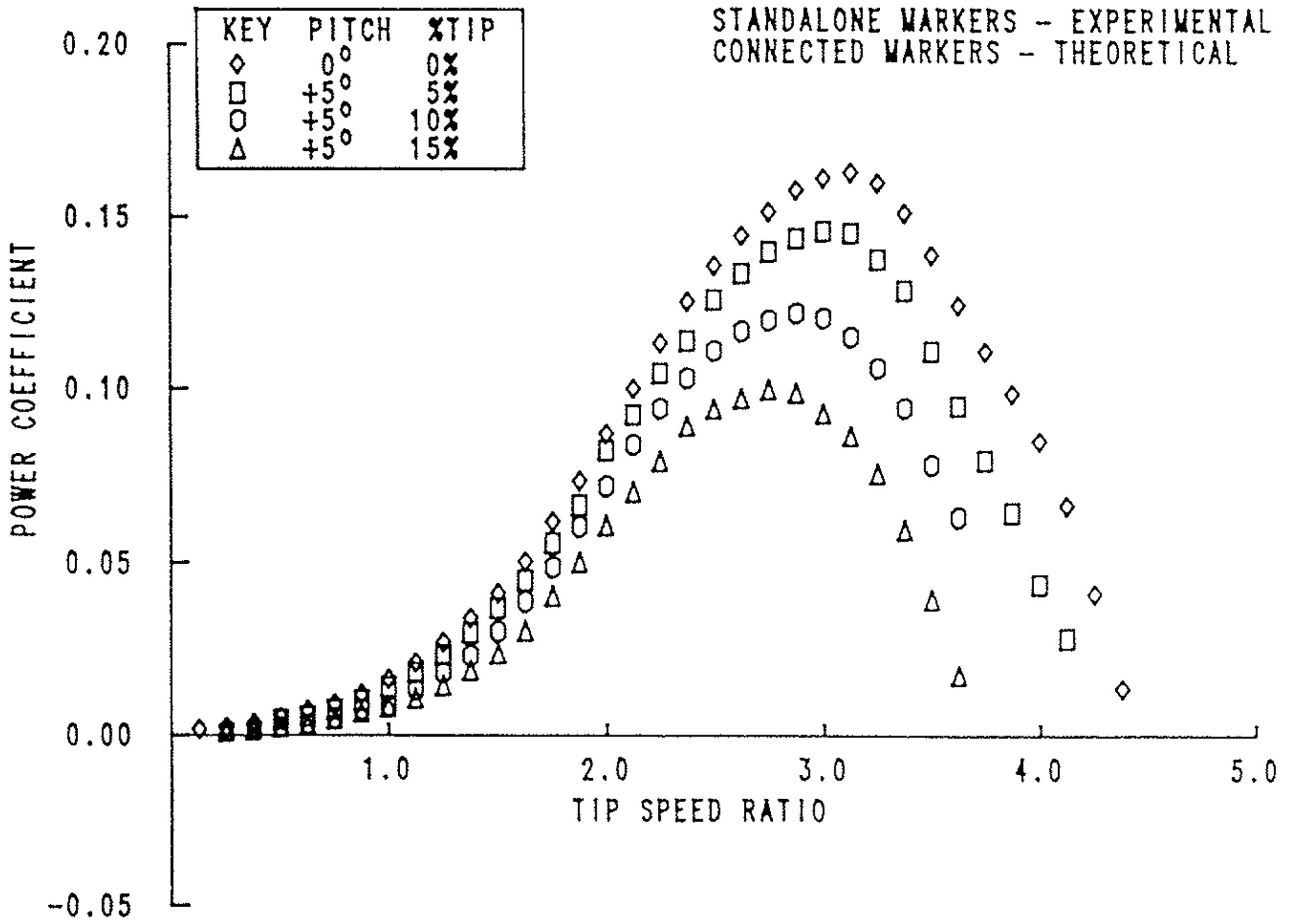

FIG. 5 MEASURED EFFECT OF TIP AREA ON POWER COEFFICIENT FOR MODEL V-VAWT FOR +5 DEGREES TIP PITCH ANGLE

how Power Coefficient is affected by changes in tip pitch angle for tip areas of 5%, 10% & 15% of the total blade area. Figure 5 compares the effect of tip area for a pitch setting of +5 degrees.

These results illustrate the effectiveness of tip pitch control as a means of power modulation and overspeed protection. Even a 5% tip area, at pitch angles in excess of +25 degrees, can effectively 'kill' all the power developed by this model wind turbine at all but the lowest tip speed ratios.

Looking again at figures 2-4, it is seen that Power Coefficient is enhanced with small negative (nose-out) pitch angles. From the test results available, a pitch angle of -5 degrees appears to optimise this enhancement. Enhancement of power with small, full-span pitch offsets was noted by Stacey and Musgrove [7] for the 'H'-VAWT, so a similar effect was not unexpected with the V-VAWT.

Figure 6 shows how Torque Coefficient varies with pitch angle for a 5% tip area. It shows the high starting torque that is a feature of the V-VAWT, and illustrates how a small negative pitch offset enhances the turbine performance. Note that the enhancement of developed torque is apparent at all tip speed ratios for a -5 degree pitch angle even at starting.

3.3 Predictions of tip pitch effects

The computer program VAWTTAY6 can be used to predict the effect of tip pitch on the performance of the model V-VAWT. However, it is not possible for these predictions to be matched directly with the wind tunnel results because at present VAWTTAY6 uses NACA0012 static aerofoil data, whereas the wind tunnel model was constructed using the thicker NACA0025 section.

Published aerofoil data for the NACA0025 aerofoil section is scarce, though Sandia Laboratories have published data for this section that has been generated using the Eppler computer code [8]. Despite the fact that this data covers angles of incidence upto 180 degrees for a range of Reynold's Numbers, none of the data presented for this section has been verified by wind tunnel tests. Consequently the authors have not used this aerofoil data for predicting the performance of the model V-VAWT. Low Reynold's Number static aerofoil tests of a NACA0025 section are planned for later this year so that more accurate predictions of performance of can be made using VAWTTAY6.

However, the predictions of Power Coefficient using the NACA0012 aerofoil data show tip pitch effects that are similar to those demonstrated by the wind tunnel tests, Fig 7. The high starting torque developed by the model V-VAWT and the enhancement of torque with small negative, nose-out pitch positions is also predicted by the theory, Fig 8.

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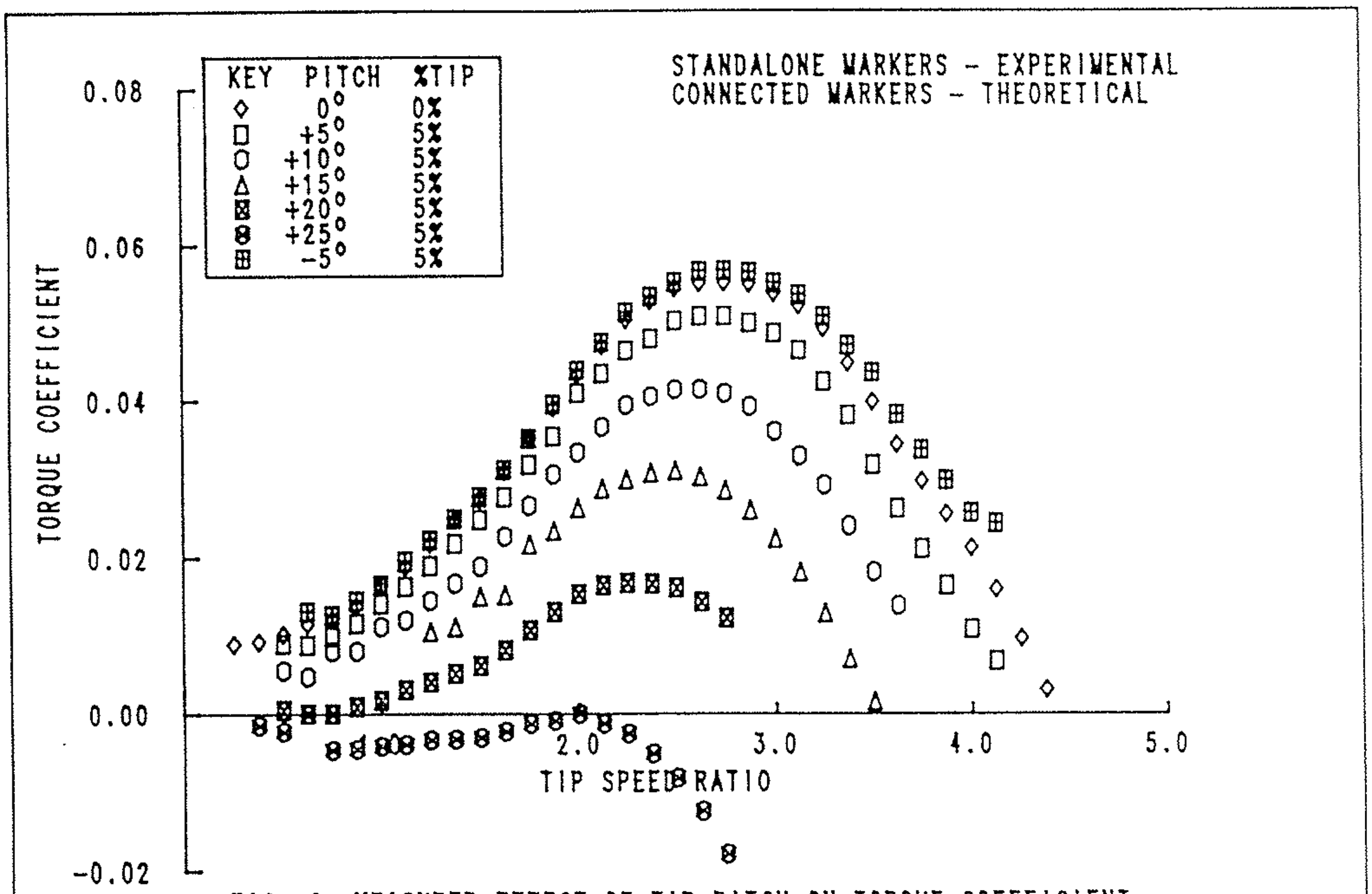

FIG. 6 MEASURED EFFECT OF TIP PITCH ON TORQUE COEFFICIENT FOR MODEL V-VAWT WITH 5% TIP AREA

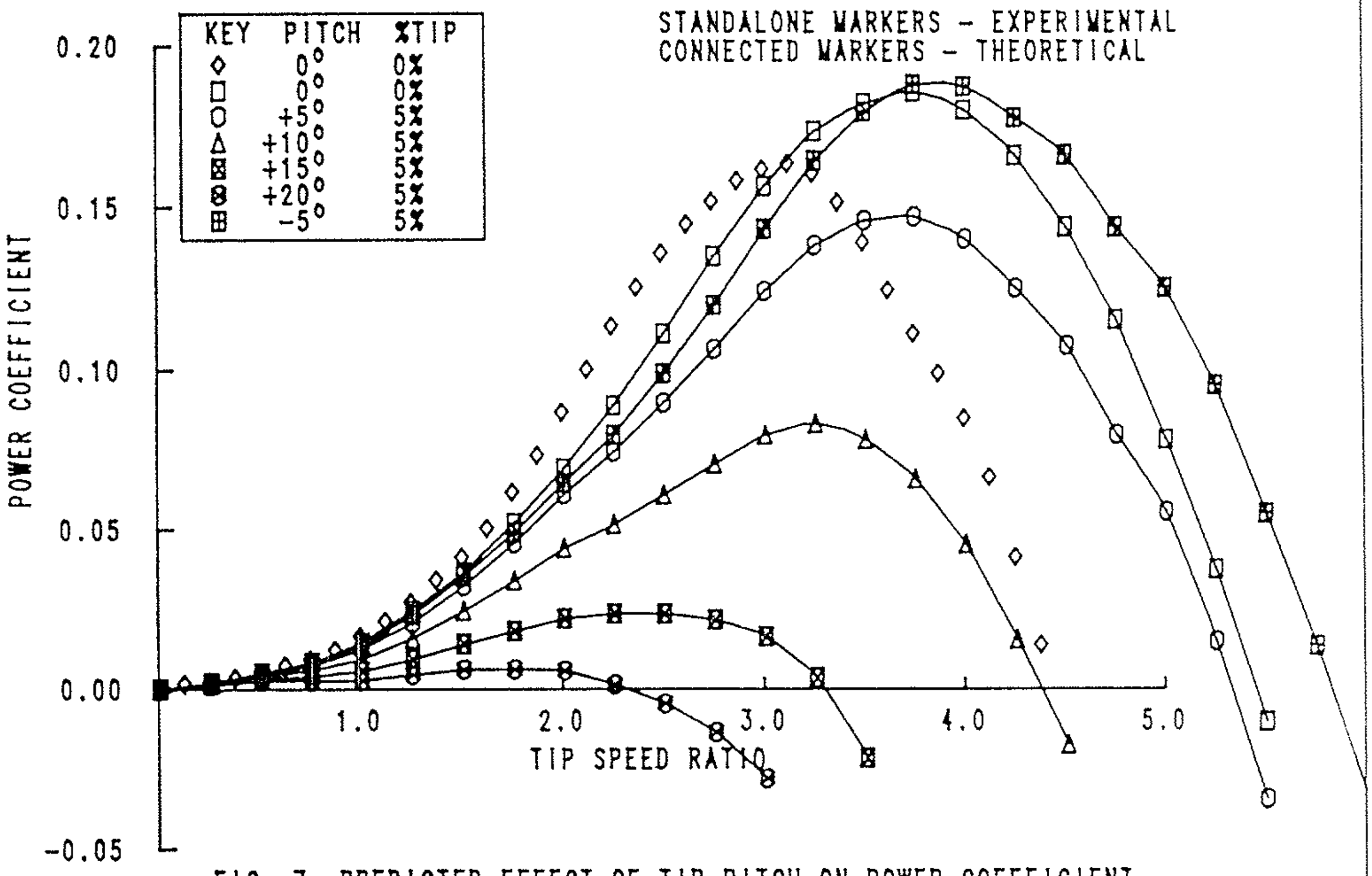

FIG. 7 PREDICTED EFFECT OF TIP PITCH ON POWER COEFFICIENT FOR MODEL V-VAWT FOR 5% TIP AREA

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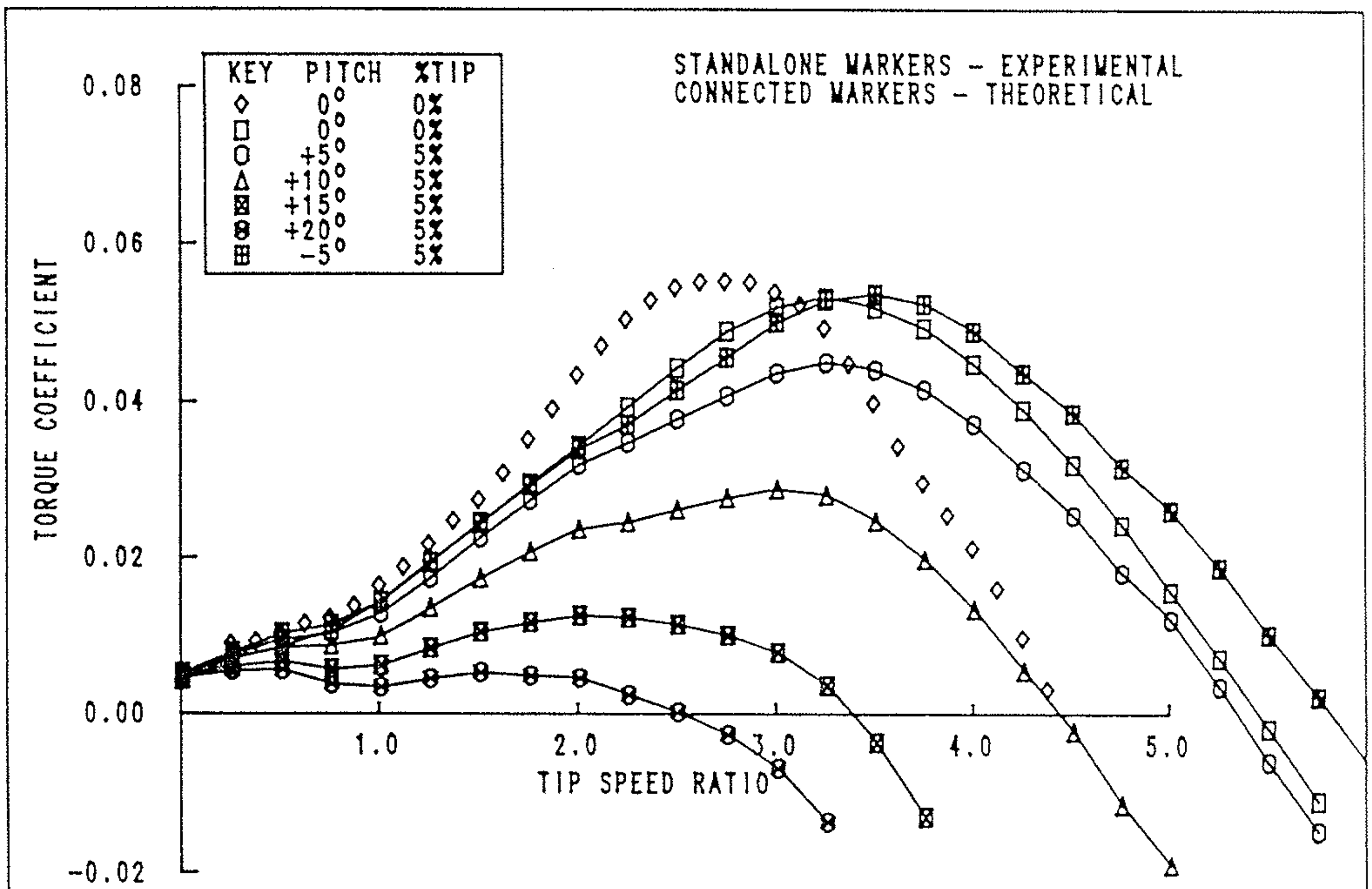

FIG. 8 PREDICTED EFFECT OF TIP PITCH ON TORQUE COEFFICIENT FOR MODEL V-VAWT WITH 5% TIP AREA

As a result of these tests, the performance of larger V-VAWTs using tip pitch control can be predicted with some confidence. Figure 9 shows the predicted performance of the 5kW 3-bladed free-air V-VAWT, that has been described previously [2-4], and the predicted effect of tip pitch for a 5% tip area.

These predictions have been made for operational Reynold's Number of approximately 1500000, and show how the developed power can be destroyed for pitch angles as little as +30 degrees. The effectiveness of a blade tip deployed at a large pitch angle is largely Reynold's Number independent, though the lift, and hence torque, generated by the fixed portion of the blade will generally increase with Reynold's Number. Consequently as the operating Reynold's Number increases, the tip must be deployed at a larger pitch angle to obtain the same net braking effect. The choice of tip size and the pitch angle range through which it is deployed will be crucially dependent upon the operating conditions and the control criterion specified for the machine. At this stage of the V-VAWT development however, blade tip areas of approximately 5% of the total blade area seem appropriate for both power regulation and overspeed control.

3.4 The T-Brake as a control device

The T-Brake offers a number of advantages over pitching tip control: it can be simply mounted at the blade tip without creating any discontinuity in the blade structure; actuation can be of a push-pull nature as opposed to pitching, and the swept area of the turbine is increased by the additional aerofoil surfaces. However, the effect on performance of the T-Brake control surface is very similar to that of the pitching the blade tip and can be predicted with some confidence using VAWTTAY6, Fig 10.

These predictions should be treated with caution though, since they do not account for any flow interaction between the T-Brake and the fixed blade. In its pitched position the trailing edge of the T-Brake will spoil the flow over the outer portion of the fixed blade. It is therefore likely that these predictions may underestimate the braking effect of the T-Brake, but at present it is not possible to quantify this underestimation. The T-Brake should also act as an end plate thus reducing the blade tip losses and so increasing the lift developed by the fixed blade.

4. CONCLUSIONS

Recent wind tunnel tests of a model V-VAWT have shown that the aerodynamic performance of this wind turbine can be modulated with tip pitch control. These tests have demonstrated that both overspeed control and power regulation can be achieved with tip areas as little as 5% of the total blade area. Some enhancement of torque at all operating speeds has been demonstrated by small negative pitch settings.

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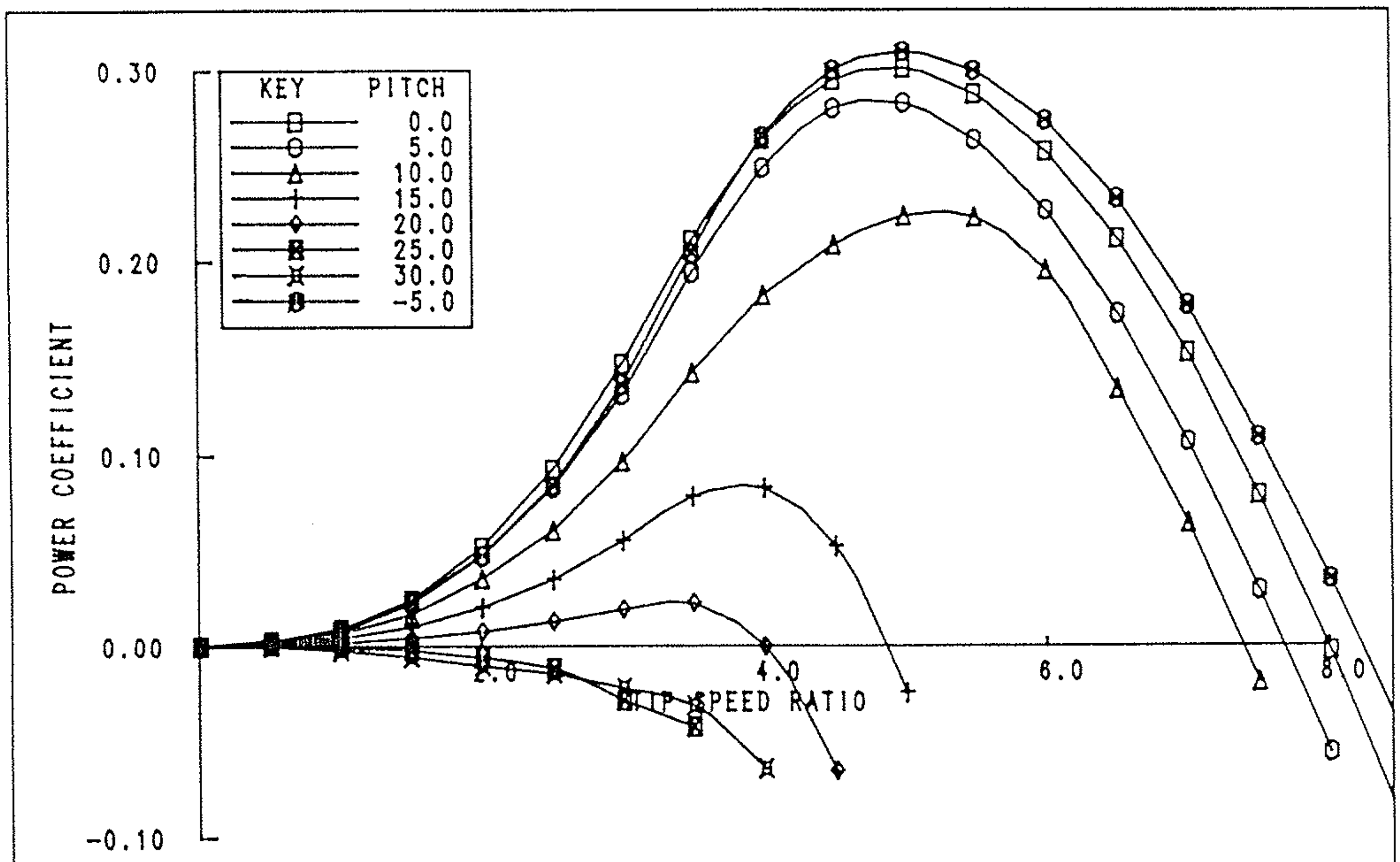

FIG. 9 POWER COEFFICIENT vs TIP SPEED RATIO: VAWTTAY6 PREDICTIONS
3-BLADED, 5KW V-VAWT WITH 5% BLADE TIP CONTROL SURFACE

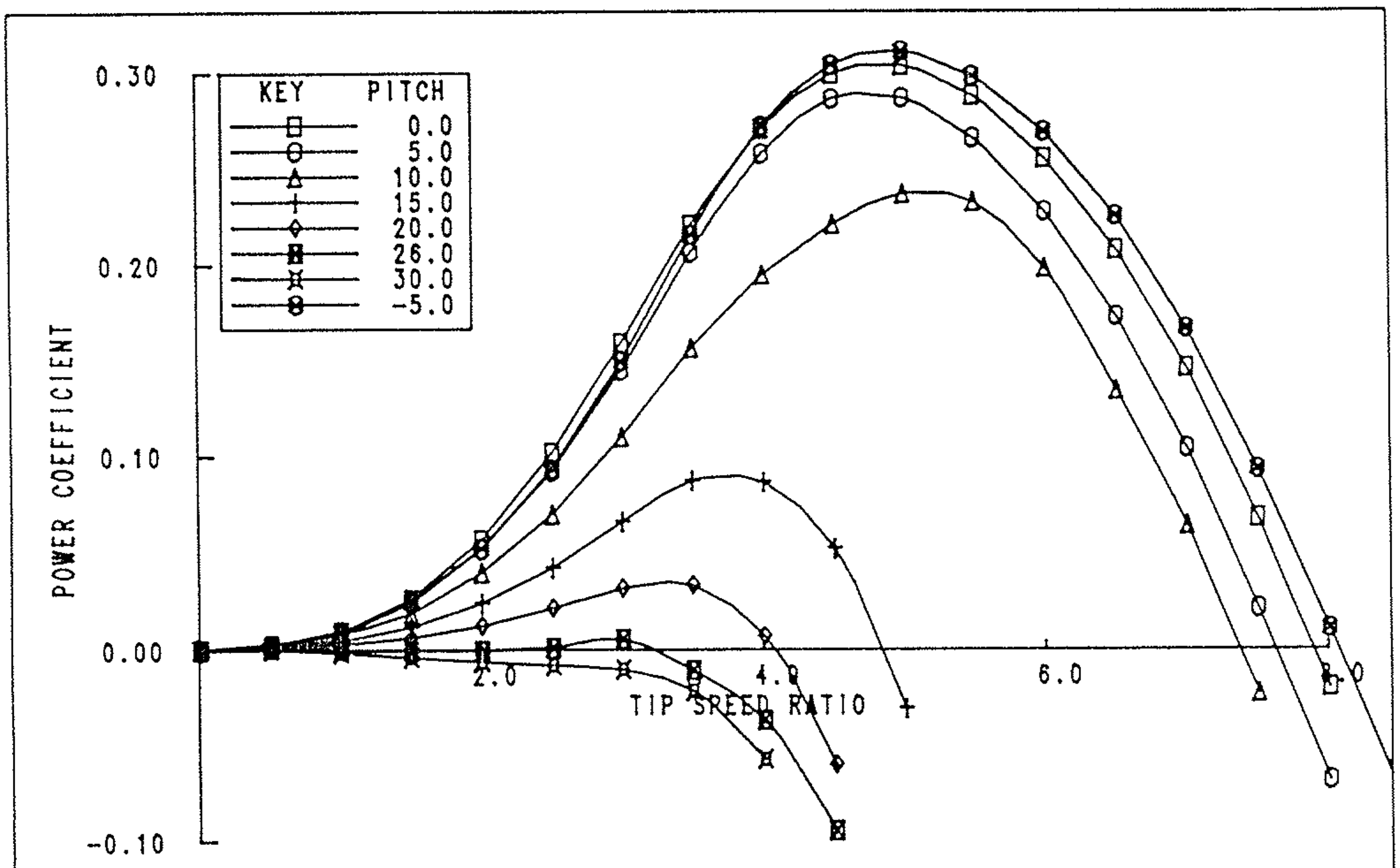

FIG. 10 POWER COEFFICIENT vs TIP SPEED RATIO: VAWTTAY6 PREDICTIONS
3-BLADED, 5KW V-VAWT WITH 5% T-BRAKE CONTROL SURFACE

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While it has not been possible to match the results exactly to predicted data, the use of the aerodynamic prediction model VAWTTAY6 for development of larger sized V-VAWTs with tip control seems reasonable.

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