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SYSTEMATIC MEASUREMENTS OF A WINDSURFER SAIL PERFORMANCE

Keith ALEXANDER and Vaughn FURNISS

Department of Mechanical Engineering
University of Canterbury, Christchurch, NEW ZEALAND

ABSTRACT

A project was undertaken to examine the effectiveness of windsurfer sail rigging for twist and belly in varying wind conditions. A further set of measurements looked at the sail's performance with rake angle.

The method of examination involved building 3 solid replicas of the sail with varying degrees of twist and belly, and testing them in steady conditions in a wind tunnel.

The results obtained showed that for the sail tested:

- the lift to drag ratio was largely unaltered with the rigging settings
- rake either forward or aft, reduced the sail force in the horizontal direction
- the center of pressure moved down as the sail twisted, but this movement was small.
- the lift coefficient reduced with increased sail twist and less belly
- the lowering of the center of pressure and the reduction on lift coefficient with sail rigging for high wind conditions combine to reduce the overturning moment, and largely confirm the board sailors' explanation that a more twisty sail prevents overturning in gusty conditions

While there were some limitations to the testing procedure, the process used here demonstrated a systematic measurement of windsurfer sail performance with quantitative results free from industry hype.

INTRODUCTION

This project set out to examine the effect of the windsurfer sail rigging adjustments that control sail twist and belly, to determine the sail's effectiveness over a range of wind speeds. A further set of results was obtained determining the sail's performance with rake angle. The project was run as a final year engineering task and is reported fully in the in-house document FURNISS 1997.

Purpose of this Work

The industry develops sails largely by using experienced board sailors to trial sails and report on performance. The development methods have evolved to meet industry requirements and while they may be commercially successful it is an advantage from time to time to "calibrate" the current theories and claims against formal measurements. This project is just such a test.

Sail twist

In recent years, a focus of windsurfer sail design has been on developing sails that offer varying degrees of twist through the head and leech section. It is thought that allowing the head and leech sections to twist off with increasing wind velocity enables the sailor to use the sail at higher wind velocities while maintaining control in gusts. The belief is that less belly in the sail reduces the lift coefficient, decreasing the sail force, while twisting off at the head lowers the center of pressure, reducing the sail overturning moment.

Control over the sail twist and belly is achieved by adjusting the "downhaul" and "outhaul" tensions. Downhaul tightens the luff, bending the mast and loosening the leech. This allows the sail to twist easily. Outhaul tightens the chord of the sail along the boom. This flattens the sail, reducing belly. For light conditions, minimal downhaul and outhaul are applied. This gives a full sail that does not twist easily. For higher wind conditions, an increase in downhaul bends the mast, loosens the leech and increases the sail's capacity to twist out at the peak. This is combined with more outhaul to flatten the sail. The correct rigging of the sail for the conditions is critical to being able to stay on the board and achieve good performance. Current practice for windsurfer sail rigging is described in such references as TWEDDEL 1990 and SHORT 1997.

MODEL SAILS USED FOR TESTING

The method of examination, described more fully below, involved building 3, 1/8th scale, rigid, GRP replicas of the sail, based on carefully derived 3D coordinate data from a full-scale sail under the appropriate wind loading and rigging conditions. These model replicas were then tested in steady flow in a wind tunnel. The models were based on the full-scale rigging:

- light wind: sail with minimum downhaul and outhaul for 20 knots

- medium wind: sail with medium downhaul and outhaul for 25 knots
- high wind: to sail with large amount of downhaul and outhaul for 30 knots

METHOD OF PRODUCING MODEL SAILS

Full Scale Sail Deflection

A full-size Gaastra 2X, twin cam, 5 square meter sail was taken to a land-based testing site where steady high winds could be experienced. When the wind was available the sail was rigged with appropriate downhaul and outhaul then set up in the wind for measurement. For each of the 3 required wind speeds the sail was rigged and photographed to show the belly and twist. In particular the angle between the camber line at the boom and the top batten of the sail was derived from the photographs.

Laboratory Deflection Simulation

In the laboratory the fully rigged sail was mounted on a frame in the horizontal position. The recorded downhaul and outhaul settings were applied to the sail. Load in the form of a number of small sand bags was applied across the sail until the required deflection was reached, when referenced to the photos. The sail was divided into 60 nodes and a plumb-line was then used to project each nodal point location to the floor of the laboratory. The height from the floor gave the sail deflection at each node.

The coordinates recorded from these loadings were downloaded into a CAD package, and scaled to model size.

Model Sail Production

A CNC mill was then used to produce an accurate mould profile of each sail in a machinable plastic. From these moulds 3 model sails were made of glass laminate. These were faired, smoothed, painted matt black and finished with white cotton tufting for flow visualisation. Each sail was fitted with a steel bar mast that could be mounted to the force balance bracket.

WIND TUNNEL TESTS

The models were set up in a boundary layer wind tunnel, mounted on a strain gauged force balance.

The test flow velocity for all three models was 12m/s, with no attempt being made to produce a twisted flow or other boundary layer effect.

While recent work by Locke and Flay has shown the effects of the twisted flow experienced by real yachts, flow twist was not modelled in this project. The reasons were partly because of the difficulty in producing it in the tunnel available, but primarily because the project was aiming at comparing different amounts sail twist and belly with each other. This comparison could be accomplished to a first order accuracy in the uniform flow available.

With 12m/s being the upper speed limit of the boundary layer wind tunnel the Reynolds number for the $1/8^{th}$ models was about 103000. Since this is a factor of 3 lower than the full scale Reynolds number the incidence at stall may not be correctly predicted. This was not really a concern since the area of interest, below the stall point, would be modelled correctly, and comparisons between sails even at the stall point will be indicative of the full scale behaviour at the stall.

Force measurements were taken over apparent wind angles of 0 to 50 deg and for a selection of rake angles between 60 and 100 degrees. (Rake angle is the angle between the mast and the horizontal line aft in the fore and aft plane; the apparent wind angle is the angle of attack of the sail at the boom)

Accuracy and Errors

An analysis of the sources of error in the original tests resulted in force and coefficient errors of +/- 3%. This results in errors of +/- 4.3% in lift to drag ratio data. Errors in apparent wind angle were +/- 2.8 degrees.

For clarity, error bars are not shown in the figures.

RESULTS AND DISCUSSION

The attached four figures are a sample of those generated from the data collected during the measurement of lift, drag and centre of lift height.

The results obtained readily showed that for the sail tested:

1. The maximum lift to drag ratio was largely unaltered over the three rigging conditions as shown in Figure 1. But this maximum occurred at higher apparent wind angles for the higher wind sails. The max L/D occurred at between 15 and 20 degrees apparent wind angle.
2. Rake either forward or aft, tended to reduce the sail lift coefficient and consequently the force in the horizontal direction (Figure 2). Another analysis of the results showed that the lift to drag ratio was highest with no rake; that is with a vertical sail.
3. The center of pressure moved down from the light to the high wind rigged conditions, but this movement was small, as shown in Figure 3. This direction of movement is as expected since the twisted out head of the sail does less work with the higher wind rigs, so the main sail force is lower.
4. The lift coefficient reduced from the light to the medium rigged conditions (Fig 4). Again this is expected as the outhaul flattens the sail, and the sail head does less work.

However there was an anomaly with the lift coefficient for the high wind sail (Figure 4); the lift coefficient was found to be higher than that of the other two sails rather than lower, in the 15 to 20 degree apparent wind range. This required closer examination.

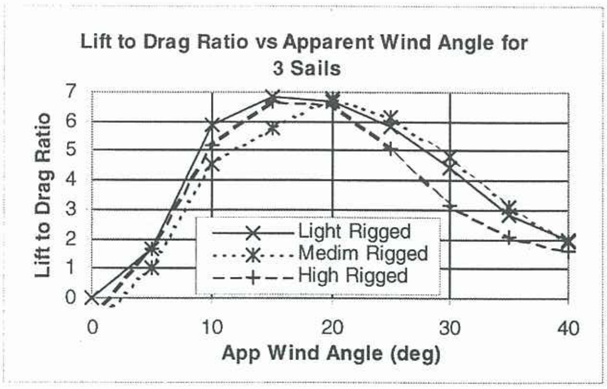

Figure 1 : While the maximum lift to drag ratio is not altered by twist, the apparent wind angle of max L/D increases with sail twist. The light wind sail has the least twist and the high wind sail has the most twist

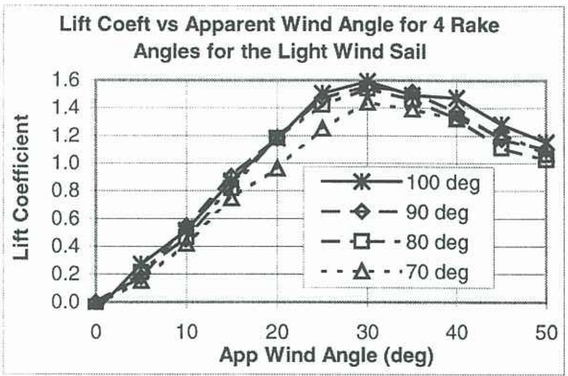

Figure 2 : Lift coefficient vs apparent wind angle for four rake angles with the light wind sail. Lift coefficient is highest with a near vertical sail.

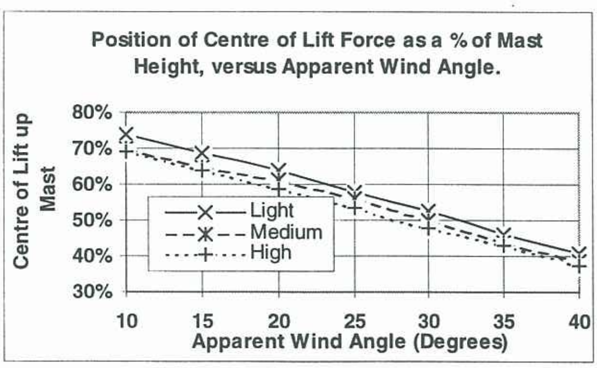

Figure 3 : The greater the sail twist the lower the center of pressure.

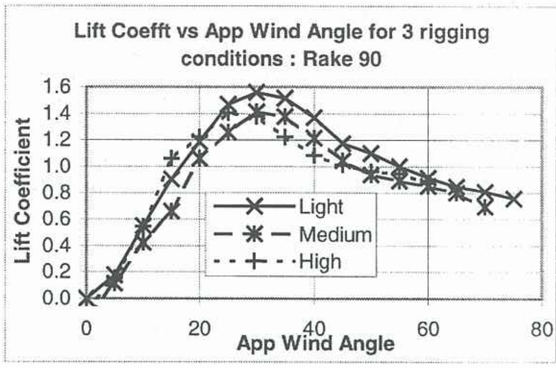

Figure 4 : For the near-vertical sail, the light wind sail (minimum twist and greater belly) has the highest lift coefficient

Analysis

It was of interest to know how effective the sail rigging was in coping with wind gusts. The results were analysed to compare the overturning moment of the medium and high wind rigs to the low wind rig. The question to be answered was: "If the sailor can only just hold the light rigged sail, what percentage increase in wind velocity can he hold against, with a medium or high wind sail?"

In the analysis the overturning moment was calculated from the lift (Figure 4) and drag coefficients, and the center of pressure heights (Figure 3).

The results of this analysis showed that the medium sail could sustain about a 12% higher wind than the light wind sail for the same overturning moment. Of this 12%, 10% was because of the reduction in lift coefficient resulting from sail twist and reduction in belly, and 2% was because the center of pressure was lower.

For the high wind sail the results were different: it could only sustain a 5% higher wind than the light wind sail. This was in spite of the fact that the center of pressure was even lower than that of the medium sail (Figure 3), and as well, it had more twist out at the peak.

The reason was found to be that the lower part of the sail had increased belly because either:

- higher wind loading had overcome the outhaul tension and filled out this part of the sail, giving it a higher lift coefficient, or
- the increased downhaul increased the sail belly.

As a result the rig was not as effective in reducing the overturning moment as the medium rigged sail.

The lesson is that the rigging must be sufficient to keep the sail flat in the expected winds, or the advantage of a twisted-out head is lost.

CONCLUSION

When a windsurfer sail is rigged for higher winds, the lowering of the center of pressure and the reduction on lift coefficient with sail twist, combine to appreciably reduce the overturning moment. This largely confirms the board sailors' explanation that a more twisty sail prevents overturning in gusty conditions.

While the sail tested achieved adequate twist in the high wind condition it did not achieve sufficient flattening of the sail to reduce the lift coefficient and compensate for wind strength. This emphasises the need for good rigging technique and adequate control in the rigging methods used.

While it is recognised that a model hard sail in steady flow has some limitations when modelling a full scale flexible sail in gusty conditions in a boundary layer, the process used here has demonstrated a successful systematic measurement of windsurfer sail performance that supports board rider claims while being free from industry pressures.

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