

From Lord Riverdale
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Twin Keel Yachts-Development Over 45 Years

by The Rt. Hon. Lord Riverdale, D.L., J.P. (Associate)

SUMMARY: In 1922-24, the possibility of twin keels was explored and model tests made. A small yacht was designed, built and tested. The findings are presented.

In the period 1936-39, a much larger twin keel yacht was developed after more extensive experiments with two models. Comments on the design and performance of this yacht are given.

Between 1947-60, there was an astonishing proliferation of twin keel and bilge keel yacht types. This development and some of these designs are reviewed.

In 1961, the author prepared a new design, attempting to apply the knowledge gained. In collaboration with Arthur Robb, this design was prepared for test and a series of tank tests was carried out at Cowes in 1962-63. A distinct advance was made. The tests are described. The yacht was built in 1963 and notes on performance are given covering 25,000 miles of cruising between 1963-67.

? * During 1958-66, John Lewis developed twin keel model racing yachts and did other experimental work. This work is examined.

Between 1962-66, Southampton University conducted a tank test programme on models of a large yacht with various appendages. Reference is made to these tests.

In 1966-67, new information and techniques made possible comparisons additional to the 1963 test data.

An attempt is made to assess present knowledge of twin keel yachts, indicate possible experimental work and forecast the potential field for this type of yacht.

INTRODUCTION

In 1922, it appeared to the author that centuries of development had produced no other alternatives for the keel appendage of sailing vessels than a pronounced fin or centre plates or lee-boards, while all versions of these three types had some obvious disadvantages. The possible use of twin keels, one on either bilge, seemed logical and to have attractive advantages for a cruising yachtsman. So far as the author could discover, however, the form had not been explored at all. Bilge keels had been confined to their use as anti-rolling devices and, even if enlarged and associated with sail, had not been other than additional to conventional hull designs.

It was possible that twin keels might have inherent drawbacks, even when applied to a yacht designed specifically with their incorporation in view, and only the building and sailing of such a craft would settle this point. One thing seemed clear to the author, a design to exploit twin keels could, and should, involve a fresh approach to an integrated conception which disregarded the centre keel and looked at the structural requirements as a fresh engineering problem. The author still believes that this is correct and that the conception of twin, and probably detached, rudder structures is a logical extension. Subsequent experience more than fulfilled the early hopes for the success of incorporating both these principles in a practical yacht.

The author's approach to designing twin keeled craft has always been bounded by the clear objective of producing cruising yachts, mainly for his own requirements, which placed emphasis on all-round qualities rather than obtaining the highest possible speed for racing. The development process has

been limited by financial considerations which may have had the virtue of keeping the various resulting projects realistic. Finally, the approach has been entirely amateur, which has encouraged free thinking.

In the present paper, some aspects of the history of twin keeled craft, as illustrated by the author's experience with the type, are presented and these are amplified whenever possible by information from other sources and from other workers in the field.

At this point it is convenient to define a difference between bilge keels and twin keels, since both occur in the discussion. In the present paper these are defined as follows:-

The Twin Keel Type involves no centre keel and has the construction arranged so that the main ballast is carried on or in the two keels. It may have single or twin rudders.

The Bilge Keel Type retains a centre keel which carries the bulk of the ballast. The construction may be conventional, with some strengthening to take the bilge keels, and in practice invariably has a single rudder.

HISTORY OF TWIN KEELED CRAFT

'Bluebird'-The First Twin Keeled Yacht 1922-24

The first design study for a twin keeled yacht revealed no serious difficulties and, as a preliminary to full size building, two models were constructed, one of them a conventional single keel control. Simple towing tests, upright and heeled,

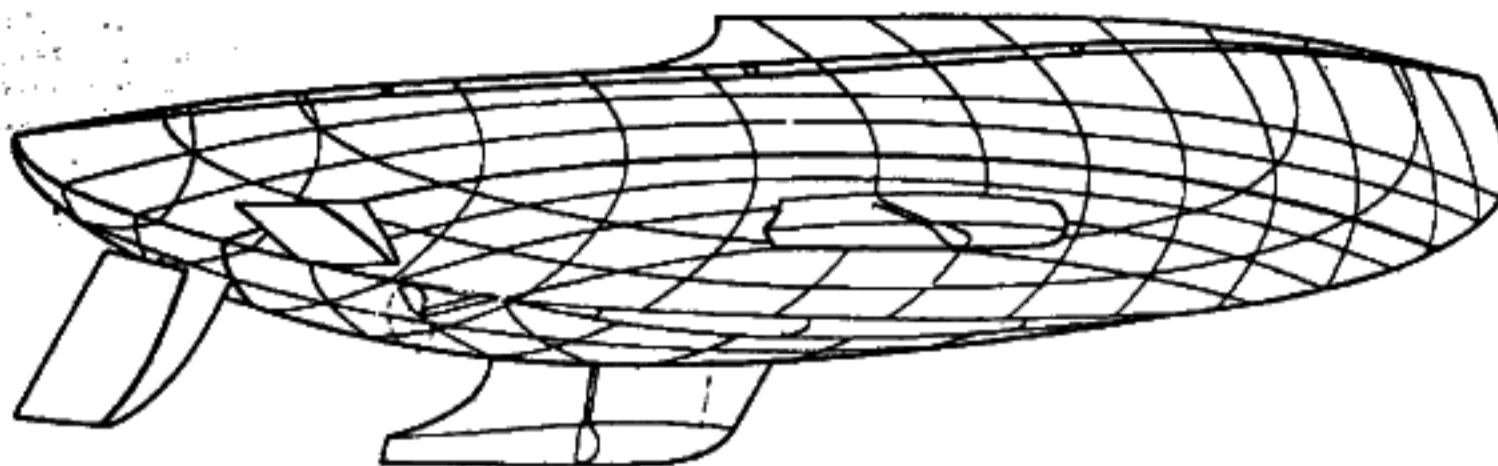


Fig. 1. 'Bluebird', 1924

and simple free sailing tests all supported the feasibility of the new concept and revealed nothing adverse. In retrospect, the models which were only 25 in. L.O.A. were too small and the tests were crude. They were valuable nevertheless.

As a result of the study a design was completed for a small cruising yacht 25 ft. L.O.A. (Fig. 1, Table 1). The objective for this design was a seakeeping cruiser, not a mere estuary cruiser, and this small yacht was built by the author as an all amateur job in 1923-24. In looking back there was little wrong with this hull, although it may seem a little unusual today with the Albert Strange canoe stern, the upright stem and the fine bow. This early design incorporated an extreme angle of keels which were 30° to vertical, detached twin spade rudders, little wetted surface penalty, and keels toed-in 2½". The ballast bulbs were asymmetrical.

In the light of later knowledge, the design tended to be on the extreme side and after cruising experience was gained with this small yacht a good deal more was known, aspects not considered in the original conception had emerged and some questions were posed to which there were no answers at that date. All these points are briefly commented on below.

Design Objectives Attained

- (a) Shallow draught and ability to take the ground upright could be combined with seakeeping qualities.
- (b) Adequate structural stability could be achieved with a design incorporating twin keels (5 rigs, 3 engines and 45 years later this yacht is still sound and in commission).

Discovered

- (a) Ability to sail off after touching bottom (due to deeper draught when heeled than when upright).
- (b) Ability to sail with the weather keel and rudder airborne with no detriment.
- (c) Ability to continue sailing and under control with ability to go about or gybe when over-powered and heeled to the point where the sails lose all drive.
- (d) With the two rudders disconnected, full control was achieved with the leeward rudder only. The weather rudder feathered itself.
- (e) Far better self-steering qualities than expected with an unbalanced hull.
- (f) Speed and performance good with sufficient wind.

Subjects for Speculation

- (a) The performance under power was good. Was this due to a good propeller location which was not sheltered by a keel appendage?

- (b) The impression was gained that the yacht had much more power to carry sail than expected. Why was this?
- (c) The light weather performance was poor. Why was this?

Bad Features of the Design

- (a) As a practical consideration, it was not good to have keels and rudders projecting beyond the hull when lying alongside quays, etc.
- (b) There was difficulty in containing or removing bilge water because there was no reverse turn in the bilge.

'Buttercup' and other yachts of the 1920's

The next serious attempt to develop a twin keel yacht after the 1924 'Bluebird' was 'Buttercup', designed by Robert Clarke.

This was similar in size and purpose to the author's first 'Bluebird'. The twin keels were nearly vertical, located fairly far forward and very thick, but of a higher aspect ratio than those on 'Bluebird' and were combined with a large skeg and single rudder. The author discussed this design with Robert Clarke and the then owner. The rudder area had to be increased considerably after the early trials to provide adequate control. The reports on performance were encouraging although a marked and possibly undesirable feature was a visible secondary wave developed by the keels at speed.

The only other example of a twin keeled yacht, known to the author in the 1920's, was a small American type of shallow draught hull with large vertical parallel flat wooden keels and single rudder. This was 'Akista' which was built by an amateur in England. It was reputed to go well although the author saw a photograph in which the rudder had lost all contact and was airborne as well as the weather keel.

The First 'Bluebird of Thorne' -1936-1939

Continuing the story in chronological order, in 1936 the author designed a larger twin keel yacht for his own use. Two models 48 in. long at 1/12th scale were built. Towing tests by balance beam, (Fig. 15) both upright and heeled, were conducted and both models were free sailed. The resultant worked up design was quite different from the first 'Bluebird', and in retrospect was almost a step backward as it had a vestigial centre keel. This was only included to facilitate the containment of ballast, bilge water and tanks and to permit taking the ground on three points. This design was therefore intermediate between the bilge keel and the twin keel type. It was completely balanced, maintaining course at various angles of heel with minimum attention. The keels were parallel to the centre line and at

TABLE I Records of Four Yachts

	'BLUEBIRD'	'BLUEBIRD OF THORNE'	'CURLIEW OF WALNEY'	'BLUEBIRD OF THORNE'
	1924 Still sailing 1967	(Now 'Inveranda') Still sailing 1967	1954 Still Sailing 1967	1963 In Commission 1967
	Designed, built and originally owned by the author	Designed by the author. Built Richard Dunston Ltd., Thorne, under the author's supervision. In his ownership for 20 years	Designed, partially built and owned by K. D. Fisher. Some collaboration with the author	Designed by Arthur Robb and the author in collaboration. Built Richard Dunston Ltd., Thorne.
	Wood construction	Steel hull	Wood construction	Steel hull

L. O. A.	25 ft.	48 ft.	29 ft. 6 in.	50 ft.
L. W. L.	22 ft. (Later made upto 24 ft. to measure for R.O.R.C. rating)	39 ft.	24 ft.	40 ft.
B	6 ft. 7 1/2 in.	11 ft.	8 ft. 2 1/2 in.	12 ft.
d - upright - heeled	2 ft. 9 in. 3 ft. 9 in.	4 ft. 9 in. 6 ft. 6 in.	2 ft. 9 in. 4 ft.	5 ft. 4 3/4 in. 6 ft. 9 in.
Displacement	3 tons	16 1/2 tons (cruising load)	4 1/2 tons	15 tons datum (+ 2 tons disposable load)
Thames Measurement	4 1/2 tons	18 1/2 tons	6 tons	21 tons
Sail Area	250 sq. ft. (various rigs from 200 to 300)	950 sq. ft. working	325 sq. ft.	950 sq. ft. working
Power	Various 4 bhp Inboard or Outboard Originally C-P feathering propeller	20 bhp. 1000 rpm. Gardner Diesel 2L2 C-P feathering propeller	8 bhp. Stuart Turner Petrol. Direct Fixed Propeller	42 bhp. 1500 rpm 2/1 Reduction. Gardner Diesel 4LK. Emergency rating 52 bhp. 1800 rpm C-P feathering propeller

bulbs
net
whole keel

Twin keels, symmetrical, cast steel, thin, heavily flat, loed-in 2 1/2° and carrying nearly all ballast in asymmetrical lead bulbs. Wide from centre line and at 30° to vertical. Projecting outside hull beam. Small lead shoe added on centre line of hull later. Twin detached rudder structures. Flat steel plate. Slightly balanced rudders with small skegs, parallel to centre line.

Twin keels, symmetrical streamline form in cast steel, comprising two-thirds of ballast, connected to twin rudder structure, also symmetrical streamline. The whole parallel to centre line. Fairly wide spaced but within hull beam and at 25° to vertical. Remaining ballast is lead within vestigial stub centre bulge. Taking ground on three points, centre bulge and twin keels.

Twin keels, very similar to 'Bluebird' of 1924 but asymmetrical. Cast iron with lead bulbs 1500 lb. each. Keels almost parallel to centre line, within hull beam and at 25° to vertical. Twin rudders. Very similar to 'Bluebird' 1924, and also flat plate type. Taking ground on tank tested form.

Twin keels, asymmetrical carrying all lead ballast. Rudder to centre line than 'Inveranda'. 19 1/2° to vertical, slightly greater aspect ratio. Toed-in slightly, 1 1/4°. Tank tested form and angles. Twin rudders, symmetrical foils of tank tested form. Skeg and rudders, detached from keels and slightly loed-in. Rudders not balanced. Taking ground on twin keels only.

Note: Since altered as result of damage to one similar rudder on centre line, located further aft. Taking ground on twin keels only.

1924

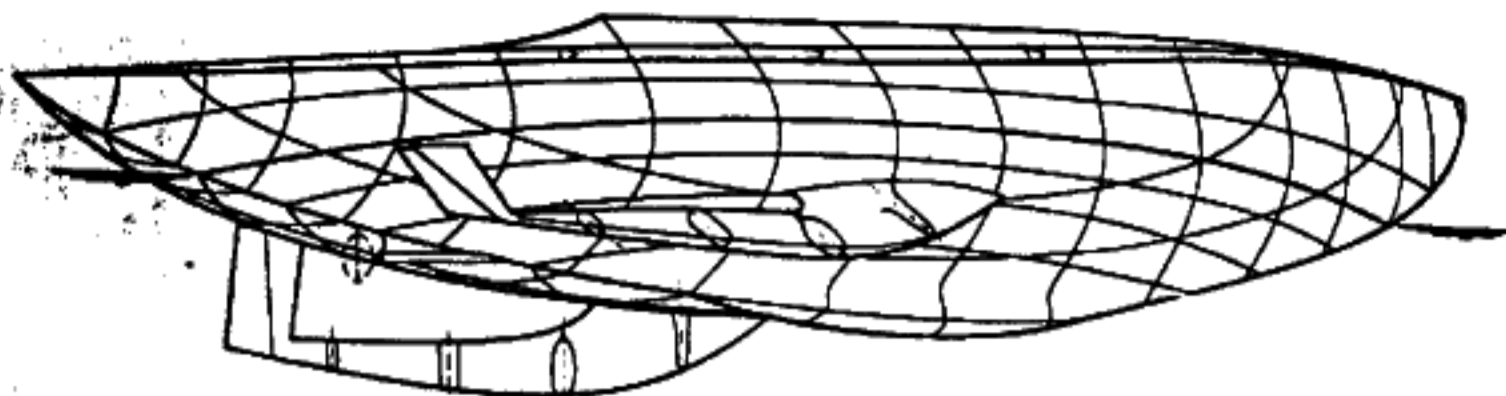


Fig. 2. 'Bluebird of Thorne', 1939

25° to the vertical and connected to the rudder structures as shown in the lines plan of Fig. 2.

Steel construction was adopted, partly for ease in dealing with the stresses involved, and partly to facilitate alteration should this be required. To some extent the design was influenced by the financial risk involved.

The author sailed this yacht from 1939 to 1961, covering perhaps 40,000 miles, and she was, and is, a good cruising machine with certain limitations. Outstanding good features were sea-keeping and heavy weather qualities, safety, balance and directional stability with an adequate behaviour in strong wind. The speed was poor in light winds. Manoeuvrability at slow speeds under power was also poor.

'Curlew of Walney'

In 1952-1954, K. D. Flather designed and built 'Curlew of Walney' an endeavour in which the author had a 'walking-on part'. This yacht, details of which are given in Table I, was very similar to, but a somewhat enlarged, 'Bluebird' of 1924. The main difference from the latter craft was that foils of an asymmetrical section were incorporated. No precise tests or findings can be reported other than a satisfactory record similar to the first 'Bluebird' in characteristics.

'Atalanta'

An entirely fresh approach of considerable merit appeared with the 24 ft. W.L. 'Atalanta' design by Uffa Fox. This was for production in hot moulded ply by Fairey Marine, by whom large numbers were produced and sold. The craft had ballasted, retractable, high aspect ratio, vertical asymmetrical foil keels. This made beaching and easy trailing possible, combined with good sea-keeping qualities. Steering was with a drop rudder, a device which must be mechanically robust in a craft the size of the 'Atalanta'.

The performance of this craft was acceptable and the class is still popular.

'Fay Loong'

J. Laurent Giles designed 'Sopranino' in which Colin Mudie made an Atlantic passage. This was almost a dinghy form hull with fin keel, the best known example of this general type being 'Trekka' in which John Guzzwell sailed round the world single-handed. For Dr. Wells Coates, Jack Giles produced a design of this same type but almost 10 ft. longer with a 30 ft. L.O.A. and fitted with unusual twin keels. Dr. Wells Coates desired keels which could be drastically increased or reduced in area without alteration in C.L.R. This was achieved by an unusual three blade opposed fan form. No results regarding the usefulness of this arrangement are available as the yacht suffered from a plethora of simultaneous experiments with an entirely unconventional rig. The operation of the keels was difficult and the owner died before these difficulties were resolved.

The yacht subsequently came into the hands of Group Captain J. H. Reynolds who applied a conventional rig, faired in the keels in the retracted form and found he had a useful yacht as a result of these changes. Dissatisfied with the steering characteristics with a single narrow drop blade rudder, and after discussion with the author, he designed and applied twin rudders with an asymmetrical Clarke Y. H. section. He reported an improvement in steering qualities and sailing performance as a result. Thus asymmetrical rudder blades have been tested with success in balanced spade form where they may be required to carry some of the lateral resistance as well as undertake the steering function.

'Transit'

In 1962-63, Laurent Giles and Partners designed 'Transit' for Robert Pretty. This was a large high-powered motor sailer type. She hardly fits the series of designs under review, but is mentioned because of her large size, details of which are given in the following table and because she was intended to sail well despite being a motor sailer.

The design was also interesting in that it was the first twin keel craft to be tested at the Stevens Institute Test Tank in the U.S.A.

Length Overall	54 ft.
Load Water Line	43 ft.
Beam	14 ft. 11 in.
Draught	5 ft. 3 in.
Sail Area	950 sq. ft.
Power	2 x 50 B.H.P.
Thames Measurement	43 tons

It is understood that initial tests were discouraging. With modified keels at different angles, the design was re-tested and a more satisfactory result emerged. It is believed that reasonable sailing performance was obtained with a slight toe-out of the keels, but at some penalty under power.

The keels are of low aspect ratio with a moderate thickness/chord ratio. They are parallel to the centre-line and slightly angled to the vertical. The hull has the form, centre keel and rudder typical of a full displacement hull of moderate speed. When sailing, the yacht has to contend with the drag of two stern gland chocks, shafts and 'A' brackets. The two sizeable propellers are, however, fully feathering.

The owner is satisfied with the sailing performance of this yacht, which is reported to be better than expected, and the craft is understood to be extremely comfortable, seakindly and easily handled at sea.

Proliferation of Design and Public Interest

By the end of the early 1960's, many professional yacht designers had produced bilge keel yachts. Classes of small

utility cruisers of this type were proliferating, with examples appearing in many countries including France, Australia, New Zealand and South Africa. There had, however, been curious little interest or development in U.S.A. and investigation has revealed no parallel experiments in that country.

By this time, the number of twin and bilge keel yachts sold to the public could be numbered in thousands. Year by year the examples of this type of yacht shown at the Boat Show increased in numbers until they became a significant proportion. A questionnaire by a large organisation to establish the type most favoured for chartering produced the astonishing result of nearly 60% in favour of 'bilge keels'.

Most of the examples of twin keeled yachts without centre keel retained a large skeg amounting almost to a centre keel although the author's experience and experiments conducted by John A. Lewis, a well-known designer in the model yacht field, suggest that this is unnecessary. Some designs have appeared which are more sophisticated and offer a better performance prospect with attention to foil form, root fairing and keel placement. The author does not know an example with other than a single rudder.

Some of these small yachts were somewhat crude, and many might be criticised as unlikely to have enough power to carry sail and were not likely to have a high performance although on the credit side, several of these have crossed the Atlantic and one sailed to England from Singapore.

As a final note on the future for larger craft of the type, Arthur Robb has a design commission for a 53 ft. twin keel yacht. This is likely to be tank tested. Four of this design are almost certain to be built and will be rather different in characteristics from 'Bluebird of Thorne'.

Another yacht, again differing from 'Bluebird of Thorne', by

another designer and about 45 ft. length overall, is also probable. From the interest and enquiries that are coming up from many countries, it seems likely that other large yachts of this type will be appearing over the next year or so.

THE DESIGN AND PERFORMANCE OF A SECOND 'BLUEBIRD OF THORNE'—1961-1966

Design

It will be clear from what has been said that when the author came to consider a new yacht for himself in 1961, the situation was very different from when the first attempt in the field was made during 1924. In the intervening period between the two designs, the whole science of tank testing sailing yachts had come into being and the earlier 'Bluebirds' had, between them, given many thousands of miles of full scale experience with the type of craft.

Both these latter points were taken into account when considering how the new design should be carried out.

With regard to the basic shape of the new craft, Fig. 3 shows that she is relatively narrow, since the author has never believed that a large beam is necessary for a relatively shallow draught yacht of twin keel type. It was hoped that an adequate performance could be achieved without necessarily entering the performance realm of the ocean racing yachts and it was as an insurance against failure in this respect that tank tests were carried out.

It was further felt that the final design should take account of the fact that any cruising yacht that does not do most of its normal sailing at less than 20° angle of heel is hardly fit to live in, and it should be remembered that the wide oceans produce seas which are apt to give an additional 10° of heel in the leeward lurch.

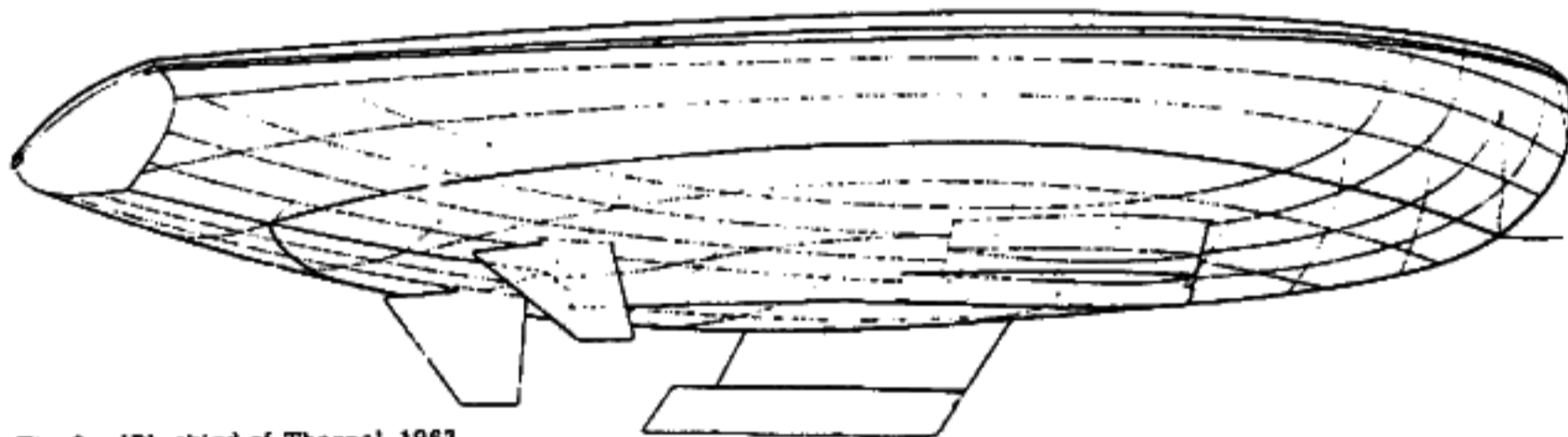


Fig. 3. 'Bluebird of Thorne', 1963

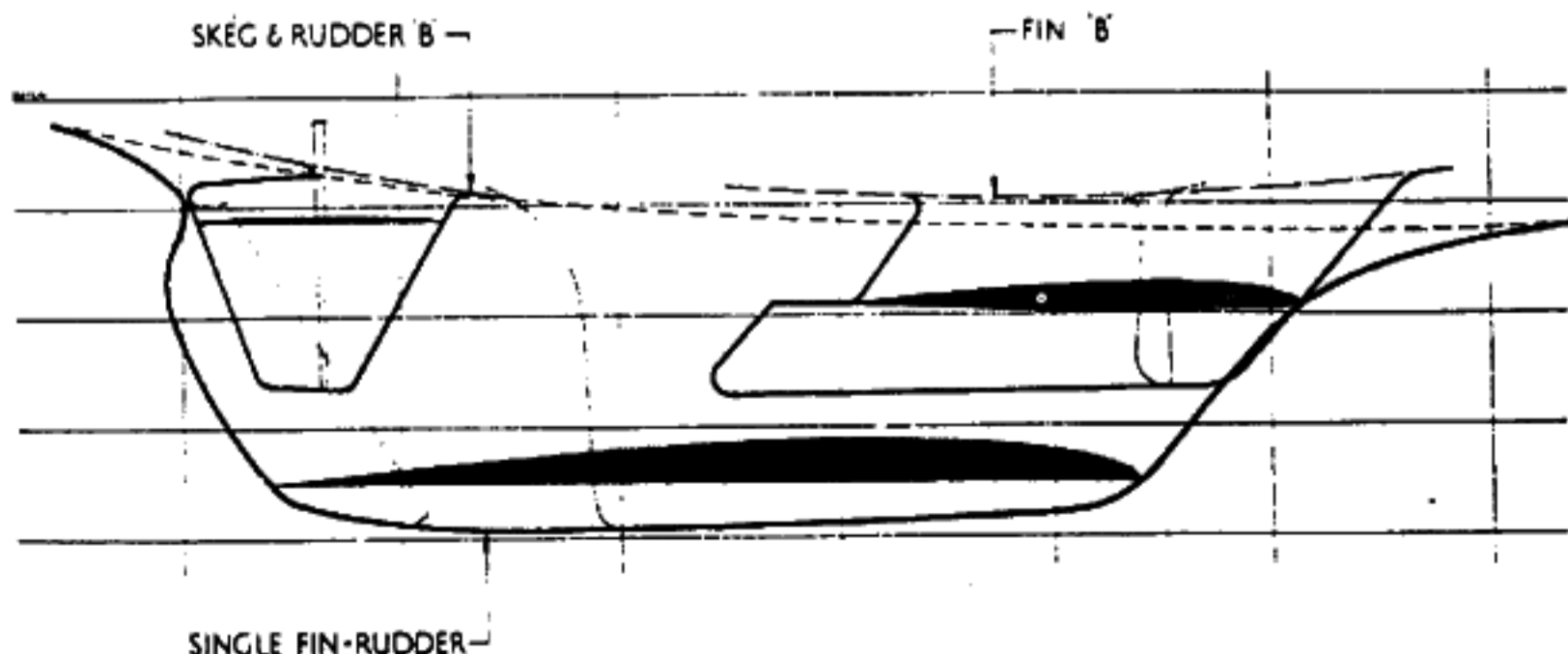


Fig. 4. Sketch comparison

TWIN KEEL YACHTS—DEVELOPMENT OVER 45 YEARS

With the foregoing and many other considerations in mind a design was prepared by the author for a 50 ft. yacht. From this point, the design was worked up by Arthur C. Robb, in collaboration with the author. The process was an interesting and rewarding exercise.

As mentioned earlier, the design of the new yacht was supported by tank tests and two features of these were of particular interest. First, it was possible to test a new design against a similar twin keel type, which had been cruised for twenty years by the author, and all its performance and behaviour characteristics were known so that an immediate practical correlation was available between the model and full scale regime. Secondly, it had transpired that the under-water canoe body of the new design was fortuitously almost identical to 'Uomie', 32 ft. W.L., a well-known and successful ocean racer designed by Arthur Robb, which was R.O.R.C. Champton, Class II in 1954.

The tests on the old and new 'Bluebird of Thorne' showed the preliminary design study for the latter to have favourable performance and the programme was extended into a limited investigation of keel and rudder configurations, the effect of differing attitudes of keels and finally, comparison with an identical hull with single keel. Dynamic rolling tests were also carried out. A measure of research was thus achieved and

this was extended by further tank work in 1967. The results of the various tests are of considerable interest and are therefore given in some detail in the discussion which follows.

The model experiment data presented are confined to those that were obtained with the new 'Bluebird of Thorne' hull, since the performance of the 1939 design was obtained merely as a yardstick by which the former craft would be judged. In this respect it may be said, at once, that a gratifying improvement was obtained.

Two alternative twin keel configurations were investigated and these were designated 'A' and 'B'. The latter was the most satisfactory and is shown in Fig. 4. The 'A' design differed by having the greatest thickness 7% further forward and had a sharp leading edge. Two twin rudder alternatives were also evaluated and these were similarly designated 'A' and 'B'. Once again, it was the 'B' form shown in this diagram, which was the most satisfactory. The 'A' rudder was a symmetrical foil, with sharp leading and trailing edges. The greatest thickness was approximately at the rudder stock. The single fin configuration as shown was derived from 'Uomie'. All the tests, including those on the single finned version, were evaluated for one displacement and V.C.G. position.

Table II shows the physical data for all the tested craft, including the 1939 'Bluebird of Thorne'. Table III gives a key

TABLE II Comparison of Full Scale Physical Data. Model Scale 1/12th

	New design for 'Bluebird of Thorne' as built 1963	The same canoe body with single fin and rudder derived from 'Uomie'	'Bluebird of Thorne' 1939
Displacement.	15.007 tons.	15.007 tons.	17.17 tons.
L.O.A. Hull.	50.26 ft.	50.26 ft.	50.66 ft.
Flotation W.L.	40.51 ft.	40.51 ft.	39.00 ft.
Designed W. L.	40.00 ft.	40.00 ft.	39.00 ft.
Maximum Beam.	12.09 ft.	12.09 ft.	11.62 ft.
Maximum Draught.	5.05 ft.	7.85 ft.	5.06 ft.
V.C.G. below D.W.L.	0.254 ft.	0.254 ft.	1.00 ft.
Sail Area.	1101 sq. ft.	1101 sq. ft.	1101 sq. ft.
Static Wetted Area.	556.3 sq. ft.	524.2 sq. ft.	654.76 sq. ft.
Longitudinal Position of C. of E. aft of stem.	16.30 ft.	16.30 ft.	18.00 ft.
Vertical position of C. of E. above D.W.L.	20.90 ft.	20.90 ft.	19.70 ft.

TABLE III Model Configurations and Comparisons

Description	Keel Configurations		Rudders and Skegs		Speed made good to windward (VMG) at true wind speed (TS) of 15 knots	Upright speed with 500 lb of thrust
	Type	Toe-in to CL.	Type	Toe-in to CL.		
New design for 'Bluebird of Thorne', 1963.	A.	2'	A.	2'	4.7	7.1
	B.	2'	A.	2'	4.7	6.9
	B.	2'	B.	2'	4.9	7.4
	B.	1 1/2'	B.	2'	5.0	7.2
	B.	-1'	B.	2'	4.7	7.0
	B.	1 1/4'	B.	2'	5.0	7.3
Hull as above. Similar 'Uomie'	Single fin & rudder	Derived from 'Uomie'	Removed		4.7	7.3
'Bluebird of Thorne' 1939.	As on 'Bluebird of Thorne'				4.3	6.8

to be expected... sharp leading edges... more pronounced

tank test

and explanation of the various 1963 configurations, together with a brief tabulation of their effect on performance. It will be seen from this that all versions of the new design were superior to the original 'Bluebird of Thorne'.

Alteration in the angle of toe-in (or out) of the keels, had a marked effect on windward ability and some effect on angle of heel. The type 'B' keels, toed-in $1\frac{1}{2}^\circ$, was the best of the configurations tested. However, a toe-in of $1\frac{1}{4}^\circ$ offered the best compromise between speed made good to windward and up-right speed.

Table III shows that the twin keeled version was better than the single keel yacht when all other variables which affect windward performance such as sail area, rig and V.C.G. were held constant. In this respect it must be stated, of course, that the single keel design was handicapped in these tests as at full scale it would have had a lower V.C.G. and this would undoubtedly have improved the performance.

No test was made with varied attitudes of toe-in of the rudder assemblies since the change would have been small and the results already obtained were accepted as satisfactory.

Photographs showing the flow patterns for the best of the tested configurations were obtained. These showed reasonably clean flow under all the examined conditions, with the exception of ventilation on the upper surface of the windward keel at the rather extreme heel angle of 30° . This is illustrated in Fig. 5. The reason for the ventilation becomes plain from Fig. 6 which shows that, under these conditions, the intersection of the keel and hull comes clear of the local water surface.

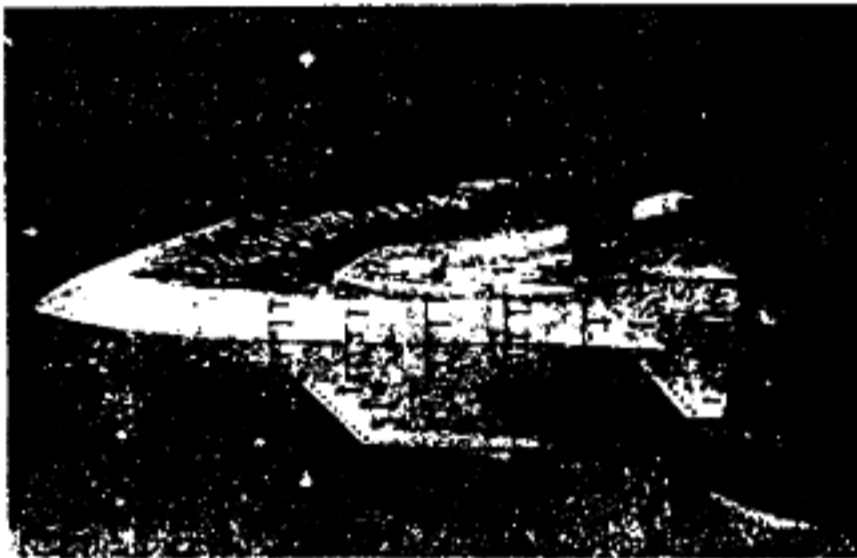


Fig. 5. Flow test at 30° heel, 8.2 knots of new design. Keels— $1\frac{1}{2}^\circ$, rudders— 2° . Toe-in.

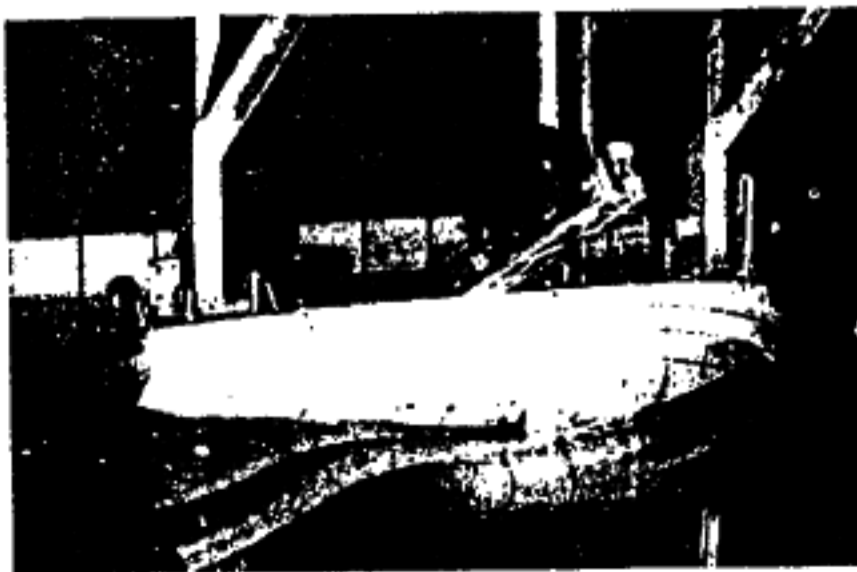


Fig. 6. Surface view at 30° heel, 8.2 knots of new design. Keels— $1\frac{1}{2}^\circ$, rudders— 2° . Toe-in.

The author wanted to investigate, by means of model tests, any possible dynamic roll-yaw interaction induced by the powerful twin rudders, since in a cruising yacht it is important to minimize the discomfort of any synchronous or excessive rolling over long periods. A mechanism was therefore devised which would give a rudder rate adjustable from 3.7° to 25° per second full scale. With a hard-over position 30° to central, the maximum rate simulated a helm oscillation of 2.4 seconds between hard-a-starboard and hard-a-port. The roll angles obtained in tests with this apparatus are plotted in Fig. 7 and show the

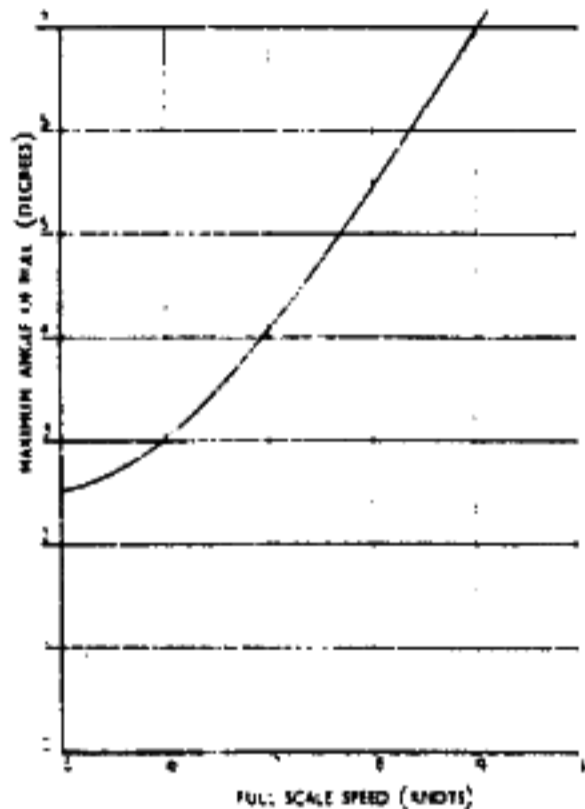


Fig. 7. Variation of max. angle of roll with speed

maximum value it was possible to produce with periodic application of port and starboard rudder at any given speed. It was concluded from the data that no appreciable reinforcement of roll would take place. However, these tests had to be carried out in smooth water without the excitation effects of waves or the effect of sails which could be either damping or exciting.

It is of interest to examine the characteristics for the best of the configurations in more detail and Fig. 8 shows the complete upright resistance curves, both for the best twin keel version and for the single fin configuration. It will be noted that the resistance differences are relatively small and become insignificant over the operational speed range. Fig. 9 shows the effect of sail area changes on the speed made good to windward. The sail area was changed from the modest design value of 1100 sq. ft. to 1550 sq. ft. so that subsequent comparisons could be made with other yachts. The sail areas shown under the heading of Actual Sail Area in the sail data of Fig. 9 are larger than those which would be carried in practice by 'Bluebird of Thorne' 1963, in the higher wind strengths. In lighter winds, sail areas of the order of those given in the upper righthand corner of Fig. 9 would be used.

The corresponding heel angles and leeway angles for the data of Fig. 9 are shown in Figs. 10 and 11. It is interesting to note that change of sail area produces a large change of heel angle but only a relatively small change in performance as shown in Fig. 9. This suggests that the original modest sail area was well chosen for cruising purposes.

Fig. 12 compares the close hauled performance of the best twin keel yacht with a wide range of ocean racers under standardised conditions. This figure shows that although at low wind speeds the twin keel craft is not as fast as yachts specifically

TWIN KEEL YACHTS—DEVELOPMENT OVER 45 YEARS

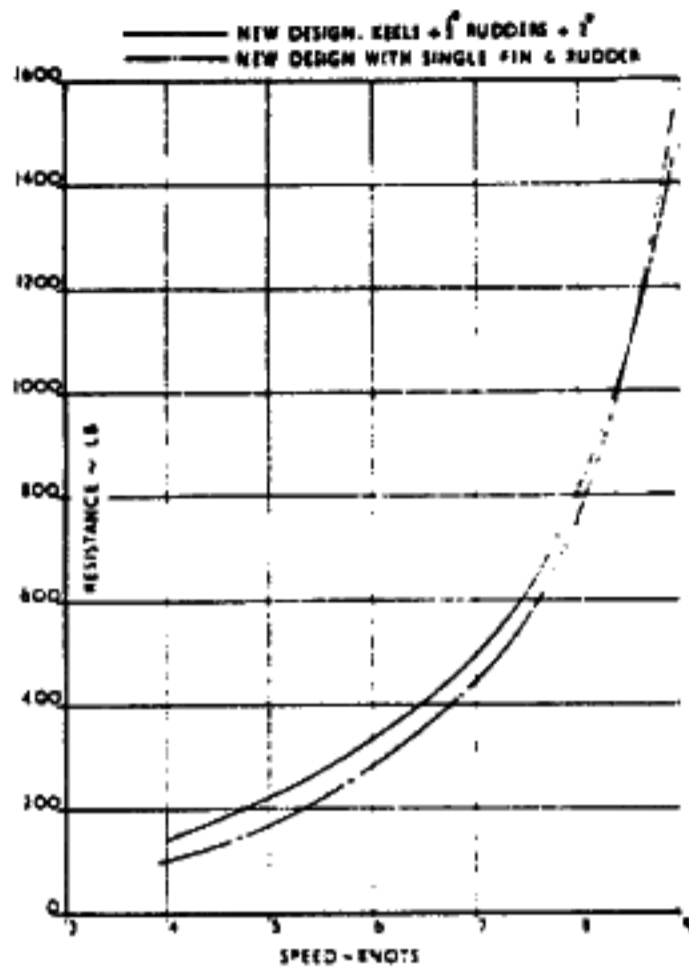


Fig. 8. Variation of upright resistance with speed

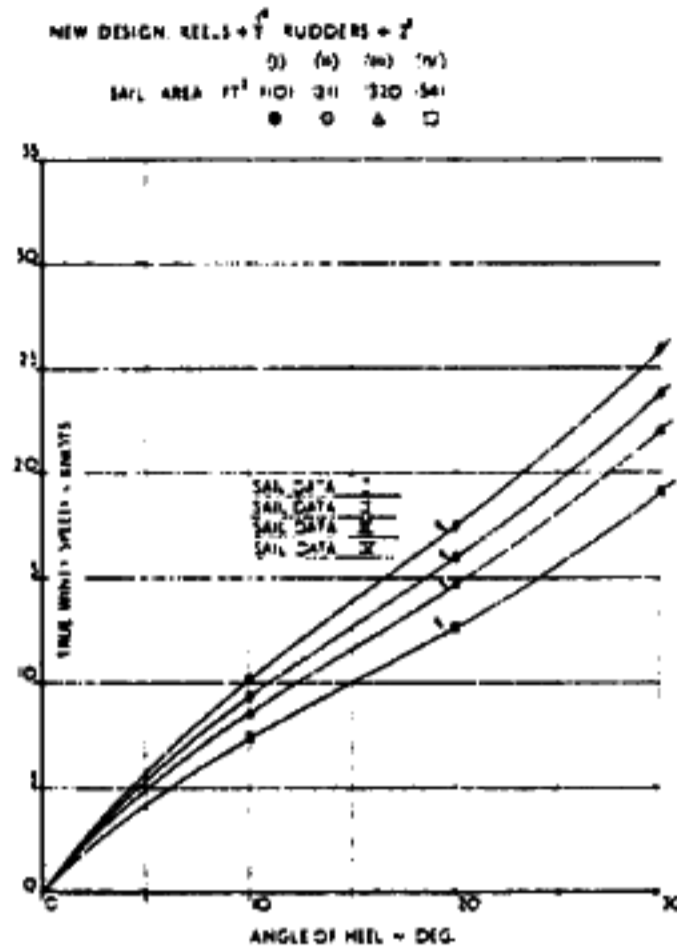


Fig. 10. Variation of angle of heel with true wind speed

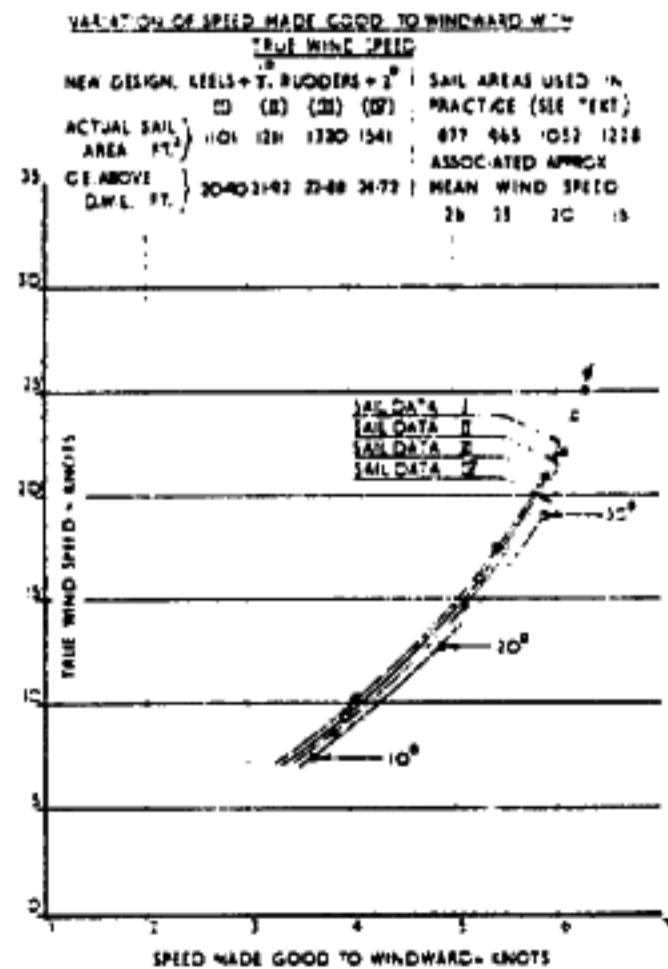


Fig. 9. Variation of speed made good to windward with true wind speed

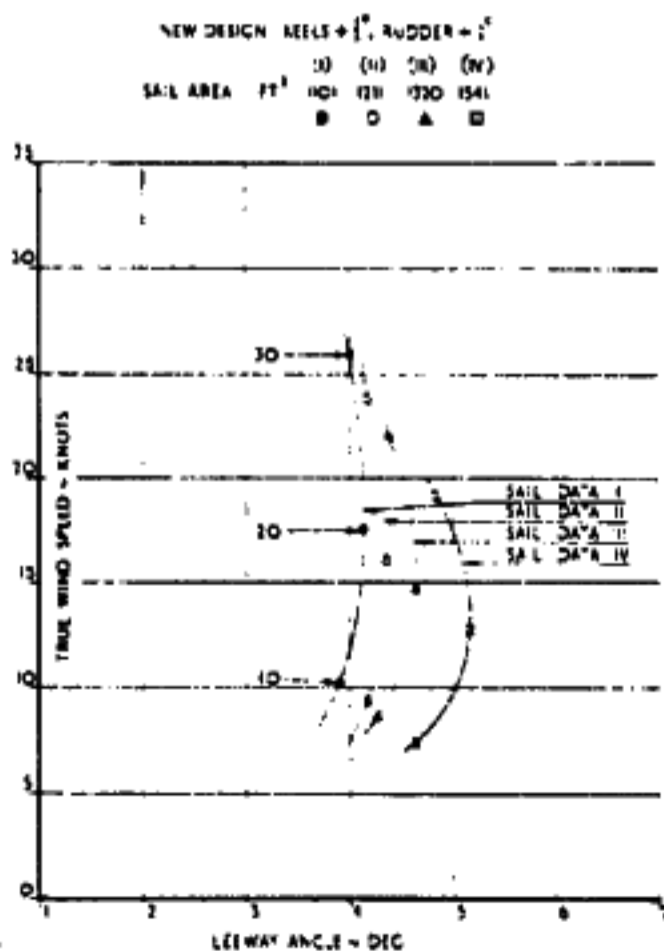


Fig. 11. Variation of leeway angle with true wind speed

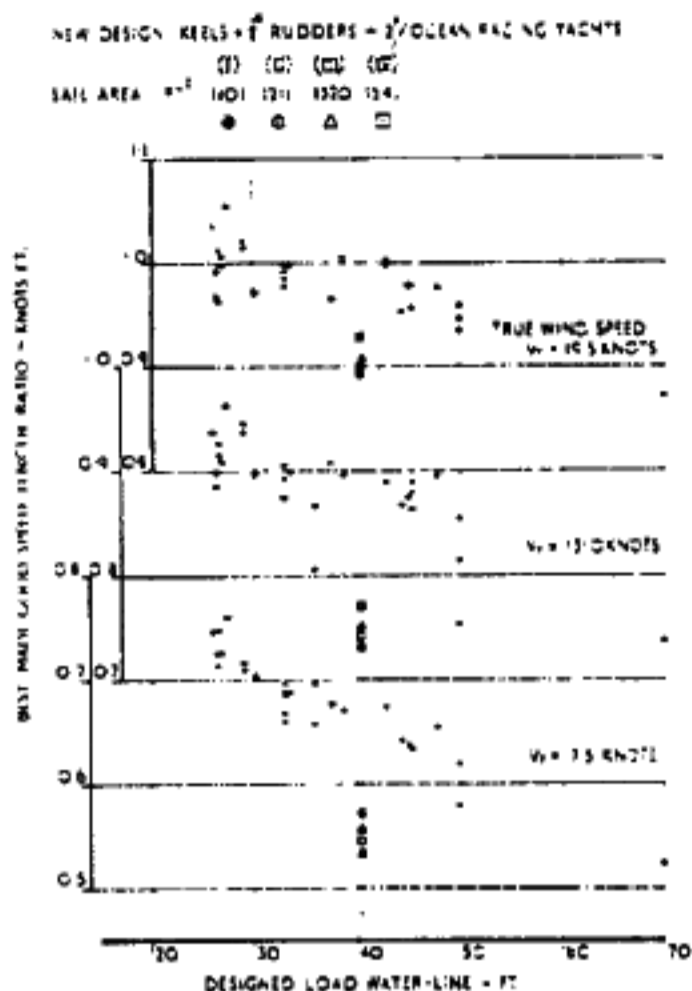


Fig. 12. Variation of VMG/vL with L.W.L. at constant values of VT.

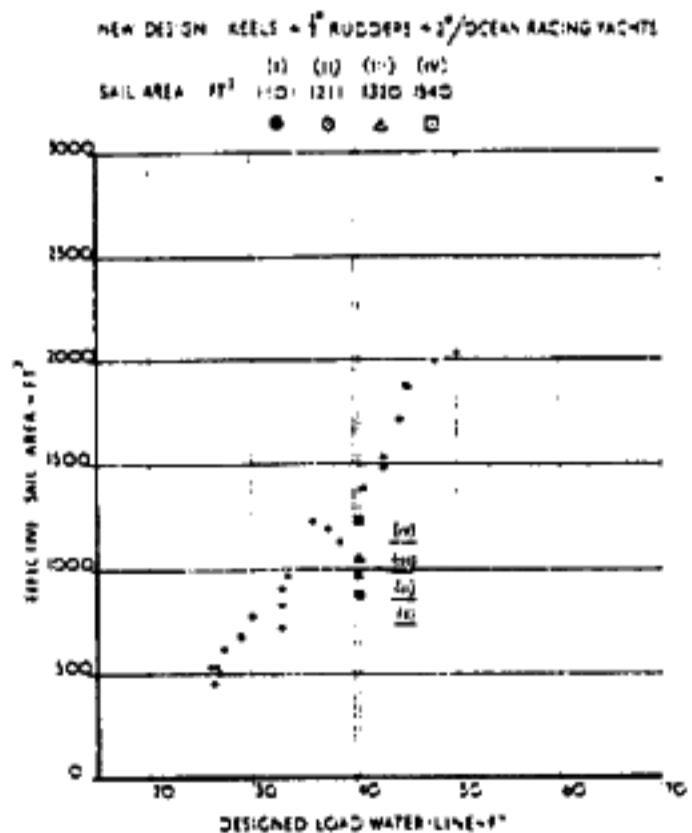


Fig. 13. Variation of effective sail area with L.W.L.

designed for ocean racing, at the higher wind strengths the performance becomes comparable if an appropriate choice of sail area is made. This probably explains why twin keel craft are known to make good passage times under strong winds. The low sail areas of the twin keel craft can be illustrated by plotting sail area against load water line, and this has been done in Fig. 13. It will be seen that the design sail area of 1101 sq. ft. is 35% less than might be expected for an ocean racing yacht of the same length.

Fig. 14 shows the E.H.P. appropriate to speeds from 3 to 9 knots. Assuming a propulsive co-efficient of 0.5 and an engine

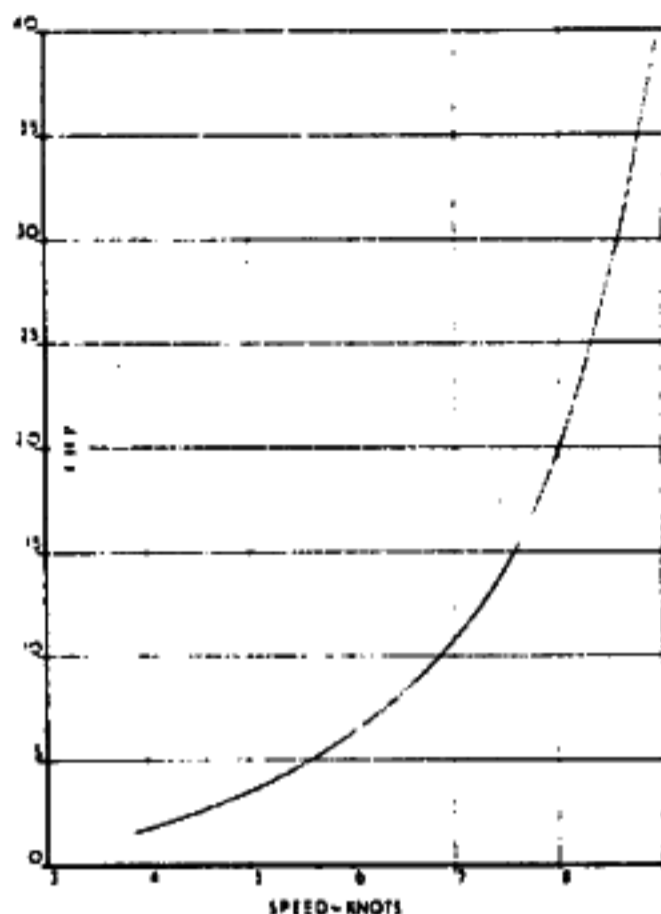


Fig. 14. Variation of E.H.P. with speed. New design as built

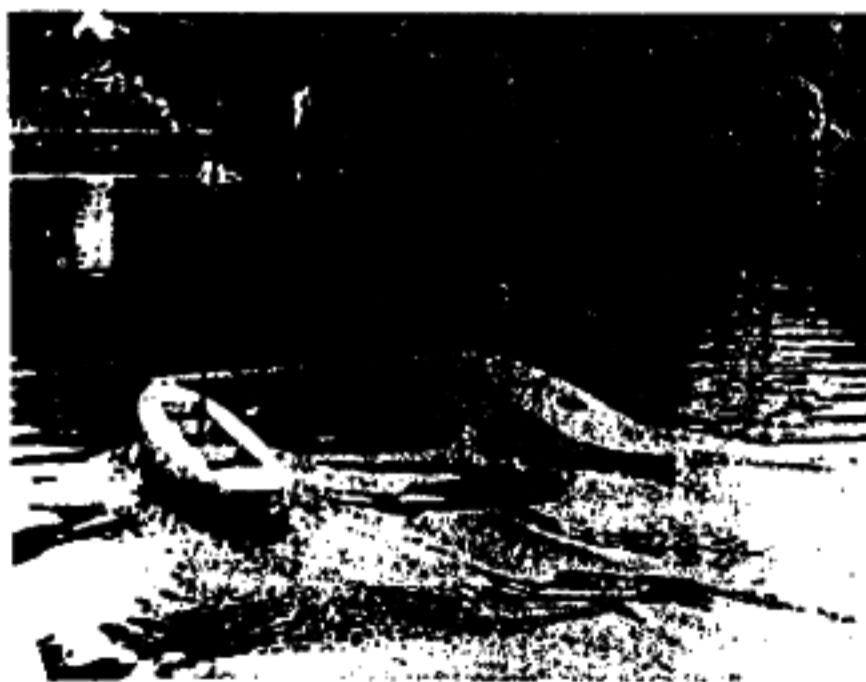


Fig. 15. Towing tests by balance beam. Models 'Bluebird of Thorne', 1939 and 'Bluebird of Thorne', 1963

capable of 40 s.h.p. a satisfactory performance was indicated. The actual trials speed achieved is discussed later.

The yacht model was also run up to the full scale equivalent of 12 1/2 knots. No readings were taken but no gross alteration of trim or excessive wave formation was observed. Subsequently, the author also conducted a whole series of model runs to obtain a photographic record of wave formations at fast, medium and slow speeds, both heeled 15° and 30°, as well as upright. Bow and quarter photographs of each case were taken and a typical example is shown in Fig. 15. The runs were made with the models of the original 'Bluebird of Thorne'

TWIN KEEL YACHTS—DEVELOPMENT OVER 45 YEARS

and the new design on a balance beam using a sensitive trout rod to provide a towing spring.

The author also carried out experiments on both models to investigate aspects of grounding, stability, docking and other practical points to ensure that the yacht was not likely to cause trouble in any respect. As a matter of interest, it was found by calculation that the moment to unbalance the yacht longitudinally when beached was 122,700 lb ft. This is equivalent to a load of 7,218 lb positioned at the stem.

CONCLUSION FROM THE TANK TEST PROGRAMME

1. An improvement over the old 'Bluebird of Thorne' of the order of 15% had been obtained. (The author and the designer, Arthur Robb, had hardly dared to hope for as much as this).
2. The yacht could compare with good normal yachts, particularly at higher wind speeds, well enough for her cruising objectives.
3. Nothing adverse to seakeeping qualities or behaviour had been observed.

Performance Under Sail

In the absence of an extensive racing programme which, in any case, is far harder to assess full size than with models, it is difficult to form an objective opinion of sailing performance. There is however, a statistical approach.

Over many years and many thousands of miles, the author had found that the old 'Bluebird of Thorne' would cruise at an average of 5 knots through the water. This included occasional use of the engine and might fluctuate between 4.75 and 5.1 knots for many reasons. The new design has now done over 25,000 cruising miles including two Atlantic crossings. Some of this has been in the Mediterranean area and should, perhaps, be ignored because sailing conditions are so different and the previous 'Bluebird' did not cruise in these waters. The comparable figures with the new design are 5.5 to 6, averaging 5.75, an advance of about 15%. This almost exactly vindicates the tank's assessment of the likely difference in performance over the useful speed range when upright and also the predicted differences in the close-hauled condition.

It is fortuitous that the power performance as used in practice is also up by about 15%, from a little over 6 to 7 knots, though with far more in reserve for the new design.

The 1963 'Bluebird of Thorne' was deliberately designed for cruising purposes with a small and easily handled working rig. She was found, in practice, to be powerful enough to carry more sail and usually carries larger headsails until the wind reaches force 5 (17-21 knots).

Fig. 16 shows 'Bluebird of Thorne' was deliberately designed for at force 5-6 (19-25 knots). The actual sail area is 1225 sq. ft., the angle of heel about 20-25° and the speed 7 to 8 knots.

All this is in reasonable agreement with the data in Fig. 9.

There are aspects of the foregoing discussion of sailing performance which may, perhaps, conflict with an often heard opinion that the way to demonstrate success in yacht design is to win races. This goal is beset with rating rules and restrictions. The weight of effort and money directed to this end has been quite overwhelming compared with that directed to cruising types and some undesirable distortions have appeared. It is not true that the best ocean racer makes the best cruiser, but racing has improved the breed of sailing yachts generally and it is apparent that a fast cruiser is better than a slow cruiser. A fast hull can be detuned but a slow one will not speed up. The author believes that a design should be prepared for cruising without regard to rating rules and, always provided that a good balance and seakeeping qualities are present, then the faster the better. There is some irony in the

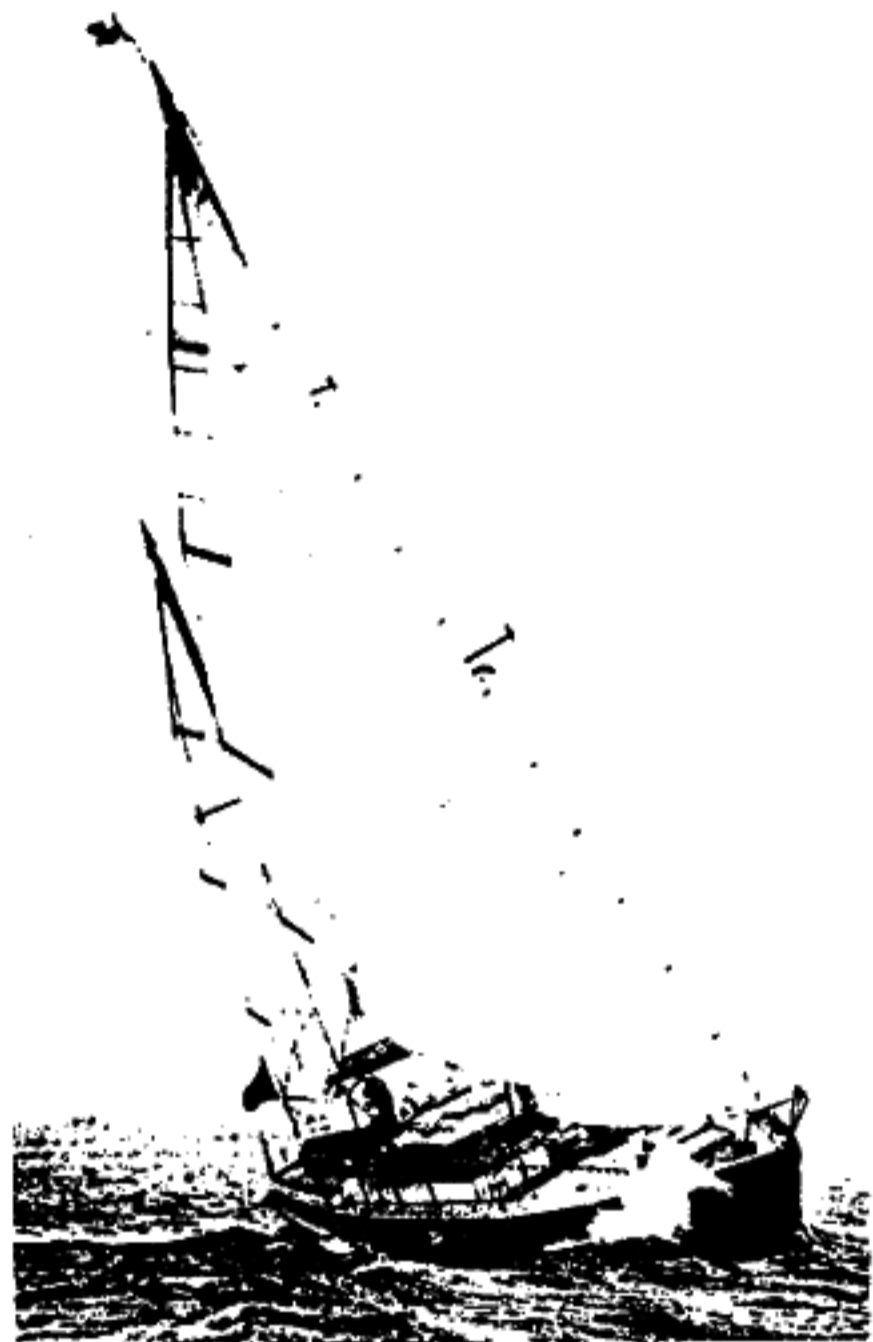


Fig. 16. 'Bluebird of Thorne', 1963 sailing on the wind

result. The first 'Bluebird of Thorne' with a 39 ft. designed L.W.L. rated at 27 ft. R.O.R.C. The second 'Bluebird of Thorne' with a designed L.W.L. of 40 ft. rates at 31.41 ft. R.O.R.C. These ratings both seem advantageous although it would be wrong to read too much into this since both were designed with modest sail areas and neither yacht has been raced.

An Atlantic passage in the north east trades emphasised the importance of minimising rolling and again vindicated the tank tests. Under ordinary (not gale or storm) conditions, the maximum roll recorded was about 20° with an average period of ten seconds for the complete port and starboard movements. In all cases, the motion was very smooth with no jerk or prolonged pause at maximum angle. These observations were taken in a trade wind force 4-5 (14-19 knots) with a normal ocean sea true to this wind, the yacht carrying twin running sails but no fore and aft sail, and making perhaps 6½ knots, steering herself with no more than 5° of rudder angle.

Performance Under Power

Under ideal conditions with 52 s.h.p., 8.5 knots could just be attained. Measured mile runs at 8.1 knots indicated a propulsive coefficient of 0.55.

For cruising, the best speed in practice settled down at 7 knots. With normal displacement and normally clean hull this did not use more than one gallon per hour, and working the makers s.h.p. data back through the e.h.p. speed curve again indicated a

a propulsive coefficient of 0.55. This confirmed the advantage of a V.P. propeller for this installation and also reflected the very favourable propeller location with an absence of flow interference from dead wood. The results obtained agree, in general, with the engine makers' curves for r.p.m., power and fuel consumption.

While not strictly an aspect of the powered performance, it is interesting to note that, if when sailing at $7\frac{1}{2}$ -8 knots with the 26 in. diameter three blade propeller fully feathered, the propeller is placed in the ahead position with the shaft stationary, speed is reduced by about one knot. The sailing handicap that would be suffered with a fixed propeller is obvious.

PRACTICAL DESIGN CONSIDERATIONS

There are a variety of design considerations to be taken into account when planning any craft. These range widely over such fields as structure, seakeeping, steering, etc., and the twin keel yacht has perhaps received less attention and documentation than the more orthodox type in this respect. Because of this, it seems of some value to discuss briefly a number of these aspects in the light of the author's and others' experience.

Structural Strength and Construction

Circumstantial proof can be built up from the positives and negatives over long periods to the point where statistical probability is sufficiently conclusive. The author has cruised 75,000 miles in three 'Bluebirds'. The three yachts have covered well over 100,000 miles. Their combined life span adds up to 75 years to date. So far as is known, none have suffered structural failure or grievous harm by sea or land.

One could also cite 'Curlew of Walney', now 13 years old and sailed for perhaps 10,000 miles. She has spent much of her life taking the ground every tide on a fairly rough and exposed foreshore without harm.

It would appear, therefore, that the twin keel type is inherently sound, and fit to keep the sea if well designed and properly constructed; furthermore, the maintenance need not be excessive.

The design displacement of all these yachts was on the light side of conventional practice for sailing yachts. Structural strengths were not, therefore, obtained by large scantlings or weighty construction. The yachts with wooden construction were double diagonal planking on longitudinal stringers with light bent frames and local stiffening only in way of keels, mast and shrouds. The two steel yachts were not substantially different from normal light steel construction for the size involved.

With the bilge keel type, there may be a tendency to regard stresses on the bilge keels as reduced because the centre keel takes the weight and when taking the ground the bilge keels only act as legs. This may be a dangerous fallacy. The greatest stress might be caused when the yacht strikes a hard bottom at maximum speed with a strong lee-going tide. Construction should be adequate for such a case. The evidence suggests that this is not difficult, since satisfactory craft have been built with wood in a variety of forms, in steel and G.R.P. Light alloy should present no abnormal problems.

Rudders

The attraction of simplicity and cost rest with the balanced spade rudder. However, the author is convinced that the greater tolerance to stall of the skeg and flap type is necessary for full control under adverse conditions in a sea-way and, with his present craft, would have adopted a conventional, slim, symmetrical foil with maximum chord at the rudder stock, slightly rounded leading edge and feathered trailing edge. Arthur Robb favoured the semi-wedge type based on other

experience. Had it not been for the need to maintain control under power at low speeds, the rudder areas could probably have been further reduced and the aspect ratio increased.

The author believes that the rudder assembly should absorb a share of the lateral resistance, apart from the steering function, and for this reason each assembly in the 1963 'Bluebird of Thorne' was given a toe-in of 2° to simulate slight weather helm on the lee rudder. This has proved satisfactory. A very slight tremble develops, luckily at the not very damaging speed of $2\frac{1}{2}$ knots and this may be due to slackness in bearings, interaction of water flow or the linkage.

The question of Ackerman linkage between the rudders was considered and regarded as possibly beneficial but was not, in fact, fitted. The free helm balance is good in the present craft so that the decision appears to have been correct if not fully tested nor necessarily the optimum.

John Lewis had tried a wedge section (blunt edge trailing) rudder of very small area on models. Control was satisfactory, in fact quite fierce, but on high-speed down wind runs the vibration was such that an audible note resulted which would have been intolerable in a full size craft.

In view of the almost universal use of single rudders on twin keeled craft, the instance mentioned earlier may be quoted, where 'Fay Loong' was improved by conversion from single to twin rudders. A contrary instance can also be quoted where, owing to a collision, one of the 1924 'Bluebird' rudders was damaged and her owner decided to cannibalise the parts into a single rudder assembly further aft. This was reported as being satisfactory, under normal conditions, but the author does not know if this has been tested under extreme conditions. It would appear, therefore, that no hard and fast rule can be laid down regarding the number of rudders.

Ability to heave-to

With a cruising objective, the welfare of crew and ultimate survival of a yacht may depend on its ability to heave-to in a gale and on its behaviour in a storm when it is no longer possible to carry sail. Many modern, high-performance yachts appear to have lost the ability to heave-to and some exhibit difficulties in control in even moderate conditions. All the twin keel yachts with which the author has been concerned will heave-to well. All have been tested and have not failed in control, when running under very bad conditions, and no dangerous behaviour has been found. The new design withstood the stresses of storms, such as running under bare poles with warps astern in wind force 11 (55-56 knots), after heaving-to under sail in wind force 9 (41-47 knots), and under bare poles in wind force 10 (48-55 knots). The wind force was substantiated by U.S.A. Coastguard records in Bermuda giving 55 knots, gusting to 65 knots.

Taking the Ground

In theory, it seems better to take the ground on three support points. Most twin and bilge keel yachts have been so arranged.

The author's 1924 'Bluebird' took the ground on the keels only; so did 'Curlew of Walney'. Neither have come to harm. Both tended to tilt forward until the hull took some load along its centreline (unless the keels bedded slightly). Neither have fallen over in spite of grounding on very steep banks or gullies.

The first 'Bluebird of Thorne' had an unusual form of three point support and was satisfactory. The new design reverted to a two point support on the keels. If, however, the ground is taken intentionally, it is either on a slip or hard, or it is likely to be on ground which permits the keels to bed until the hull centre and/or rudder skegs share the load. No trouble in grounding or slipping has been encountered with the 1963 'Bluebird of Thorne'.

Balance and Steering

With the 'Bluebird' of 1924, the hull design was unbalanced and carried weather helm as the result. For such a small yacht this was probably correct, or at least advantageous. Nevertheless, this craft could be made to steer herself for hours and never gave trouble although she carried considerable weather helm when driven at maximum speed and well heeled.

The first 'Bluebird of Thorne' was quite different. The larger keel and rudder assemblies were symmetrical and Admiral Turner's metacentric shelf theory was in the air, Ref. 1. The author found that the design was so nearly balanced that he decided to complete the job and the design became a metacenter with a straight line shelf. The keels and rudders were parallel to the hull centreline and the result was directional stability and self-steering to an unusual degree.

The new 'Bluebird of Thorne' design was in this respect a conscious attempt by the author to balance the hull with the intention of subsequently introducing very slight unbalance so as to put in a better feel and benefit performance. The resultant craft has steering characteristics as intended and there is no desire for change. Unbalance is sufficiently small that wheel steering can be employed which is so highly geared ($1\frac{1}{2}$ turns from full port to full starboard) that it is rarely necessary to move the rim of the 27 in. wheel more than 1 ft. to port and starboard, except for harbour manoeuvres, when it is necessary to give ample helm to obtain propeller effect on the rudders.

The twin keel type is inherently less liable to broach and this may well be because the lever arm between the C.E. and the centre of resistance (longitudinal) is shorter when heeled than with a comparable single keel craft. Whatever the cause, there is no doubt that a profile, which by experience would be expected to produce wild steering in a single keel design, may be perfectly satisfactory with twin keels. This has been further endorsed by John Lewis with free sailing models.

Wave Interaction between Keels and Rudders

Observations of the test models when running in the tank and of the full size yacht, both support the idea that with twin keels one may, if lucky, avoid detrimental effects from wave interference between the keels and rudders, and by this means and the flow guiding effect of the weather keel in particular, lengthen the wave generated and push the crests apart so that high speed performance is improved. These points require further study. In the design of the 1963 'Bluebird of Thorne', the author has gained the impression that the interference effects are favourable rather than detrimental.

Keel Form and Location

The twin keel yacht opens new possibilities in the choice of fin geometry and location. Quite a few forms have been tried and they all work—after a fashion. The sometimes poor existing designs may lead to pessimism regarding the type. This is unjustified, however, since a study of single keeled yacht designs and their performance shows that these craft are not automatically satisfactory merely because they incorporate a single fin.

Twin keels are unique in that they allow the use of asymmetrical sections. The temptation to use available data on aerofoils is great and while fascinating, may be misleading. With low aspect ratios, unknown root and tip losses, the effects of waves and the wide operating ranges of speed and conditions, the injudicious use of wind tunnel data obtained for aircraft tends to be rather dangerous.

In choosing a section, it seems reasonable to suppose that the thickness-chord ratio should be as small as possible commensurate with containment of the required ballast. There are other considerations, however, and these are associated with the difficulties of successfully marrying the chosen fin planform, location, vertical angle and desired incidence to a given

hull. The last of these factors appears to be one of the most significant that the designer is able to control, once he has made a decision to attempt an improvement in performance by setting the fins at some attitude other than parallel with the centreline.

Speed loss arising from sea-induced motions is likely to increase the leeway angle beyond what might be expected from, say, tank tests, which provide calm water data only. Thus the keel attitude which is suitable for calm water may, at sea, increase its running attitude to one which is unacceptably close to the stall. Whatever keel attitude is finally chosen, the designer should have borne in mind that the incident flow is probably unlikely to be aligned either with the track sailed or the geometric centre plane of the yacht. Cross flow, due to the pressure differences on the lee and windward sides of the yacht, will distort the flow in a way which will probably be dependent on whether a deep and narrow or shallow and broad hull is used. Special care needs to be taken with asymmetric sections since their 'no lift' attitude is not coincident with their zero chordline attitude and they are thus that much closer to the stall even before any toe-in is incorporated in the design.

GENERAL MODEL RESEARCH

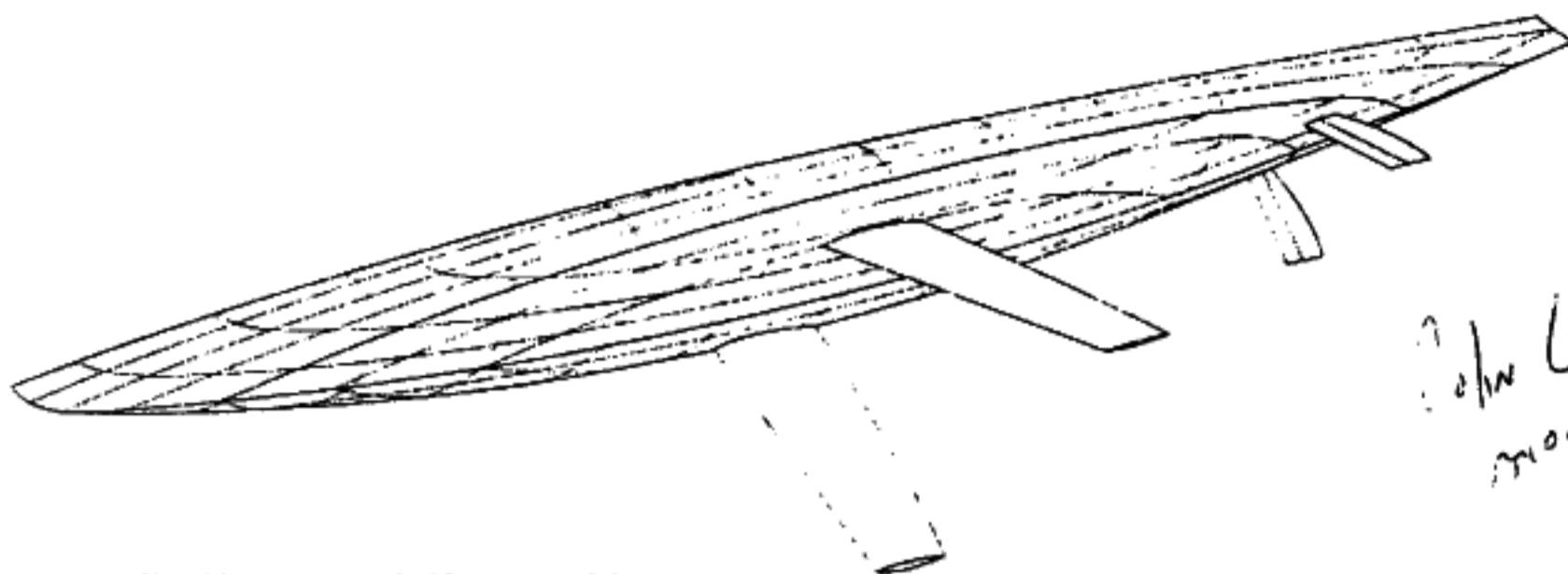
In recent years, the interest in full scale twin keeled craft has been paralleled by model experiments of varying degrees of technical sophistication. These have been aimed more at a comparison of the absolute performance characteristics than at the evaluation of a particular yacht design and they are particularly interesting because of this.

Tank tests

Southampton University have sponsored tests on a hull fitted with a range of alternative side force producing appendages and this work, which was carried out in the tank at the British Hovercraft Corporation, Cowes, was completed in 1966. Early in 1967, the author and Mr. Paul Spens of Southampton University discussed the findings of these tests and their possible relationship to those obtained during the 'Bluebird of Thorne' programme and mutually agreed that it would be a pity if either set were treated in isolation as there was much to be learned by comparison and cross comment. A full report by Southampton University will be available in due course and the author therefore confines himself to brief remarks intended only to draw attention to points of interest in the work which relates solely to twin keels.

The object of the Southampton University series of tests was to examine the relative merits of a centreboard, bilge keels and leeboards when fitted as alternatives on a shallow draught hull. The hull form chosen was that of a large yacht of 50 ft. L.W.L. designed by Philip Rhodes, an example of the beamy shallow-draught centreboard type which was proved most successful and popular, particularly in the U.S.A., as a combined cruiser and racer. In order to avoid the complications which would arise from simultaneous changes of the hull form and appendages, the small central ballast keel with single rudder was retained for all the tests, and consequently the V.C.G. remained constant. On account of possible structural and other complications it was decided that the bilge keels should not extend below the central keel. The draught was therefore proportionately less than that of 'Bluebird of Thorne' and the bilge keels were of lower aspect ratio and correspondingly less efficient. They were symmetrical foils of NACA 66.008 section set at 25° to the vertical and parallel to the centreline. The experiment programme did not permit an attempt to obtain the optimum in the design and location of the bilge keels.

The addition of the bilge keels led to a large increase in the resistance. This had a very detrimental effect on the predicted windward performance in light winds. In fact, the speed made good to windward calculated for such conditions was only



John Lewis's
model studies
A/R/S ?

Fig. 17. 'Herald', John Lewis's 10 rater model



Fig. 18. John Lewis with 'Herald' 10 rater model

of the order of $\frac{4}{5}$ ths of that with the centreboard. On the other hand, it appeared that the bilge keel hull would heel less in strong winds than the centreboard version. Consequently, the bilge keels gave a predicted windward performance in strong winds not much inferior to that with the centreboard. It may well be that the resistance of the bilge keel hull could have been reduced by judicious improvements of the form of the keels, etc. On the other hand, there is the possibility that when further work is undertaken it may emerge that the bilge keel hull with a central ballast keel is a configuration which is associated with high resistance.

Free Sailing Models

Col. C. E. Bowden is well known among amateur yacht researchers and for several years was engaged in a series of experiments conducted with free sailing and radio-controlled models. He applied twin keels to a model hull of the shallow, beamy American centreboard type and found that the sailing qualities were good while the control and directional stability were so satisfactory that this model became a control for comparison with some of his experimental series.

Further development started in 1958 when John Lewis applied his successful model yacht design experience to twin keels in the 10 rater class. He produced two designs. The first called 'Herald', is shown in Figs. 17 and 18. This was a round bilge model 80 in. W.L., 30lb displacement and had symmetrical section keels with no toe-in. The second, called 'Moonstone' is described in Ref. 2. After considerable racing trials against other models, John Lewis came to the following conclusions regarding the use of twin keels:-

1. The wetted surface of a twin keel design could be made similar to that of a conventional single fin design.
2. No problems of control developed.
3. Twin Rudders did not work well. (The author feels that this may have been due to inadequate area or an excess of mechanical friction in the operating mechanism).
4. The best performance was not obtained with the largest aspect ratio (3:1) investigated.
5. When close hauled, the twin keeled craft had similar performance to single finned craft in strong winds. The latter type was the better in light winds.
6. Off the wind, the discrepancy between the two types of yacht was less noticeable in light conditions.
7. A good twin keel model could give the champion a good run for her money.

Thus, John Lewis had tried, in a short space of time, features which would have been impracticable or costly at full scale.

None of this work had any influence on the design of 'Bluebird of Thorne', which was already under way before this information came to the author's knowledge, but it will be clear that much of the information gained from the free sailing models supports full scale and tank test findings discussed earlier. At this stage, both the author and John Lewis believed that very considerable further development was possible in the full size yacht.

In 1963, Colonel H.G. Hasler evolved the idea of a cheap, easily constructed, monohull, ocean racing yacht with twin keels.

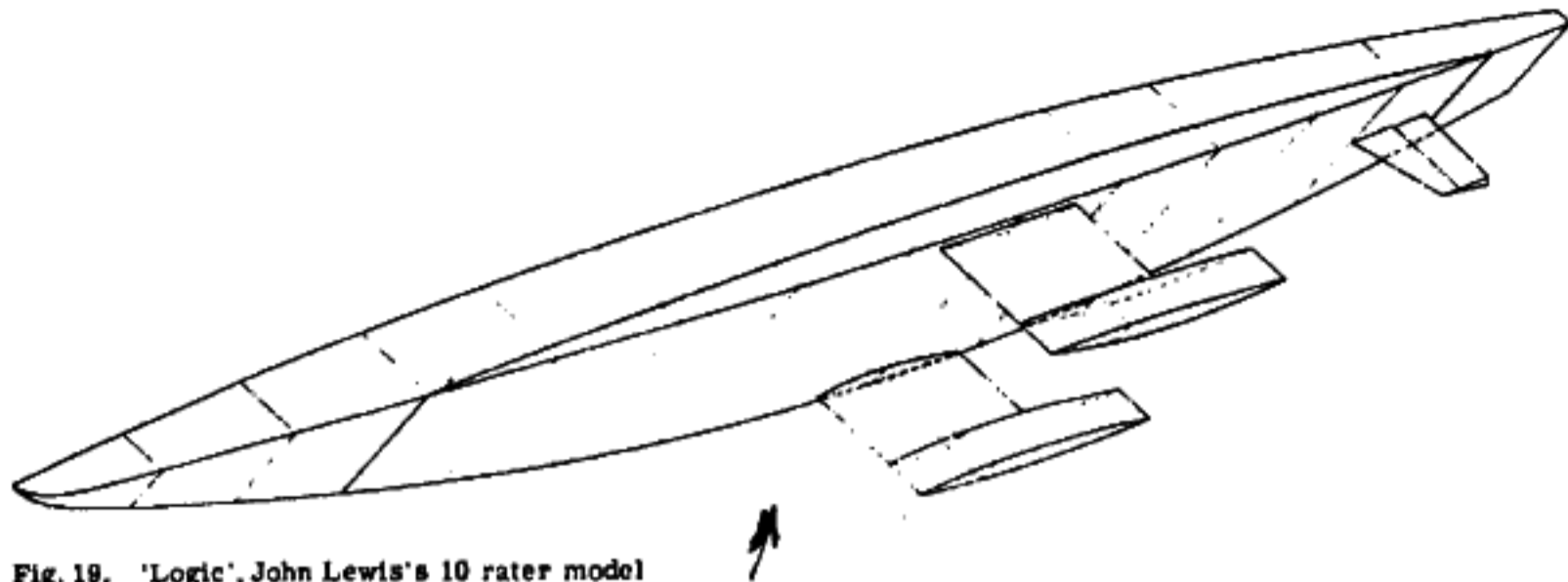


Fig. 19. 'Logic', John Lewis's 10 rater model

This conception was developed, in conjunction with John Lewis, who carried out much of the development work. This included 7 ft., 1/6th scale free sailing models, being the largest that could be handled and relating to full size without too much scale effect. Designs known as 'Dum Dum' and 'Tum Tum' resulted in the design of the full scale yacht 'Sumner'. All these were box shaped wood ply constructions with simple twin keels. A description of 'Sumner' has appeared in the yachting press but the design has not been released. No doubt more will be heard of this unusual yacht in the hands of the redoubtable Colonel 'Blondie' Hasler.

In 1965, John Lewis was impelled by the encouraging performance of 'Sumner's' test models to take a fresh departure. He returned to the racing model and designed a 10 rater on a modified 'Sumner' conception. This was 'Logic', Fig. 19. The 55 in. W.L. model had square body sections, 29 lb displacement and asymmetric keels with no toe-in. It was purely fortuitous that, under the rule, the hull proportions came out rather similar to 'Sumner' but the requirements for V.C.G. resulted in keels which were of appreciably higher aspect ratio, though still modest compared with the earlier experiments. The keel form was peculiar and developed accidentally. The outboard surface conformed with the curve of the hull side panel, while the inner curve of the keels was simply an arc giving sufficient thickness to the fin for mechanical strength. The keels were vertical.

The performance of this craft was sensational. It decisively defeated champion 10 raters in fresh breezes to windward and the performance was consistent. The performance fell away sharply from a certain and apparently critical point in wind force. Off the wind, the relative performance still declined but at a much slower and regular rate. John Lewis, while encouraged and pleased with these results, confessed to the author that he almost wished that they had not been associated with this form. It was clear that development and refinement of this still admittedly crude, though obviously effective, hull form and simple keels might be the breakthrough that he and the author felt possible.

FUTURE DEVELOPMENT OF TWIN KEELED CRAFT

The encouraging results obtained by John Lewis with his sailing models indicates that the development process for the twin bilge keel yacht is likely to continue with considerable success for a long time to come. In the detail sense, data are required on the flow pattern over the hull in the location of keels, on the proper choice of toe-in, on the best proportions of root fairings and on configurations which discourage ventilation of the windward keel.

In the broader sense, there is a wide range of hull and keel combinations yet to be explored and the author's speculation in

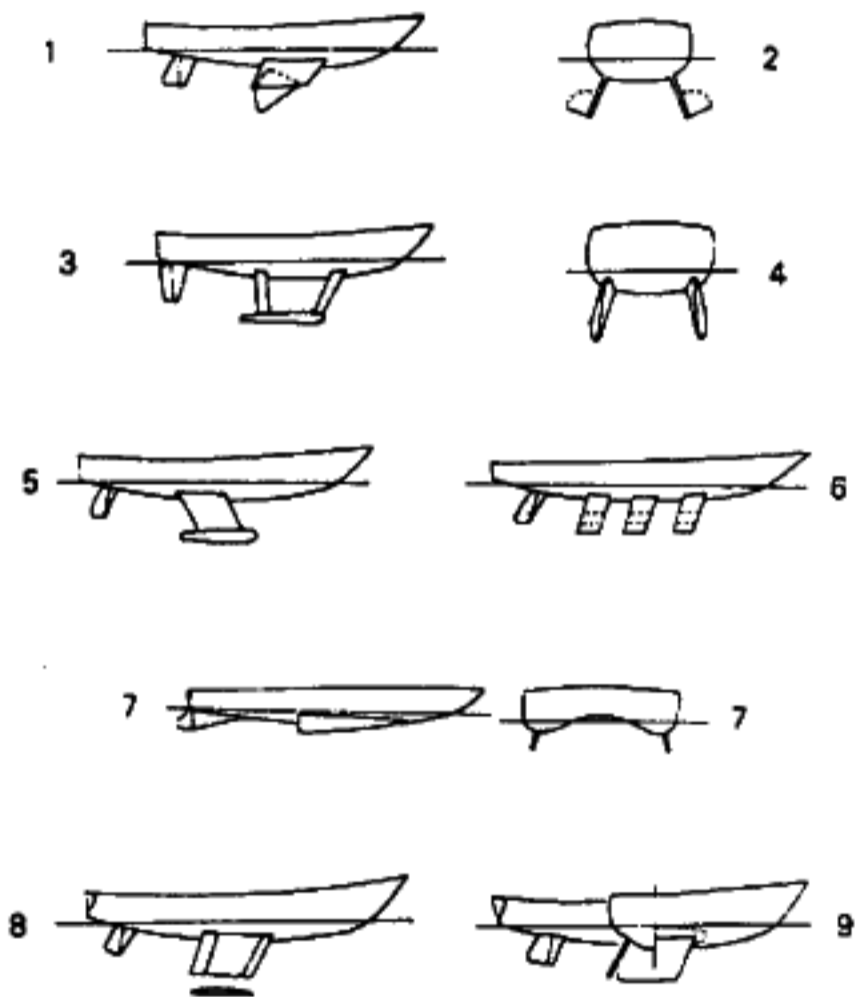


Fig. 20. Untried configurations

this direction is illustrated by Fig. 20. Very briefly, the various proposals are commented on below:-

1. Rather like 'Fay Loong' but with lifting plates inside the keels. Twin toed-in lifting plates located at the bilges were tried successfully by the author with a friend's sailing canoe.
2. This approaches the hydrofoil conception and would probably require hydraulic actuation. Differential operation of the foils could provide a possible way to increase the sail drive-displacement ratio. Might go wrong in a big sea.
3. This idea was tried in the 1890's with raters. The author believes it was banned for racing but has discovered no reference.

4. If research on flow revealed a significant difference in the angle of incidence at the hull and at the tip of the foil, then consideration might be given to a slight twist or propeller form of foil.
5. John Lewis has knowledge that this prognathous keel form has been tried on models with a single keel. It was banned in some classes. This leaves a suspicion that this (and 3) might have shown promise of embarrassing success.
6. A shallow draught configuration in which high aspect ratio is retained for the keels.
7. Flow-guiding shallow foils might be worked into a sea sled bow. The hollow mid-section could be tried and is not necessarily confined to the shoal draught hulls. It was employed with Great Lake scows, was successful and banned from racing in consequence.
8. Trailing edge flaps on the keel, in conjunction with a balanced spade rudder, have been applied successfully by Van de Stadt. John Lewis and the author would like to try the leading edge flap, possibly with a trailing edge flap also. It would enable experiments to be made with flow and angle of incidence under different conditions. Internal hydraulic operation would be an effective method of control. Forces on one flap could be made to balance those on the other.
9. The area rule has probably been tested with single keel. It could be tested with twin keels. It alters so many hull factors that the result is difficult to predict. Interesting to try.

CONCLUSIONS

It may be considered that twin keel and bilge keel yachts have made a significant contribution to the naval architecture of yachts. It is not clear that this type has established a particular or limited field, and the author considers that further progress is possible. John Lewis agrees, from his work with models and full scale yachts. Arthur Robb has stated:—'In ten or fifteen years' time, many successful yachts of normal form may well be of twin keel type'.

The author's only desire is to see the development of better yachts, whatever form they may take, and to this end apply any experience that he may have gained during forty-five years with his own twin keel yachts and any knowledge gained from the experiments set out in this paper.

The author would like to thank all those who have, at various times, and in various ways helped him with the developments outlined and in the preparation of this paper. Some of these are indicated in the text, but the enthusiasm of the whole team at Cowes has been an essential contribution.

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5) forward swept
 would probably require
 thicker cross section at
 bottom, getting thinner at top)