AeroRig® - The Rig of the Future
by

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Introduction

Over six years has passed since the prototype AeroRig® on a 21 ft trainer sailer was built. Numbers of AeroRigs® have doubled each year with some 65 now on the water and the fleet extending to the Far East, the USA and South Africa, the largest carrying a 224 sq m rig on a 36 m spar (this is on a 70 ft yacht). This expansion continues and the coming year will include the launching of several large yachts, (eg. an 87 ft Bill Dixon design, and a 57 ft G Dijkstra designed schooner).

The AeroRig® is a free-standing rotating spar that features an integral boom extending fore and aft of the mast. A conventional furling nonoverlapping fractional headsail is set off the front of the boom and a conventional fully battened slab reefing mainsail set off the main boom. The jib is, once unfuried, permanently sheeted to a short transverse track mounted on the foreboom immediately in front of the mast so as to make the jib completely self-tending. The angie of attack of the entire sailplan is controlled by a single line, "the mainsheet", which is usually led to a convenient winch close to the helmsman. Both sails are thus always attached and tensioned at three points and consequently do not twist off on any point of sailing nor can they flog uncontrollably if the sailplan is head to wind. As the mainsheet controls only the rotation and because the jib, by being in front of the pivot point, introduces a counter-balancing force, the mainsheet is very lightly loaded compared to that on a similar sized conventional yacht. *See Figure 1 - AeroRig® Profile., Figures 1a and 1b.*

Ease of use and safety are the prime design criteria however practical experience indicaties that the AeroRig® is remarkably efficient, particularly downwind, generating more power than conventional rigs and consequently AeroRig® cruising yachts consistently achieve higher average speeds than their conventionally rigged counterparts.

The ongoing development of the AeroRig® has more recently utilised wind tunnel techniques and practical on the water comparisons in order to assess these advantages and introduce further improvements.

Wind tunnel tests

Practical experience on the water of the 65 of so AeroRigs® built to date has adequately demonstrated not only ease of handling but also high performance. In order to evaluate this performance accurately and because of the growing interest in the AeroRig® in boats of all types and sizes, it was necessary to analyse the aerodynamic behaviour of the special rig configuration with the aim of determining the aerodynamic coefficients so that VPPs could be prepared to predict individual yacht performances with the AeroRig®

The Wolfson Unit at the University of Southampton has carried out two sets of wind tunnel tests on AeroRigs ® - the first series being used to compare the AeroRig ® with a conventional Bermudan sloop rig and the second series in order to assess schooner/ketch AeroRig ® combinations. In these tests the Wolfson Unit used the standard wind tunnel techniques that they had been perfecting over the past several years (see HISWA 1994). Their approach permits accurate measurement of drive force and heel moment coefficients of the rig at varying angies of attack (apparent wind angle). This allows the determination of the necessary aerodynamic coefficients required to run the VPP programmes.

Comparison of Conventional Rig vs AeroRig®

The conventional rig model chosen for the control was one that had previously been used for the development of Americas Cup Class rigs for he last series and thus represented a highly developed and optimised racing rig configuration (non-overlapping fractional jib with fully battened mainsail). This rig was readily adjustable by remote-control so that sail sets could be optimised from outside the tunnel. The AeroRig ® model was made to the standard rig geometry with a set of sails that were not adjustable from outside the tunnel (only the angle of attack of the sailplan could be so adjusted) and a set of sails that had undergone no optimisation. This lack of adjustment from outside the tunnel, if anything could be considered somewhat unfair to the AeroRig ®.

Perhaps the most interesting outcome of these wind tunnel tests is the comparison of the drive force produced.

Figure 2 indicaties the drive force coefficients for the entire range of apparent wind angles for the rigs. lt should be pointed out that no spinnaker were set on either rig and where possible on the conventional rig the jib was poled out to weather (goose-winged).

Figures 2a and 2b show the coefficients for the AeroRig® and conventional rig for the range of apparent wind angles.

lt can be seen that the AeroRig® has significantly higher drive force coefficient at apparent wind angles of greater than 45°, at some angles up to 40% more! lt does indicate however the AeroRig® has a marginal decrease in drive force coefficient at apparent wind angles of less than 40°. The main reason for the higher drive force at angles greater than 40° is that the lift coefficient for the AeroRig ® remains at a high value consistentie for apparent wind angles of between 30 and 130° (presumably because the manner in which the rig is oriented to the wind allows the sails to work together and to use the slot efficiently. The conventional rig has similar values of lift coefficient at 30° apparent wind angie but this quickly reduces as the angle increases and the slot effect becomes less efficient. One reason that the AeroRig ® geometry is not quite as good at very high angles of attack could be associated with the end effects/losses under the foreboom - this reduces the effective aspect ratio of the rig (however a quick sail on an AeroRig® yacht will convince all but out and out racers that this is a small price to pay for the all-round visibility of an AeroRig® compared with the severely restricted visibility to leeward resuiting from the deck sweeping foresail of a conventional rig).

The AeroRig ® also produces a high drag coefficient at apparent wind angles of 170° and 180° which resuited in the high driving force coefficient for downwind sailing.

Figure 3 shows the result of the Wolfson's VPP performed on a 25.9 m 66 tonne Bill Dixon designed luxury cruising yacht. The VPP was run using a conventional rig geometry and an AeroRig® geometry using the coefficients obtained from the wind tunnel tests. As can be seen at true wind angles of greater than 70° the AeroRig® out performs the conventional rig - at angles of over 100° it is up to 1.5 knots faster. The reduction in performance at true wind angle of attack below 60° is very slight, ie. less than 3% and would hardly be noticed in practice.

The VPP does take into account the balance between optimum boat speed and the maximum lift being produced by the rig and accordingly reefs the rigs at the appropriate point, however this may not be the case in reality as the yacht could be sailed with different amount of reefing as sail trims, sail shape and heel angles change and the ease of handling the AeroRig® again would further work to its favour.

Ketch and Schooner AeroRig® Combinations

In a separate series of wind tunnel tests the sail area of the sloop-rigged model was split over two masts, one with 60% and the other with 40% of the sail area.

Figure 3a shows the AeroRig® performance estimate comparison between sloop and ketch.

The complete series of tests were then carried out on both ketch (60% of area on the front AeroRig® and 40% on the back) and schooner (40% on the front and 60% on the back).

A number of runs were carried out to determine the effect of increasing the separation between the rigs.

For both series of runs the relative balance between the rigs was determined and a simple spreadsheet made up in order to predict the locations of the centre of effort.

It was interesting to note, and this was evident from both the series 1 tests and the series 2 tests that the AeroRig® at its optimum setting would always be further outboard than the conventional rig. This is of great benefit to the two masted combination as the interference between the rigs is less than that expected with conventional rigs. Indeed reducing the spacing by 20% of the chord length of the sail made no significant difference to the driving forces produced on any upwind wind angle.

Practical corroboration

We have been fortunate to have had the opportunity to carry out on the water tests to validate the performance of the AeroRig® compared with the Bermudan rig and our practical observations appear to back up the wind tunnel data, although from our tests we rarely find the AeroRig® suffering degradation of upwind speed - frequently it outperforms conventional rigs. On the water tests tend to be subjective and we have rarely had exactly similar boats but have had specific tests carried out by third parties on a number of occasions.

On one such series of tests two Beneteau 42s7s were compared by Mark Chisnell, one with the conventional cruising rig and the other with an AeroRig® (both without spinnakers). Sailing in company, timed runs were carried out with two experienced yachtspersons on each vessel. Mark Chisnell's findings were that the AeroRig® vessel was 10% faster upwind and 30% faster downwind, even though it had 16% less sail. *See Figure 4.*

Another series of tests were carried out by Yachting World using their own instrumentation, on board two identical Hirondelle catamarans. Again the findings were the same, the AeroRig® being faster on all points of sailing with the largest gains offwind. *See Figure 5.*

Aside from these advantages, there are other aspects that help to contribute to the remarkable passage making times that some short-handed AeroRigged® boats have recorded:

- The ease with which AeroRig® yachts are able to bear away and the apparent lack of weather helm when reaching (which manifests itself by clear ability of autohelm systems to control the AeroRigged® yacht satisfactorily in worse sea states than the conventionally rigged yacht) is due to the relative lack of movement of the centre of effort in the athwartships (to the yacht) plane. As sheets are eased in the conventional rig, the centre of effort of the mainsail and jib move to leeward, thus increasing the moment turning the boat to windward - in the AeroRig® yacht the centre of effort remains the same distance from the mast and thus does not move to leeward as far. (This can also help to explain reduction in rolling as any initial roll will not have the same effect on the steering as on the conventional boat).

- The rig exhibits very good 'ghosting' performance primarily because the sails are held more securely and thus are unable to slat as their conventional counterparts.

- Much of the performance gained however has to be due to the owners themselves becoming more confident in using the AeroRig ® than they may have been with conventional rigs. As reefing is so easy and as depowering the rig can be done on any point of sail simply by easing the sheet, the cruising person is less likely to be as conservative and to reef early and thus naturally pushes the yacht harder. By way of example the 70 footer 'Fly' has regularly passaged from the UK to the Canaries in 7 days, on the first such time (her maiden voyage) with only 3 person on board they overtook the tail-enders of the British Steel Round the World Race Fleet that had started 48 hours earlier). The owner of the Dijkstra 63 excitedly reported back after entering the Tradewinds Zone for the first time that he doubted whether any fully crewed yacht with spinnakers could have consistently achieved the average speeds that he was making (a 186 miles per day) and even more recently a Beneteau 42s7 on two days achieved runs of 200 miles (this vessel also won her class in this year's Round the Island Two Handed Race circumnavigating the Isle of Wight in only 6.5 hours, this being only one hour outside the record breaking time established by an IOR Maxi with full crew and spinnakers, etc.

Superyachts

The advantages of the AeroRig® become more apparent when applied to larger yachts. There is no engineering reason why the rig cannot be increased in size and applied to yachts of 110, 150 ft LOA and perhaps even larger. Some designers are already talking to potential clients for AeroRig®yachts of this size.

Here the lower centre of gravity and the fact that no downwind sails are required means that the effect of the rig will be even more dramatic than that shown in the VPPS.

Loads on deck, equipment, sheets and halyards on conventional large yachts are huge, the deck is not a safe place to be in all but the lightest of sailing winds. On the other hand for the AeroRig® the semi-balanced nature of the rig means that the primary sail control line (the only sheet led to deck) is lightly loaded. The rig can be easily handled by an onboard crew of two, thus maximising space for guests. As the basic sail handling system is simple, complicated electro-hydraulic systems are avoided thus facilitating maintenance and minimising down-time due to mechanical or electrical problems so often associated with these large complex sailing yachts. Furthermore despite the additional cost of carbon fibre the actual cost savings in the whole yacht resulting from the reduced winch hardware, reduced rigging, reduced rigging attachment points and of course no need for local stiffening and strengthening, reduction in sail costs outweigh the cost of the hightech carbon rig leading to a real cost saving. (On a 110 footer we recently looked at the cost saving was in excess of US$250,000).

AeroRigs® for such yachts are feasible today using existing technology.

Future Development

We have developed techniques to produce a semi-wing section that is as light and as robust as our present round section. This has obvious windage/lift advantages, particularly as the wind will always be oriented in the correct direction. Although we have not as yet analysed the performance gains, early indications suggest there could be a noticeable improvement. The lengthened mast section also lends itself to the development of a new inmast furling system that we are currently designing.

So far we have concentrated on building cruising masts for safe, costeffective, efficient cruising. As the obvious handling advantages become more apparent and the aerodynamic gains increasingly evident, the application of the AeroRig® to some specialised race boats (short-handed or single-handed races) may become more attractive. The performance of the AeroRig® can be taken to a higher level utilising higher roached mains and jibs, lighter weight sandwich construction in part of the masts, more exotic carbon fibres, all of which we are currently utilising in the construction of our other composite race masts.

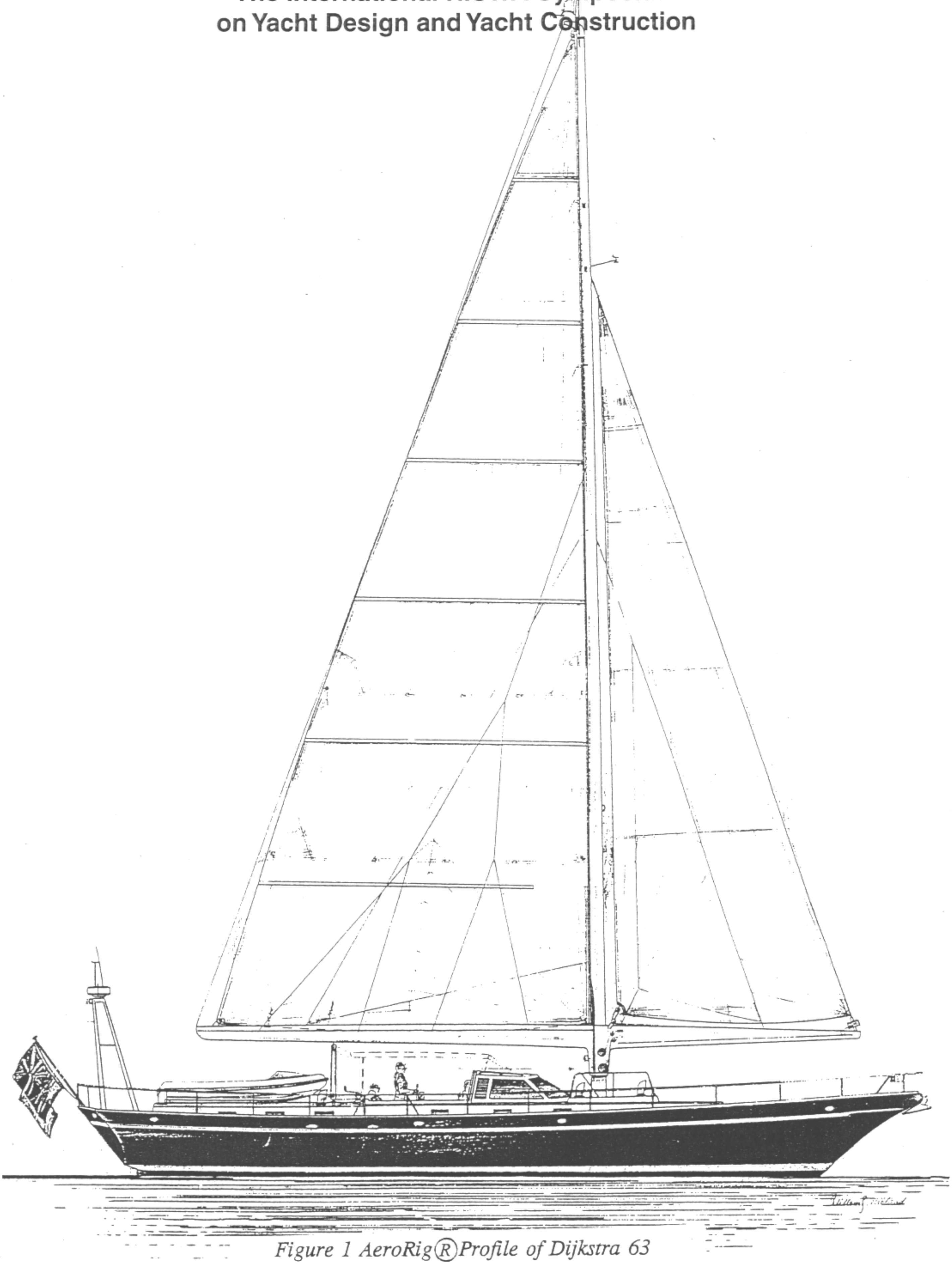


Figure 1 AeroRig® Profile of Dijkstra 63

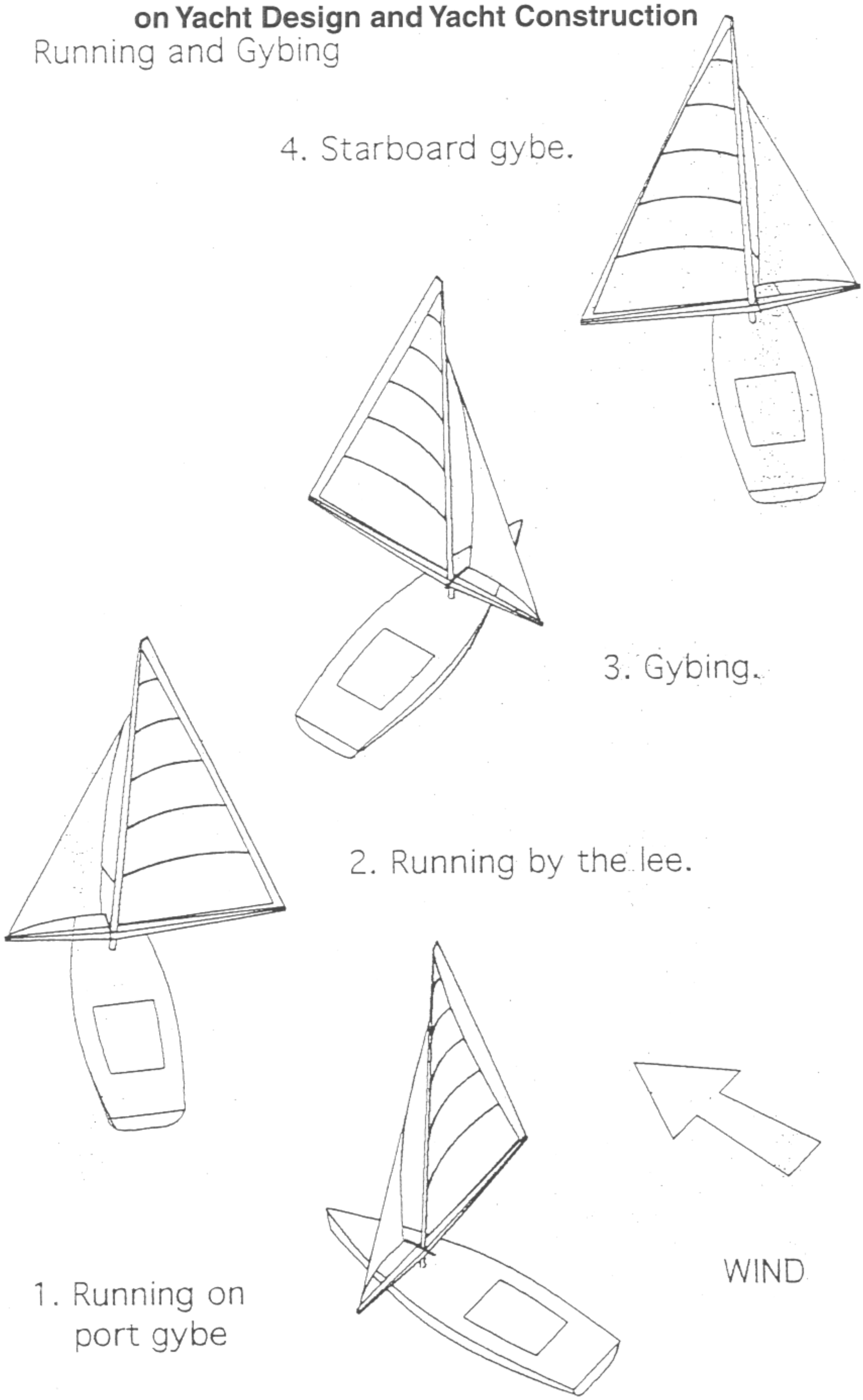
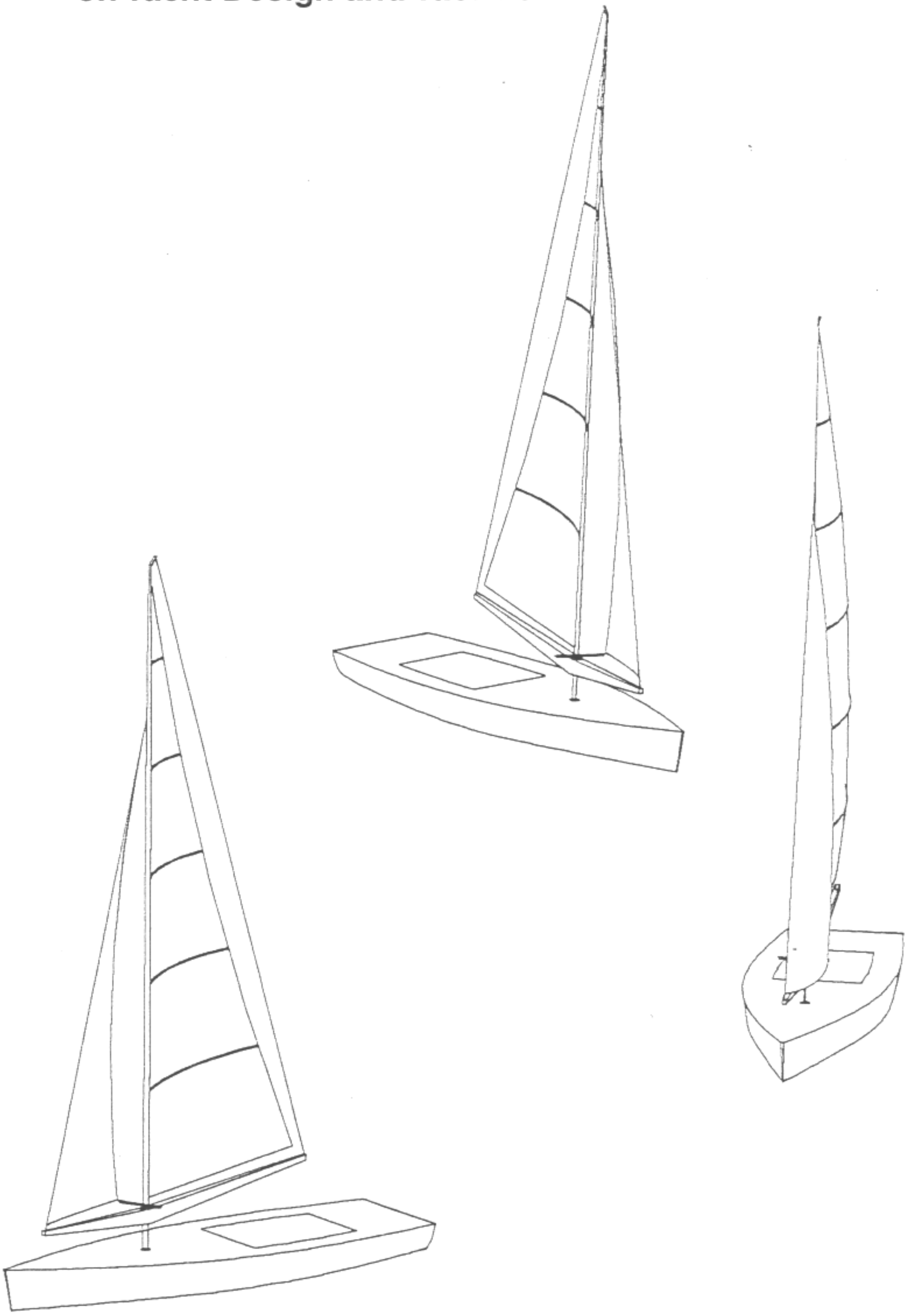


Figure 1a AeroRig®- Running and Gybing



Carbospars AeroRig

Figure 1b AeroRig®- Tacking

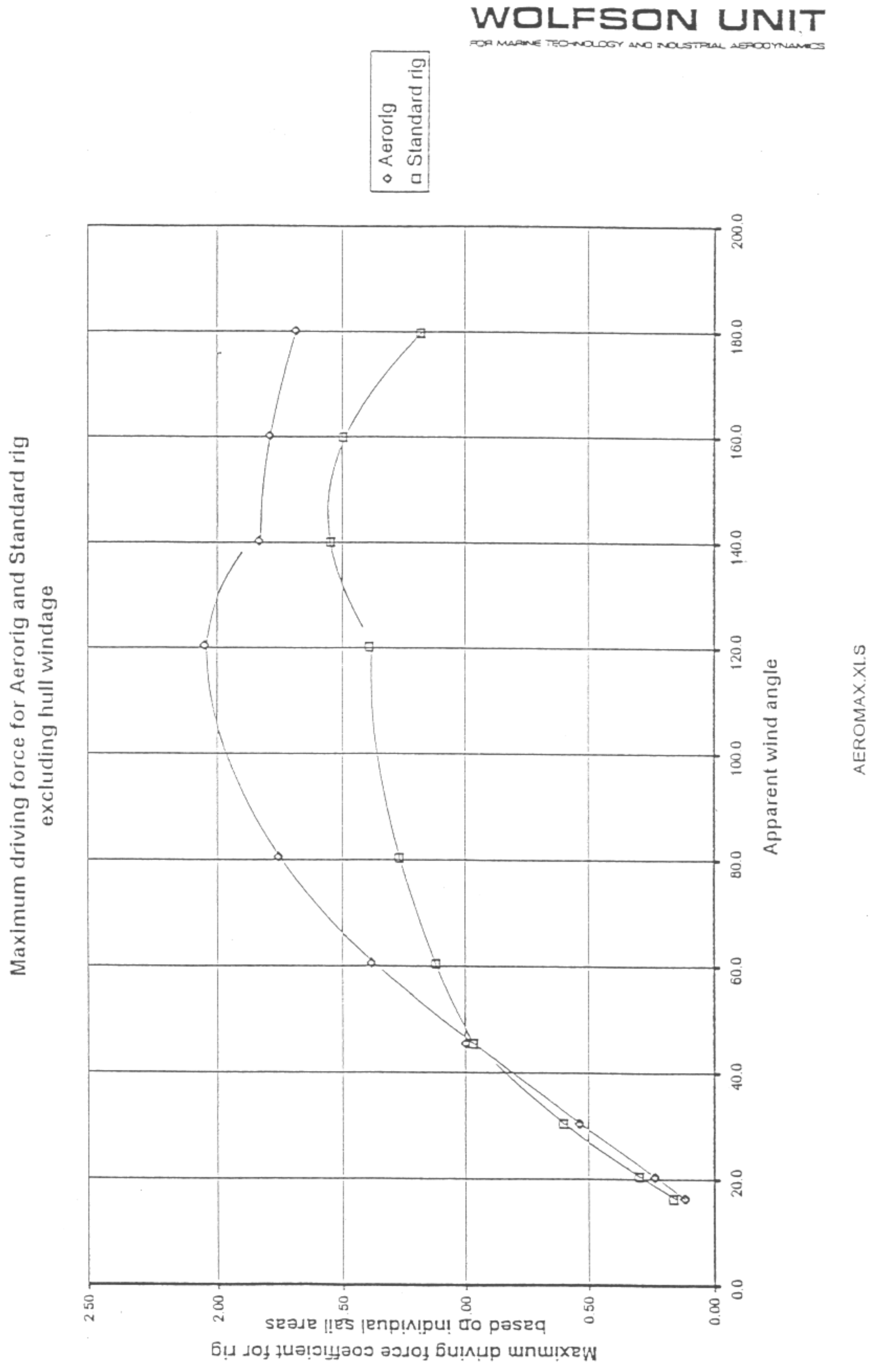


Figure 2 Comparison of Driving Force Coefficients of AeroRig®and Bermudan Rig for 80' Sloop

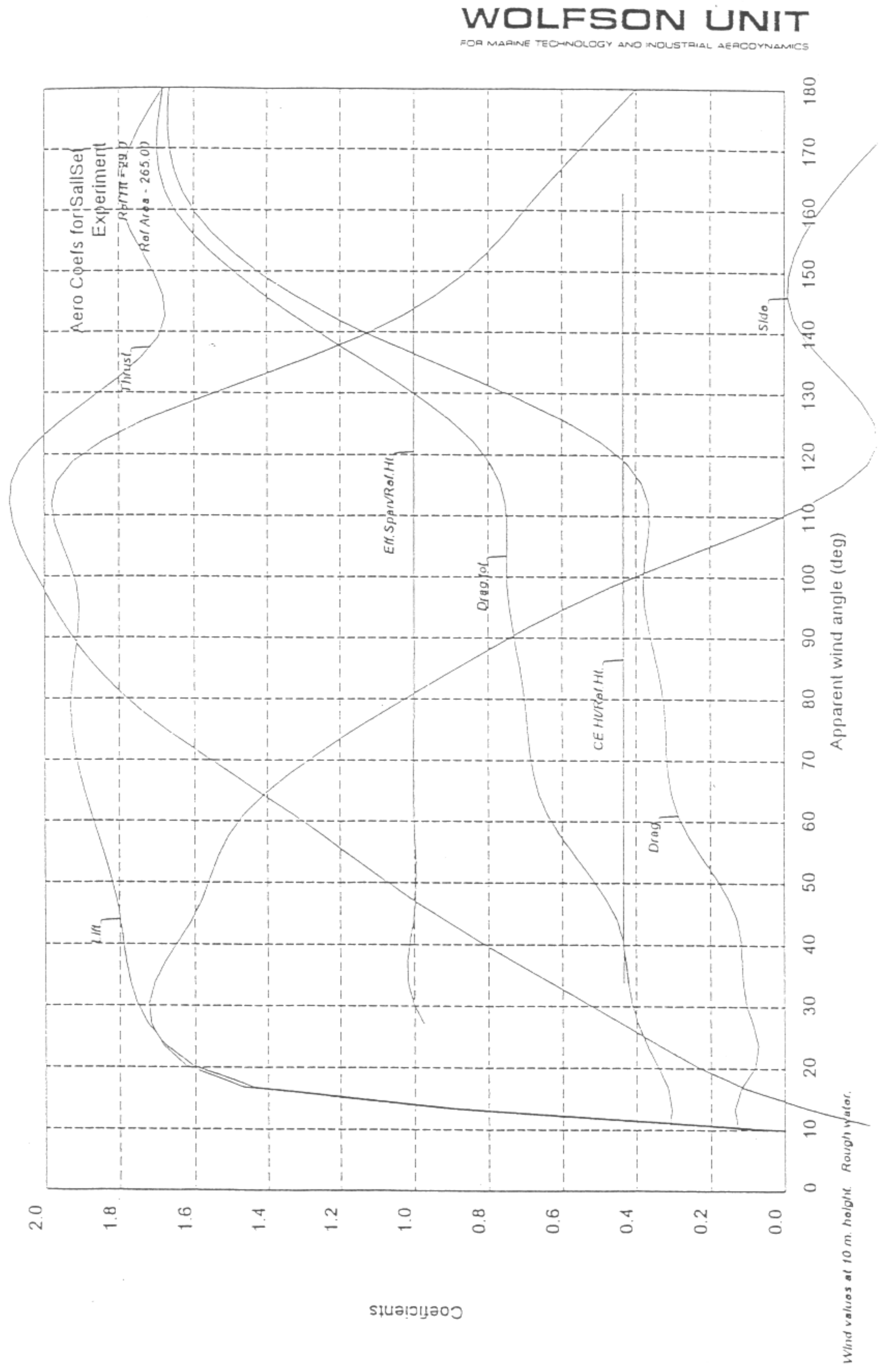


Figure 2a AeroRig® Coefficients for full range of Apparent Wind Angles

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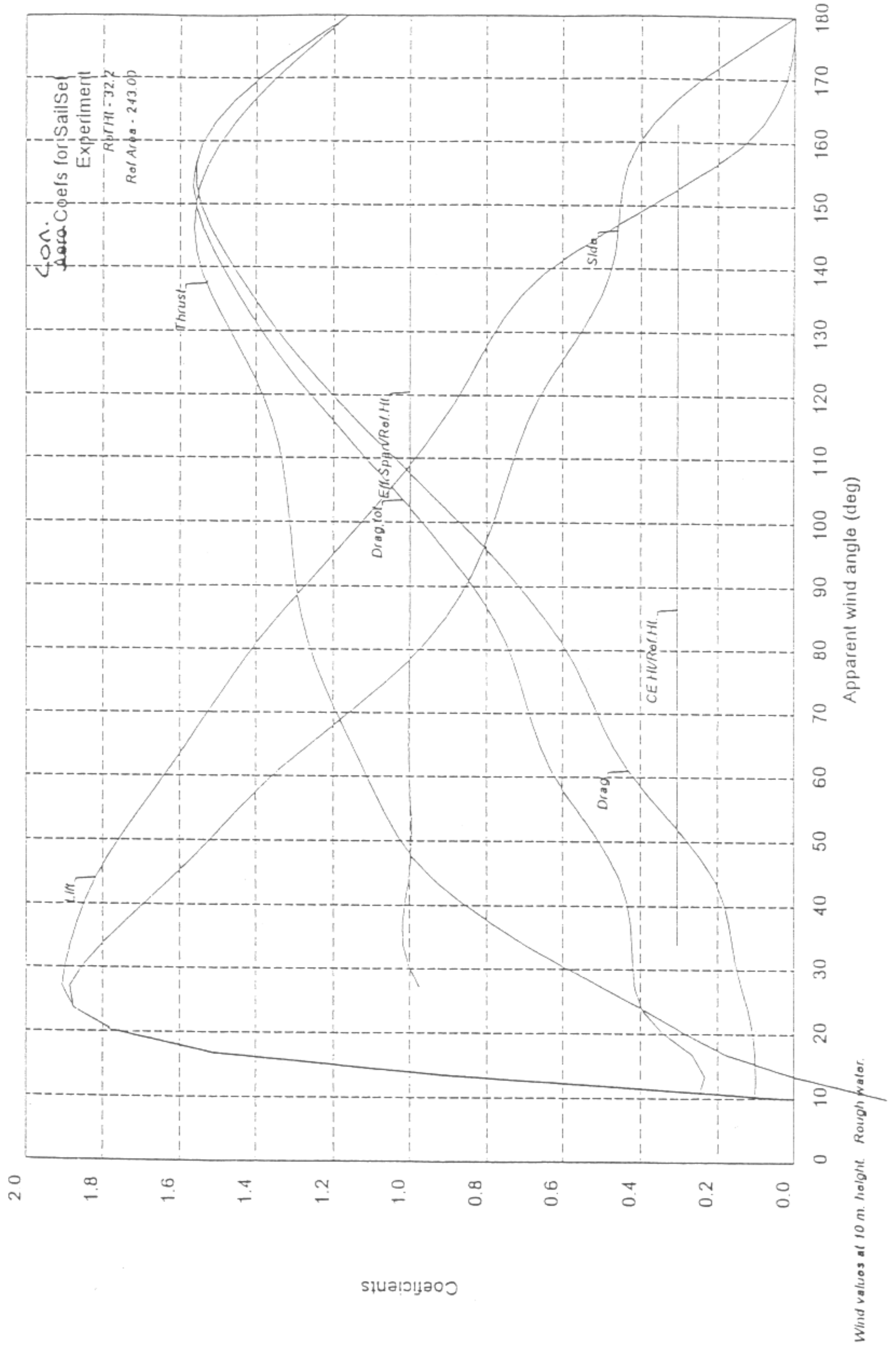

Figure 2b Bermudan Rig Coefficients for Full Range of Apparent Wind Angles

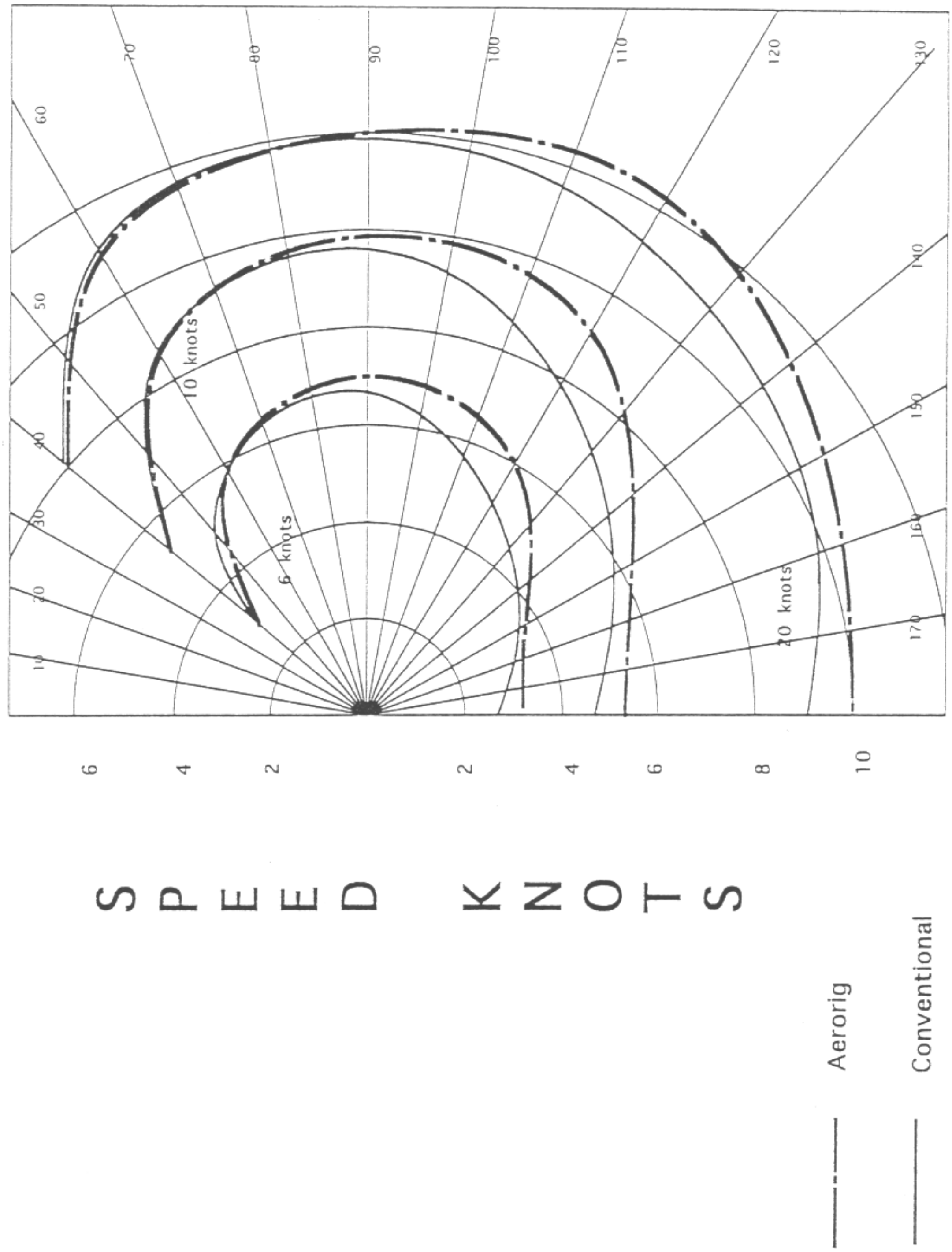

Figure 3 VPP Predictions for AeroRig(R)80' Sloop compared to Bermudan Rig courtesy of Angus Primrose Design (Bill Dixon)

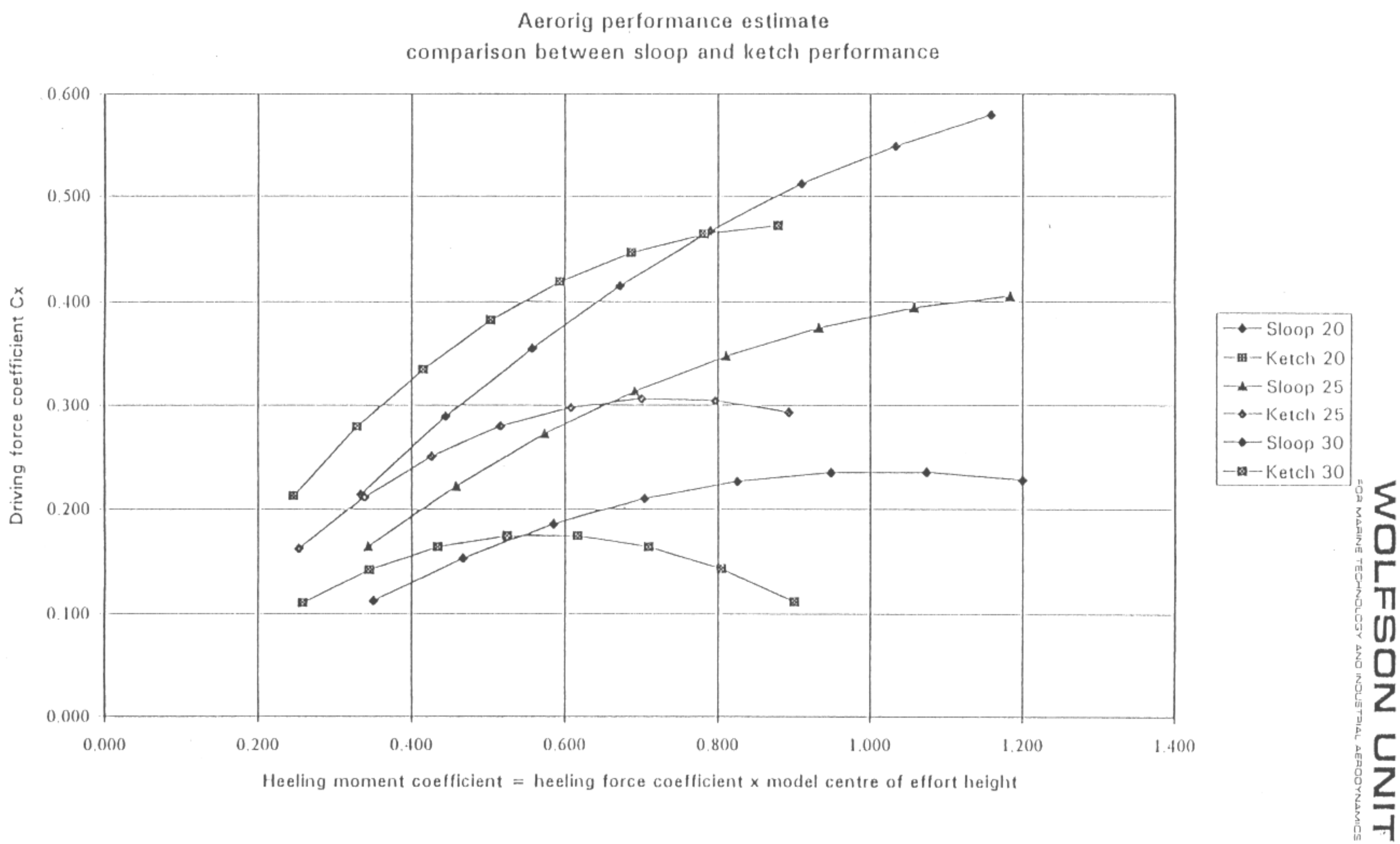

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Figure 3a Driving Force Coefficients - Comparison between Sloop and Ketch AeroRigs®

Comparison Beneteau 42s7

Wind Speed	Leg AWA	Time in Seconds Standard	Time in Seconds AeroRig	Standard Rig Slower by: Seconds	Standard Rig Slower by: Percentage
6	25 (no tacks)	264	224	40	15
10	25 (3 tacks)	630	555	75	11
7	35	210	188	22	10
5	90	288	208	80	27
7	135	280	207	73	26
7	180 (poled out jib)	387	267	120	31

	AeroRig®	Standard Rig
Total Sail Area	78 sq m	93 sq m
Mainsail Area	54.6 sq m	42 sq m
Headsail Area	23.4 sq m	51 sq m
C of G above deck	28%	48%

Figure 4 Independent on-the-water Comparison of Conventional Beneteau 42s7 with AeroRig® 42s7 courtesy of Mark Chisnell

Performance Comparison of two Hirondelle 23' Catamarans

'First Swallow' - Bermudan rig (245 sq ft)

'Magic Roundabout' - AeroRig® (212 sq ft)

Sea state:	Calm
Windspeed:	8 knots
Performance figures:	As recorded by Yachting World's computerised data logging system.

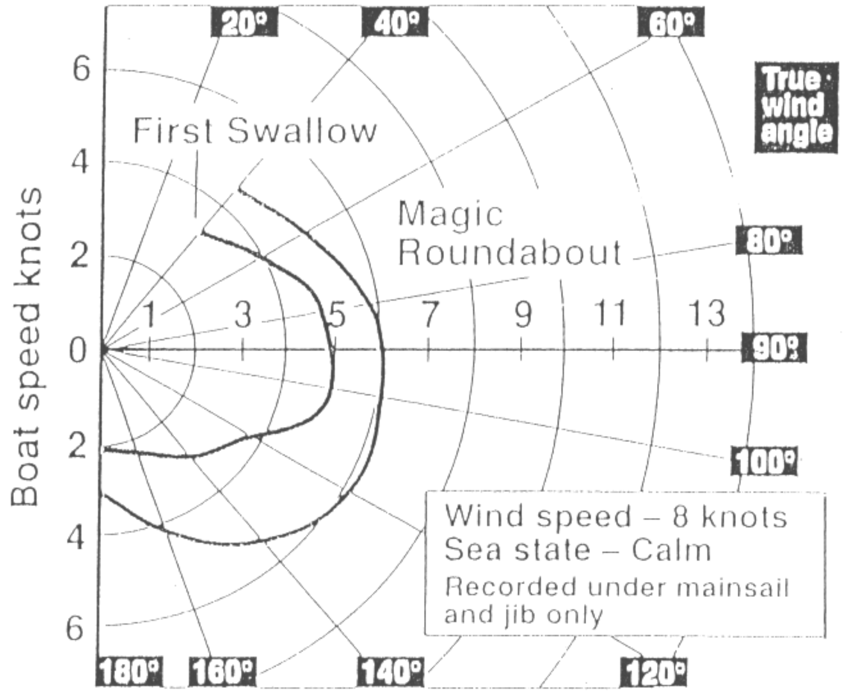

Figure 5 Performance Comparison of two Hirondelle 23' Catamarans courtesy of Yachting World