VOLVO 60 GENNAKER-MAINSAIL INTERACTION

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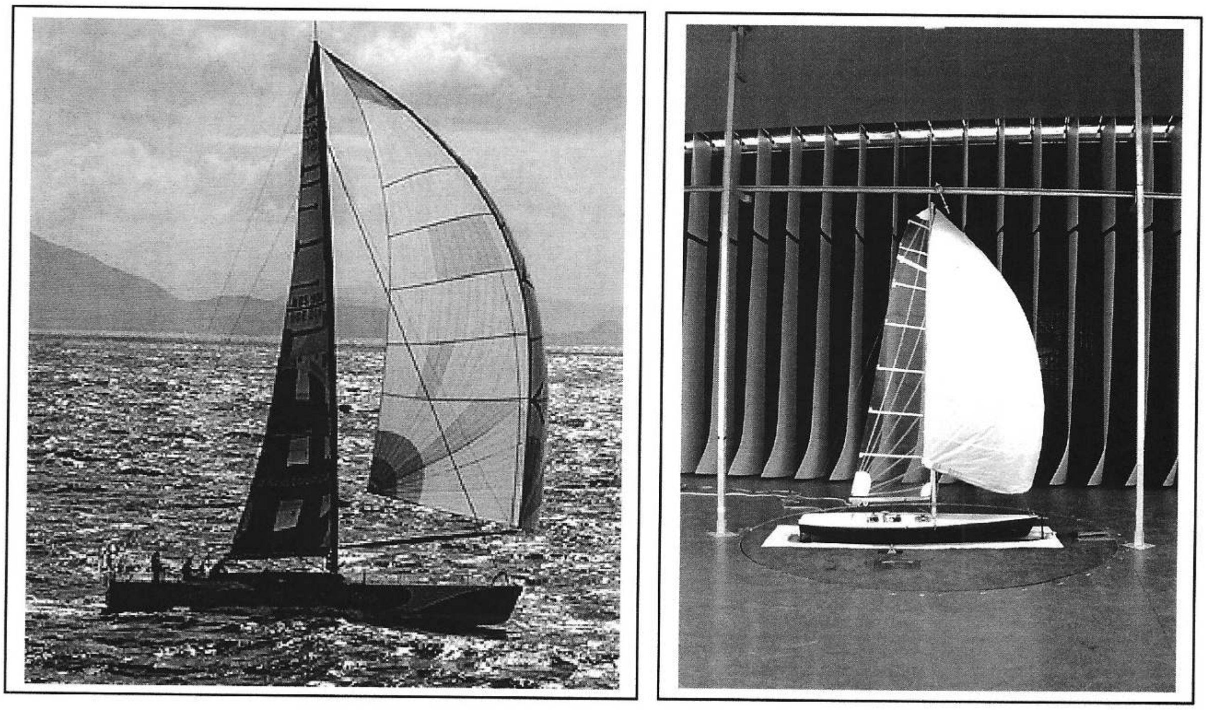
1. INTRODUCTION

Conventional wind-tunnel testing of sails provides information of the forces and moments generated by a pair of sails, such as a gennaker and mainsail, but cannot provide information relating to what forces are resulting from each sail or how the sails affect each other. In this study a technique of independent support has been used in order to derive individual sail contributions. With downwind sailing, such as the situation shown in Fig. 1a, a gennaker is often flown from a spinnaker pole and hence is attached at the masthead, at the end of the pole and through the clew sheet to the stern of the hull. If supported in this manner on the model yacht then the force balance measures the combined sail forces. However if these attachments are replaced by independent supports which are located as close as possible to the normal positions but without making contact with the hull or rigging then the forces on the mainsail alone may be measured, but with the influence of the gennaker still present. By taking the difference between these measurements the forces provided by the gennaker may be deduced. Further information relating to the interaction of the sails may be obtained by measuring the forces on each individual sail when only one sail is present. Using independent support with the mainsail is not so straightforward since it is attached all along the mast. However by replacing the normal model mainsail by a sheet aluminium sail with approximately the correct shape and curvature it has been possible to use three point support and to make an approximate check on the gennaker forces deduced from the other tests.



(a) (b)

Figure 1. (a) A Volvo 60 flying a gennaker and (b) the generic wind tunnel model.

2. TEST PROCEDURE

This series of tests used the yacht model and sails previously tested by Le Pelley et al. [1] but focused on the interaction of these sails rather than the effect of heel, which had been the primary focus of their study. The tests were carried out on a typical Volvo 60 Code 4 gennaker and mainsail over a range of apparent wind angles of 80-110°. This range represents the useful extent of the gennaker. The model used was a generic Volvo 60 hull and rig. The model was positioned on a six component force balance which is mounted under a rotating turntable. The gap between the hull and the turntable was sealed by sitting the model in a trough of water. This creates a perfect seal without transferring any external forces to the model, and is a good physical simulation of full scale. The hull was fitted with remote controlled electric winches and the model forces were recorded using a PC-based data acquisition system.

Suitable velocity and twist profiles have been calculated for the range of apparent wind angles, for a nominal true wind speed of 8 knots. The apparent wind velocity and twist profiles vary only slightly with wind speed and are much more dependent on the apparent wind angle. A suitable profile was created and measured in the wind tunnel such that it covered the range of apparent wind angles of interest. It was found that, by setting the profile for an apparent wind angle(AWA) of 100°, the required range of 80-110° could be covered sufficiently. All wind speeds and angles are referenced to a 10m height, which is conveniently close to the centre of effort height of the model. The velocity profile was simulated by placing roughness elements on the floor of the wind tunnel upstream of the model. The twist was simulated by twisting a series of flexible vanes upstream of the model by different amounts over the height range, as shown in Figure 1b. The velocity profile was measured using a hotwire anemometer and the twist was measured using a direction vane.

In the previous study [1] the sails were trimmed both by visual inspection and observation of the real-time drive force as computed by the data acquisition software. The sails were trimmed for maximum drive force and the sail trim settings recorded to allow results to be repeated. This trimming showed that the angle between the spinnaker pole and the hull centreline needed to increase from 12.5° with an AWA of 80° to 36° at an AWA of 110°. At the same time the gennaker clew sheet is eased which means that the sail has effectively rotated around the mast. These gennaker trim settings were also used in this study but the mainsail position was systematically varied with mainsheet lengths between 150 and 400 mm. The mainsheet ran from the hull centreline to the boom 150mm above, both attachment points were 510 mm from the mast. Hence the angle between the boom and the centreline varied from 0° with a length of 150 mm to 43° with 400 mm.

The Code 4 gennaker is conventionally flown from the masthead and a spinnaker pole. Initial measurements were made with the gennaker attached in this conventional manner and hence the forces from both sails were transferred to the force balance and measured. The gennaker was then detached from the masthead and attached to a hook supported by a cross-beam (visible in Fig. 1b). The spinnaker pole and clew sheet were also replaced by hooks attached to floor mounted stands. In this manner the gennaker could be flown in a position very close to its original situation but with the forces taken by the hook and stands. Hence the only forces measured by the balance were those from the mainsail and rigging. The forces on the gennaker could therefore be calculated by taking the difference between these two sets of measurements. In addition the forces on the mainsail were measured with the gennaker removed. The parasitic forces of the hull and rigging were also measured for all conditions and have been subtracted from the results when calculating coefficients. In all cases the forces were averaged over a period of 3 minutes.

In a final series of tests the mainsail was replaced with an aluminium sail with approximately the correct shape and curvature. This was also supported by the framework and stands. By using this technique it was possible to check the forces on the gennaker with the mainsail present by direct measurement rather than by the difference method discussed above.

3. RESULTS AND DISCUSSION

Conventional measurements on a gennaker-mainsail combination provide results such as those shown in Fig. 2. These show that the position of the mainsail has more effect on the side force than on the drive force. In addition since conventional trimming seeks to maximise drive force, it can be seen that with an apparent wind angle of 80° the optimal mainsheet length is 300mm, at 90° it is about 350mm, at 100° it is less clear but the drive force seems to be near a maximum at 400mm and at 110° the drive force is still increasing at 400mm. What is not clear from this data is whether the drive force provided by the gennaker or mainsail that is maximised at these points or whether it is combination of effects.

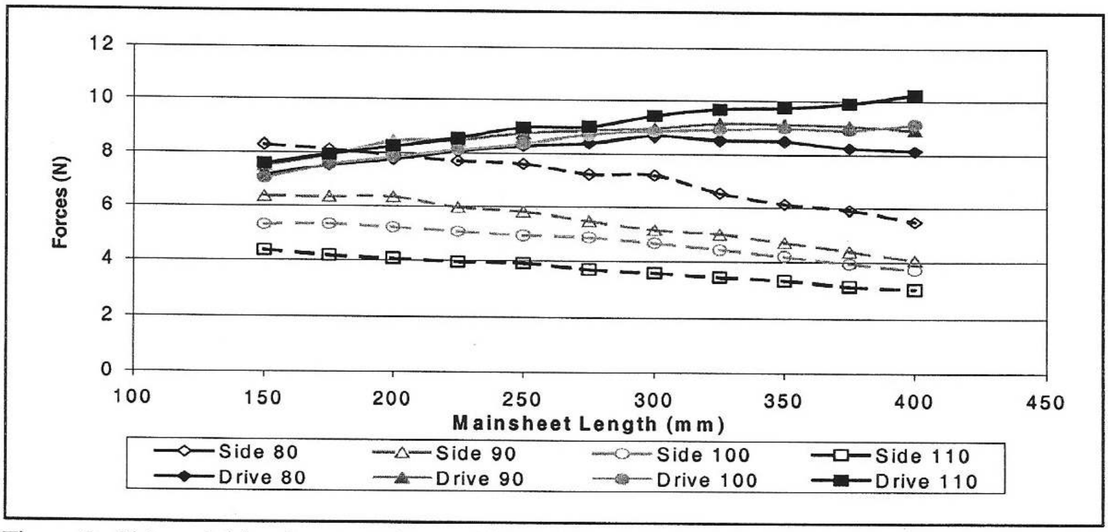


Figure 2. Side and drive forces on the combined sails

By using the independent support technique the force coefficient for the gennaker are obtained and shown in Fig. 3. These show that the gennaker forces are similar at all apparent wind angles and mainsail positions. The apparent wind angle has little effect on lift and drag since the gennaker position is altered until the effective angle of the sail relative to the wind is similar in each case. In addition these results show that the mainsail has little effect on the gennaker forces and so it must be variations in the mainsail forces which are responsible for the drive force maxima in Fig. 2.

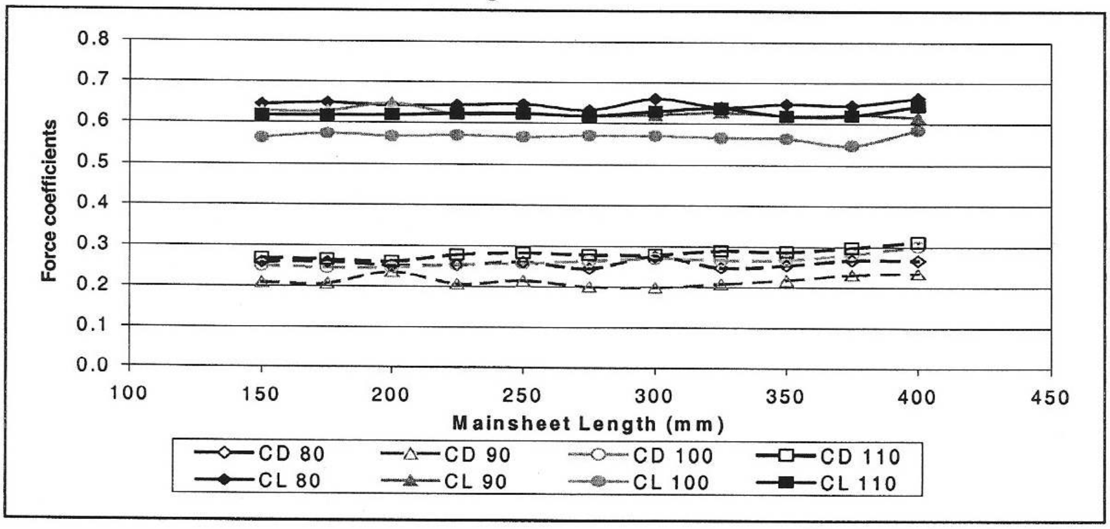


Figure 3. Lift and drag coefficients for the gennaker

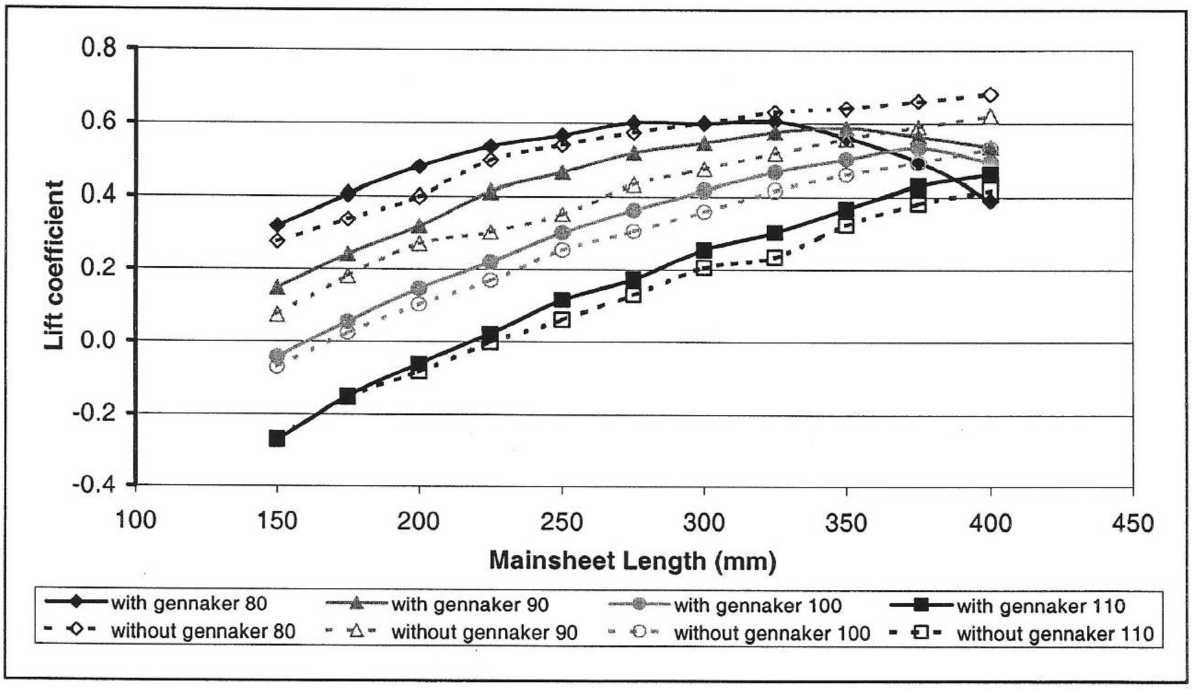


Figure 4. Mainsail lift coefficient with and without the gennaker.

Fig. 4 shows the mainsail lift coefficient with and without the influence of the gennaker. It may be noted that at an AWA of 90° the drive force is equal to the lift force and that at other AWA the lift is the primary contributor to the drive. From the measurements without the gennaker it can be seen that in each case the maximum lift, and hence drive, would be obtained by letting the mainsheet out as far as possible. However with the gennaker present there are distinct maxima. At an AWA of 80° the maximum lift occurs with a mainsheet length of 300mm, at 90° the maximum is at 350mm, 100° at 375mm and at 110° the lift is still increasing at 400mm. These results reasonably correlate with the combined drive force maxima discussed earlier. It is also clear that the gennaker has much more effect at 80° than at 110°, which makes sense since at 80° the gap between the two sails is relatively closed whereas at greater AWA the rotation of the gennaker around the mast opens this gap and reduces the interaction. Further analysis shows that the interaction is roughly correlated with the angle between the spinnaker pole and the boom, with the angle measured on the windward side of the sails. If this angle is less than 190° then both the lift and drag on the mainsail are slightly larger with the gennaker present. However if this angle increases beyond 190° then both the lift and the drag on mainsail decrease rapidly. Prior to this study it was thought that the effect of the gennaker on the mainsail would take the form of altering the effective angle of attack, however the fact that both the lift and drag decrease with pole-to-boom angles > 190° suggests that the effect is more related to a decrease of suction on the leeward side of the mainsail when the gap between the sails is reduced.

4. CONCLUSION

Independent sail supports have been used to obtain forces on individual sails and to investigate their interactions. The results show that the mainsail has little effect on the gennaker but the mainsail forces are affected by the presence of the gennaker.

REFERENCE

1. D. Le Pelley, P. Ekblom and R.G.J Flay, *Wind Tunnel Testing of Downwind Sails,* Proceedings of the High Performance Yacht Design Conference, Auckland, New Zealand, 4-6 December 2002, pages 155-161.