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USYRU

IMS PERFORMANCE PACKAGE

Box 209
NEWPORT, RI 02840

USYRU-IMS PERFORMANCE PACKAGE

The Performance Package is custom-calculated for each individual boat. It is intended to augment, not to replace the many excellent books and articles offering general suggestions for improvement of sailing performance. At first study, the Performance Package will be of greater interest to the more sophisticated sailors but ultimately it may prove more useful to the beginner for whom there is more to be learned.

The speed predictions for the individual boats which are central elements of the Performance Package are derived in two steps. First the hull is measured by use of an electronic device so as to put the hull lines into the computer data bank. The other elements of measurement, the rig dimensions, the flotation and stability are added to the data bank for this one boat. Second, a series of complex calculations is made to find the boat speeds at which all of the elements of drag come into equilibrium with the drive provided by the sails.

At the speeds shown on the VPP data sheet, various factors of drag have been balanced against the driving force. The important thing to have in mind is that each factor contributes either to drive or to drag. There are no "speed producing" elements in the hull. Thus length is not a speed producer. It simply affects the drag differently under different sailing conditions. But drive (from the sails) and drag can be influenced in some degree by the way a boat is sailed.

How accurate are the speed predictions? They are printed out to a thousandth of a knot but they aren't that accurate. (Thousandths are printed out so as to obviate the practice of adjusting flotation and the like with the intention of getting a new measurement which rounds off to a lower rating by a tenth of a foot.) One answer to the question of accuracy is that no one can know exactly. Onboard measurements of wind angle and speed are very hard to take with accuracy. So also it is hard to measure the speed of the boat. Wind conditions are constantly changing. But actual sailing trials have been conducted and about the best one can say is that speed predictions are as close as the instruments can measure. In a later section we will explain adjustments or corrections for wind instruments.

It must be understood also that the speed predictions are based on perfect steering in smooth water and sails perfectly optimized to the sailing conditions.

THE POLAR DIAGRAMS AND HOW TO READ THEM

For many years polar diagrams derived from designers' estimates and from sailing trials have been used at sophisticated levels of sail racing, for example in tuning Twelve Meters for America's Cup competition. But for most sailors they will be new and the explanation which follows assumes that this is an initial encounter.

The wind direction is indicated by the drawn arrow and may be seen as blowing from the top of the diagram toward the bottom.

Each radial line extending from the center represents a sailing angle relative to the indicated wind. Thus the horizontal line is at 90° to the wind. On one of the diagrams this is the true wind direction and on the other it is the apparent wind direction as it would appear on the wind direction indicator. For the wind direction of 90° apparent, the wind direction true must be farther aft. You will see that on the diagram for true wind angle the direction is about 105° to result in the same boat speed as achieved in a wind of 90° apparent. Of course it is all the same wind, just a difference in how the direction is defined, relative to itself (true) or relative to the moving boat (apparent). Most of the time you will be interested in the apparent wind; this is what you feel and what your indicator displays.

Each radial line is graduated into one-knot increments by tick marks. These show the predicted boat speed. The farther from the center the higher the boat speed. The corresponding speeds in knots are shown along the 90° line.

The irregular curves are the plots of boat speeds at five different wind speeds; 8, 10, 12, 16 and 20 knots. The inner curve nearest the center presents the boat speeds at the eight-knot wind speed and the curve farthest from the center presents boat speeds at the 20-knot wind speed.

Notice that in the close hauled sailing angle, near 45°, the speeds do not increase very much with stronger winds. But in the reaching conditions they do increase greatly with wind strength. This accords, of course, with sailing experience.

The boats drawn at the inner ends of the radial lines are only to facilitate orientation when first viewing the graph and should not be taken as indicating the precise trim of your sails.

You will see that the highest boat speeds occur for strong (20-knot) winds at about 90° apparent and for lighter winds at closer angles, perhaps as close as 60° apparent or closer (at 8 knots). This is because in lighter winds the powerful spinnaker can be carried close to the wind whereas in strong winds at such close angles the spinnaker would overpower the boat.

Now referring to the diagram based on true wind speed you will see that the highest boat speeds occur not at 90° (for the 20-knot condition) but at a broader angle. It will be useful when possible to sight the true wind by watching its pattern on the water and taking a bearing across the compass. This will permit checking the wind direction instrument for accuracy both intrinsically in the instrument and in the effect of upwash of wind from the sails. The sighted wind direction under good conditions is likely to be more accurate than the instrument reading on most boats.

For mathematical conversion of apparent wind to true wind and vice versa, use the following formulae:

True given Apparent:

$$VTW = \sqrt{\left[VAW \sin(BAW)\right]^2 + \left[VAW \cos(BAW) - Vboat\right]^2}$$

$$BTW = \arctan\left[\frac{VAW \sin(BAW)}{VAW \cos(BAW) - Vboat}\right]$$

Apparent given True:

$$VAW = \sqrt{\left[VTW \sin(BTW)\right]^2 + \left[VTW \cos(BTW) + Vboat\right]^2}$$

$$BAW = \arctan\left[\frac{VTW \sin(BTW)}{VTW \cos(BTW) + Vboat}\right]$$

Add 180 degrees to BTW or BAW if negative.

VTW is the velocity of the true wind

VAW is the velocity of the apparent wind

BTW is the bearing of the true wind

BAW is the bearing of the apparent wind

Vboat is the velocity of the boat

NOTE: Wind reading is assumed to be sensed at 10 meters (33') above water --see CORRECTIONS of READINGS, page 5).

There will be some utility in becoming familiar with these conversions. More than one skipper, after sailing a long spinnaker leg, is lulled into a feeling of light air only to discover, on rounding up to windward at the mark, that he has hoisted a jib too large for the beat. Or he may have resisted the tendency to underguess the wind strength and over compensated. It is relatively easy to calculate the true wind speed and from this to calculate the apparent wind over the deck for the coming beat. This permits selecting the jib that is just right for the conditions.

For example, suppose we are sailing towards the leeward mark at 6 knots with the apparent wind from 150^o at 6 knots. This gives a true wind speed of:

$$VTW = \sqrt{\left[6 \sin(150^o)\right]^2 + \left[6 \cos(150^o) - 6\right]^2}$$

$$= 11.6 \text{ knots.}$$

For making the calculation of apparent wind velocity upwind it is necessary to estimate the speed through the water on the beat. The polar diagram can supply this needed information.

Suppose the optimum tacking angle is 40^o and the 12-knot true wind polar curve shows a boat speed of 6.3 knots at 40^o. The apparent wind over the deck will be:

$$VAW = \sqrt{\left[11.6 \sin(40^o)\right]^2 + \left[11.6 \cos(40^o) + 6.3\right]^2}$$

$$= 16.9 \text{ knots}$$

MAKING SAILING TESTS

One of the obvious uses of the polar diagram is for testing your boat's speed against the predictions. For your first trial: Pick a good day with steady wind and smooth water. In rough water the speed may be affected on some courses. Also it may affect the steering, obviously a factor in good speed and in reading the instruments. It may help to assign three crew members to read the three instruments: the speedometer, the anemometer and the wind direction indicator. Signal at half minute intervals for simultaneous readings.

Ask the crew members to make a mental average of the reading during the preceding interval and to record these averages. Sail both tacks on each course. Be sure that your sails are set and trimmed as nearly perfectly as possible. The speed predictions assume perfection. Also get the bottom clean before making any tests. When the heel angle is significant, put the crew on the rail as far out as the rules permit.

Do not be dismayed if your actual boat speed is lower than the speed prediction. It is not likely that the steering, the bottom and the sail shape and trim will all be perfect at the same time.

CORRECTIONS OF INSTRUMENT READINGS

There are corrections which must be made in the meter readings for the most accurate comparisons. Before going on with further uses of the Performance Package, here are a few suggestions for correction of the wind readings.

If your instruments are accurate in themselves, and are correctly installed you should still expect that your indicated speeds will be a little lower or higher than the predictions according to the height of your wind instrument sensor above the water. Because of the "wind gradient" (higher velocities at greater heights above the water) the masthead true wind velocity for your yacht may be different from that of yachts in larger or smaller classes at any given instant.

Predictions are given on the polar diagrams and data sheets for true wind velocities (VTW) of 8 knots, 10 knots, 12 knots and so forth. The VTW shown is at 10 meters (33 ft.) above the water. If your sensor is higher than 33 feet, say 50 feet, it will "see" 8 knots of wind when the true velocity at the 33-foot height on which the table is based is less than 8 knots. In rough approximation, the following formula will provide the correct true wind velocity at 33 feet, given true wind velocity at the height of sensor:

$$VTW_{33ft} = VTW_{sensor}\left[\frac{1}{.9 + .003(H_{sensor})}\right]$$

where H_{sensor} is sensor height in feet above water.

Thus, in the preceding example, we have:

$$VTW_{33ft} = 8.0 \left[\frac{1}{.9 + .003(50)} \right] = 7.62 \text{ kts.}$$

Since the velocity at 33 feet is somewhat less than 8 knots, the 8-knot predictions from the polars or tables will be slightly higher than the actual speed of the boat.

Second, the leeway angle must be added to the indicated (instrument) angle. For example, if the wind direction indicator reads 30° and the leeway is 5°, add 5° to 30° to get 35°.

Third, the effect of upwash from the sails must be subtracted from the instrument reading. This effect is at a maximum going to windward in light to moderate air and drops to zero in the run condition. The controlling influence is the lift coefficient of the sail plan. This is found on the data sheet shown as CL. For windward going lift is maximized; but lift drops off to nothing when running and the drag then provides the driving force.

For a rough correction of wind direction instrument reading, multiply lift coefficient by 4 and subtract from the reading.

Example: If instrument reads 30° and if lift coefficient is 1.5, multiply this by 4 to get 6°, subtract this from 30° to yield 24°. Note that as the boat sails more broadly the lift coefficient diminishes.

Both the upwash (lift coefficient) and the leeway corrections must be applied simultaneously. When we do this with the examples recited here we add 5° (from leeway) and subtract 6° (from upwash) for a net negative correction of 1°. Instead of the instrument readout of 30° the corrected value is 29°.

In smooth water to windward at wind velocity of 10 knots, the opposing corrections almost cancel out for most boats.

The attached printout schedule for your boat shows lift coefficients for various sailing conditions of wind angle and wind speed. For leeway you will have to make your own estimates or measurements. (Tow a thin wire with a weight at the end and lay it across a compass.)

You are likely to find in comparing your actual speeds with the predicted that some of the sailing conditions will show close correspondence, within a tenth or two. Other courses may show more deviation. If this is the case, look first for instrument error. Instruments which are quite accurate for reaching may be off for beating.

A common instrument error is in the speedometer installation. The flow across the transducers may be accelerated, disturbed or misdirected by the water flow washing across the hull. For speed calibration a simple expedient is to tow a Walker log extending the spinner line about two boat lengths astern. Though this instrument has to be timed and gives no continuous reading, it is amazingly accurate. Some skippers have reported successful use of Loran C for speedometer calibration. This will be done best in steady wind conditions; averaging a constantly changing speedometer reading is not easy or as reliable as one would wish. If you make a deviation card for your speedometer be sure to write down the sailing conditions at the time of comparisons.

After you have done the best you can with instrument corrections, use one of the blank polar diagrams enclosed and compare your sailing diagram with the calculated diagram.

CHECK FOR DEFICIENT PERFORMANCE

If you find deficient performance of your boat after optimizing the instrumentation, look for opportunities to improve the sails. If the deficiency persists get someone whom you trust as knowledgeable to sail with you for a critique. Your ideas about the optimum set of sails for one sailing angle or another may be well imbedded from years of experience--and wrong. Perhaps you are lacking a sail, for example a good staysail, under a reacher. At any rate, the polar diagram can be used to point up performance deficiencies in various sailing conditions. It is not a part of this explanation to suggest all of the adjustments which might be tried.

FLATTENING AND REEFING

The data sheet shows the relative flattening and reefing required for best performance. The "FLAT" column indicates a flattening of the sails to reduce the heeling drag of the sails (at the expense of some loss of drive). Flattening as used here includes not only using a cunningham, flattening through more outhaul on the main or through tighter halyards, lowering the main sheet traveler or increasing twist off, but also the flattening accomplished through change of jibs including not only a flatter sail but one with a shorter foot as well. The "REEF" column shows the percent of sail area reduction but the reduction will usually be accomplished both by reefing the main and also by using smaller jibs. A reefing factor of 1.000 indicates no reduction in sail. The reefing factor is a linear measure that must be squared to get the percentage of sail area remaining after reefing. In other words, a reefing factor of 0.95 squared indicates that a reduction in sail area of about 10 percent is needed.

CHECKING SPEED AT NIGHT

Another use of the polar diagram is for making a quick check of your speed performance when sailing at night with no other boats in sight for comparison.

BEST SAILING ANGLES DOWNWIND

Still another use of the Performance Package is the establishment of the optimum downwind sailing angles. These are shown on the polar diagram itself and on the adjoining table. Slight deviations from the optimum angle shown will not make much difference and exigencies such as making a mark at close distance will justify small deviations. One useful bit of information will help judge the new course on the other tack. If you have been sailing at an apparent wind angle, say, of 125 degrees (the optimum for eight knots of wind) the use of the second polar diagram (showing the true wind angle) shows that this is an angle to true wind of 154°. This is 26 degrees from dead downwind. When you jibe you will have to turn through twice this or 52°. So when the mark bears 52° from your present course you can jibe over and sail at an optimum angle directly for the mark. This leaves aside the tactical question as to whether you want to wait until you can do this. It may be better to jibe earlier hoping for a favorable shift. If you don't get it you can always jibe back. But it is important in making your decision to know with some accuracy what course you can sail to advantage on the new jibe.

Experienced skippers and navigators learn to do this intuitively but for others the aid of the Performance Package will be useful.

The optimum angle to windward is not shown on the diagram because in practice the helmsman has to develop the sensitivity to sail at the best windward heading. The likely effect of seas in this sailing condition is another important factor. Only on long races in open water and when separated from competitors of similar performance will it be useful to see whether the boat is sailing approximately at the optimum angle shown in the table.

NOTE: "Course" above means the direction of the midline of the hull without any allowance for leeway.

STATIC STABILITY--DON'T CAPSIZE

Finally, the Performance Package includes a graph depicting the static stability of your yacht at various angles of heel. You will see that the righting arm increases at first as the boat is heeled. From that point on the stability decreases. With further heeling the righting arm which provides positive stability comes to zero. As the boat is rolled still further the righting arm becomes negative. That is, the boat wants to capsize and float upside down.

The crossover point is called the limit of positive stability. The graph also shows the ratio of positive stability to the negative stability, the area under the positive part of the curve divided by the area above the negative part of the curve.

A wide, flat-bottomed boat will have high initial stability but after reaching an early peak, the stability declines rapidly. Its limit of positive stability may occur at 90° and if inclined this far the boat will not be self-righting. Some modern offshore racers have been of this type thus requiring screening and actual tests of self-righting ability.

Deep narrow boats with deep keels will not have high initial stability but their limits of static stability may extend to 150° or more. That is, they can be heeled past 90° by 60° more before they capsize. If one did capsize, only a small amount of rolling would move the hull into the positive righting area and the boat would come upright.

No specific limits for safety have been set. Probably none can be. But if you have a modern, racy, flat-bottomed boat and if its limit of positive stability is close to 90° it will be better not to sail it in dangerous seas.

A somewhat expanded statement on static stability can be found elsewhere in this package.

POLAR DIAGRAM TRANSPARENCIES

The polar diagrams are included both on conventional paper and also on transparency material. The transparencies will be more permanent in damp conditions and can be used as overlays in comparing to plots you may make yourself on the extra blank sheets of plotting paper.

IMS AMENDED TO JANUARY 1990
VPP - RUN: 5/ 1/90 23:58:38

CERT# 26265

CLASS: CAT38

RIG: SLOOP
PROP: FOLDING
INST: OUT OF APERTURE

SPEED, HEEL ANGLE, REEF, SAIL FLATTENING AND LIFT COEFFICIENTS BY SAILING ANGLE & WIND STRENGTH.

VTW = TRUE WIND VELOCITY
BTW = TRUE WIND ANGLE
VAW = APPARENT WIND VELOCITY
BAW = APPARENT WIND ANGLE
V = BOAT SPEED
VMG = VELOCITY MADE GOOD
HEEL = HEEL ANGLE IN DEGREES
REEF = % OF SAIL AREA REMAINING
FLAT = % OF FULL DRAFT REMAINING
CL = COEFFICIENT OF LIFT
S = SPINNAKER FASTER AT THIS COURSE
J = JIB FASTER AT THIS COURSE

VTW	BTW	VAW	BAW	V	VMG	HEEL	REEF	FLAT	CL	
6.0	45.5	9.30	26.3	4.285	3.001	4.7	1.000	1.000	1.993	J
6.0	52.0	9.43	28.8	4.701	2.894	4.8	1.000	1.000	1.996	J
6.0	60.0	9.38	32.1	5.051	2.526	4.7	1.000	1.000	2.001	J
6.0	70.0	9.07	36.7	5.299	1.813	4.3	1.000	1.000	2.004	J
6.0	80.0	8.83	41.3	5.599	.972	6.6	1.000	1.000	2.330	S
6.0	90.0	8.31	45.4	5.830	.000	6.4	1.000	1.000	2.589	S
6.0	110.0	6.64	57.4	5.614	-1.920	3.8	1.000	1.000	2.740	S
6.0	120.0	5.63	66.4	5.237	-2.619	2.8	1.000	1.000	2.712	S
6.0	135.0	4.23	85.4	4.556	-3.221	1.5	1.000	1.000	2.504	S
6.0	142.1	3.70	98.2	4.175	-3.293	1.0	1.000	1.000	2.216	S
6.0	150.0	3.31	115.6	3.735	-3.234	.6	1.000	1.000	1.703	S
6.0	165.0	2.97	148.7	3.220	-3.110	.2	1.000	1.000	.776	S
6.0	180.0	2.98	180.0	2.981	-2.981	.0	1.000	1.000	-.039	S
8.0	44.6	11.96	26.4	5.226	3.724	9.9	1.000	1.000	1.993	J
8.0	52.0	12.10	29.6	5.788	3.563	10.1	1.000	1.000	1.998	J
8.0	60.0	11.95	33.4	6.133	3.066	9.6	1.000	1.000	2.003	J
8.0	70.0	11.48	38.6	6.329	2.165	8.2	1.000	1.000	2.001	J
8.0	80.0	10.96	43.6	6.570	1.141	14.3	1.000	1.000	2.505	S
8.0	90.0	10.22	49.1	6.687	.000	12.6	1.000	1.000	2.684	S
8.0	110.0	8.36	62.5	6.573	-2.248	6.5	1.000	1.000	2.728	S
8.0	120.0	7.26	70.9	6.355	-3.178	4.4	1.000	1.000	2.686	S
8.0	135.0	5.62	88.7	5.746	-4.063	2.4	1.000	1.000	2.439	S
8.0	144.6	4.80	106.2	5.143	-4.192	1.3	1.000	1.000	1.991	S
8.0	150.0	4.48	117.5	4.814	-4.169	.9	1.000	1.000	1.644	S
8.0	165.0	4.03	149.3	4.212	-4.069	.3	1.000	1.000	.760	S
8.0	180.0	4.04	180.0	3.909	-3.909	.0	1.000	1.000	-.039	S

VTW	BTW	VAW	BAW	V	VMG	HEEL	REEF	FLAT	CL
10.0	43.4	14.29	26.2	5.866	4.263	16.8	1.000	1.000	1.993 J
10.0	52.0	14.29	30.4	6.419	3.952	16.5	1.000	1.000	1.999 J
10.0	60.0	13.99	35.0	6.664	3.332	15.1	1.000	1.000	2.004 J
10.0	70.0	13.40	41.1	6.817	2.332	12.8	1.000	1.000	1.994 J
10.0	80.0	12.47	45.9	6.977	1.212	22.3	1.000	1.000	2.603 S
10.0	90.0	11.72	52.7	7.107	.000	19.1	1.000	1.000	2.728 S
10.0	110.0	9.87	68.1	7.071	-2.418	10.6	1.000	1.000	2.704 S
10.0	120.0	8.76	77.0	6.938	-3.469	6.7	1.000	1.000	2.629 S
10.0	135.0	7.03	93.9	6.553	-4.634	3.2	1.000	1.000	2.326 S
10.0	149.5	5.74	118.6	5.824	-5.020	1.4	1.000	1.000	1.612 S
10.0	150.0	5.71	119.5	5.796	-5.020	1.3	1.000	1.000	1.582 S
10.0	165.0	5.16	150.1	5.131	-4.956	.5	1.000	1.000	.740 S
10.0	180.0	5.15	180.0	4.789	-4.789	-.1	1.000	1.000	-.039 S
12.0	41.3	16.31	25.7	6.085	4.571	20.5	1.000	.875	1.742 J
12.0	52.0	16.04	31.0	6.714	4.133	23.3	1.000	.991	1.983 J
12.0	60.0	15.69	36.1	6.955	3.478	21.4	1.000	1.000	2.004 J
12.0	70.0	15.09	42.9	7.125	2.437	17.9	1.000	1.000	1.985 J
12.0	80.0	13.89	48.3	7.195	1.249	26.2	1.000	.885	2.362 S
12.0	90.0	12.89	55.2	7.359	.000	25.8	1.000	1.000	2.740 S
12.0	110.0	11.28	72.6	7.433	-2.542	15.2	1.000	1.000	2.673 S
12.0	120.0	10.24	82.1	7.352	-3.676	10.0	1.000	1.000	2.559 S
12.0	135.0	8.52	99.4	7.039	-4.977	4.0	1.000	1.000	2.185 S
12.0	150.0	7.08	122.6	6.512	-5.640	1.8	1.000	1.000	1.487 S
12.0	162.7	6.40	146.3	6.062	-5.787	.8	1.000	1.000	.840 S
12.0	165.0	6.34	150.8	5.986	-5.782	.7	1.000	1.000	.719 S
12.0	180.0	6.31	180.0	5.617	-5.617	-.1	1.000	1.000	-.039 S
14.0	39.9	18.23	25.6	6.208	4.761	22.8	1.000	.751	1.495 J
14.0	52.0	17.77	32.1	6.873	4.231	25.7	1.000	.863	1.727 J
14.0	60.0	17.17	36.8	7.117	3.558	26.6	1.000	.955	1.913 J
14.0	70.0	16.53	44.0	7.331	2.507	23.6	1.000	1.000	1.978 J
14.0	80.0	15.89	52.1	7.427	1.290	18.1	1.000	1.000	1.870 J
14.0	90.0	14.15	57.9	7.515	.000	28.6	1.000	.899	2.462 S
14.0	110.0	12.53	76.2	7.710	-2.637	20.1	1.000	1.000	2.638 S
14.0	120.0	11.69	86.3	7.687	-3.844	13.6	1.000	1.000	2.488 S
14.0	135.0	10.09	103.8	7.426	-5.251	5.1	1.000	1.000	2.061 S
14.0	150.0	8.60	126.1	6.983	-6.047	2.3	1.000	1.000	1.384 S
14.0	165.0	7.73	152.2	6.603	-6.378	.9	1.000	1.000	.682 S
14.0	169.2	7.62	160.0	6.508	-6.392	.6	1.000	1.000	.473 S
14.0	180.0	7.59	180.0	6.321	-6.321	-.1	1.000	1.000	-.039 S

VTW	BTW	VAW	BAW	V	VMG	HEEL	REEF	FLAT	CL	
16.0	39.1	20.08	25.7	6.289	4.877	24.8	1.000	.650	1.295	J
16.0	52.0	19.44	33.0	6.976	4.295	27.6	1.000	.754	1.510	J
16.0	60.0	18.75	37.9	7.218	3.609	28.4	1.000	.837	1.677	J
16.0	70.0	17.75	44.6	7.453	2.549	28.7	1.000	.975	1.924	J
16.0	80.0	17.24	53.5	7.608	1.321	22.6	1.000	1.000	1.842	J
16.0	90.0	15.46	60.4	7.630	.000	29.8	.955	.880	2.193	S
16.0	110.0	13.59	79.2	7.919	-2.708	25.0	1.000	1.000	2.602	S
16.0	120.0	13.05	89.7	7.966	-3.983	17.4	1.000	1.000	2.420	S
16.0	135.0	11.68	107.3	7.761	-5.488	7.0	1.000	1.000	1.958	S
16.0	150.0	10.20	128.9	7.365	-6.378	2.8	1.000	1.000	1.303	S
16.0	165.0	9.28	153.7	7.040	-6.800	1.1	1.000	1.000	.643	S
16.0	172.5	9.10	166.9	6.904	-6.846	.6	1.000	1.000	.288	S
16.0	180.0	9.09	180.0	6.808	-6.808	-.2	1.000	1.000	-.039	S
20.0	38.8	23.56	26.5	6.383	4.975	27.3	.966	.546	1.015	J
20.0	52.0	22.62	34.7	7.093	4.367	29.1	.916	.724	1.217	J
20.0	60.0	21.79	40.1	7.346	3.673	29.6	.903	.833	1.358	J
20.0	70.0	20.64	47.4	7.599	2.599	29.8	.902	.985	1.557	J
20.0	80.0	19.48	55.3	7.813	1.357	30.2	.980	1.000	1.731	J
20.0	90.0	19.28	65.8	7.910	.000	22.7	1.000	1.000	1.539	J
20.0	110.0	15.69	84.2	8.197	-2.803	30.8	.958	1.000	2.318	S
20.0	120.0	15.42	95.2	8.396	-4.198	25.1	1.000	1.000	2.293	S
20.0	135.0	14.83	112.5	8.346	-5.901	11.9	1.000	1.000	1.801	S
20.0	150.0	13.51	132.8	8.020	-6.945	4.2	1.000	1.000	1.194	S
20.0	165.0	12.57	155.9	7.731	-7.468	1.7	1.000	1.000	.585	S
20.0	174.4	12.35	171.0	7.585	-7.549	.8	1.000	1.000	.181	S
20.0	180.0	12.36	180.0	7.523	-7.523	-.3	1.000	1.000	-.039	S

STATIC STABILITY

The Fastnet Race, and other casualties of the past years, have focused attention on all aspects of yacht safety including stability with respect to capsizing. The hydrostatic analysis of stability is a long-accepted practice in naval architecture, which requires a lengthy set of calculations based upon a complete description of the underwater portion of the yacht.

The availability of hull offsets has permitted this analysis to be made on the USYRU computer for the entire IMS fleet. The results for your yacht are included in the lower portion of the HYDROSTATICS & THEORETIC STABILITY data sheet and on the CALCULATED STATIC STABILITY graph. The significance of these results is described below, and two bar graphs (histograms) showing the IMS fleet distributions are enclosed to permit you to judge your boat's stability in relation to the IMS fleet as a whole.

A positive righting moment acts to restore a heeled vessel to its upright condition. The conventional measure is righting moment per degree, which has been included in several rating rules to assess sail-carrying ability. This single parameter fails to account for the reduction in righting moment which occurs at large heel angles, however. For this reason, the IMS takes account of the theoretical stability at 25° heel in predicting boat performance, and for safety purposes certificates include calculations of the righting arm from 25° to 165°. The HYDROSTATICS & THEORETIC STABILITY data sheet shows the righting arm (righting moment divided by displacement) for several heel angles between 25° and 165°. (The righting arm at 180° is equal to zero.)

Examine the CALCULATED STATIC STABILITY graph showing righting arm plotted against heel angle for your yacht. It may be instructive to compare this with the graph for a representative 41' keel boat (below). The complete curve of righting moments includes a positive range, between zero and the "stability limit" which varies from boat to boat. For the representative 41' boat the calculated limit is 126°. The bar chart of stability limits should be used for comparison of your own boat in relation to the entire IMS fleet.

In principle, a yacht which is heeled beyond the stability limit will capsize, since the righting moment and righting arm are negative beyond the stability limit. The area under the positive portion of the righting arm curve is proportional to the amount of energy required to capsize the hull. Conversely, the area enclosed by the negative portion of the curve is proportional to the energy required to return to an upright condition. These two areas are tabulated in units of degree-feet. The ratio of these two areas, also shown on the graph and data sheet, is a measure of relative stability in the upright and capsized conditions. In the case of the representative 41' keel boat, this ratio is equal to 4.96, implying that five times as much energy is required to capsize the boat as to return it. A large value of this ratio implies that the yacht will be returned to its upright condition by a succeeding wave, if not by the angular momentum in its original capsize motion.

The bar chart of the stability ratio may be consulted in a similar manner as for the stability limit. If your yacht is among those with relatively small values of these two stability parameters, you may wish to consult your designer regarding the appropriate explanation or corrective actions.

USYRU IMS AMENDED TO JANUARY 1990
LPP - RUN: 5/ 1/90 23:55:52

CERT# 26265

YACHT:

CLASS: CAT38

HYDROSTATICS & THEORETIC STABILITY

VCG = VERTICAL CENTER GRAVITY
VCB = VERTICAL CENTER BUOYANCY
LCB = LONGITUDINAL CENTER BUOYANCY

HYDROSTATIC DATA

FLOTATION CONDITION:	MEAS TRIM (NO CREW WGT)		SAILING TRIM (WITH CREW WEIGHT)			
HEEL IN DEGREES:	0	2	0	2	25	0
DISPL'T LBS-SW:	17266	17266	18801	18801	18801	33331
WETTED AREA:	301.7	301.5	312.2	311.9	297.7	388.8
RIGHTING MOM'T/DEG:	1280	1280	1332	1332	1051	0
VCG ABOVE MEASM'T WL:	-.44	-.44	-.18	-.18	-.18	-.19
VCB ABOVE MEASM'T WL:	-.98	-.99	-.90	-.90	-1.68	-.23
LCB AFT OF STEM:	20.59	20.59	20.96	20.96	20.96	21.45
PRISMATIC COEF:	.484	.484	.495	.495	.490	.532
2ND MOMENT WL LENGTH:	29.58	29.58	29.84	29.84	29.21	32.97

THEORETIC STABILITY

HEEL IN DEGREES	RT ARM IN FT	RANGE OF POSITIVE STABILITY
25	1.397	
60	1.941	0 - 122
90	1.427	DEGREES
120	.099	
150	-.995	
165	-.919	

AREA POS STAB CURVE: 159 DG-FT
AREA NEG STAB CURVE: 39 DG-FT

POS AREA / NEG AREA: 4.045

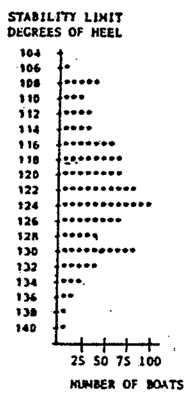
EFFECTIVE BEAM:	10.265
BEAM/DEPTH RATIO:	3.965
KEEL DRAFT:	7.044
CENTERBOARD EXTENSION:	.000
POUNDS PER INCH OF IMMERSION:	1102
MOMENT TO CHANGE TRIM 1 INCH:	1292

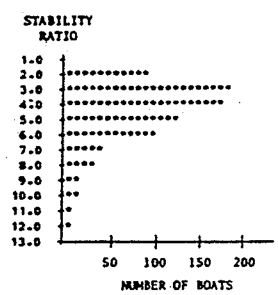
The theoretical predictions of stability are affected by several assumptions and restrictions:

1. The vertical position of the center of gravity is derived from the inclining test; and subject to measurement errors.
2. No account has been given to the positive buoyancy from deck camber, house, and other structures above the rail which, depending on their integrity, may improve the stability at large heel angles.
3. The negative effect due to cockpit volume has been neglected.
4. Internal fluid free surfaces, either in tankage or in bilge water, will serve to reduce both the positive and negative righting arm.
5. It is impossible to account for many of the factors which affect the dynamics of a hypothetical capsize in a steep breaking wave.

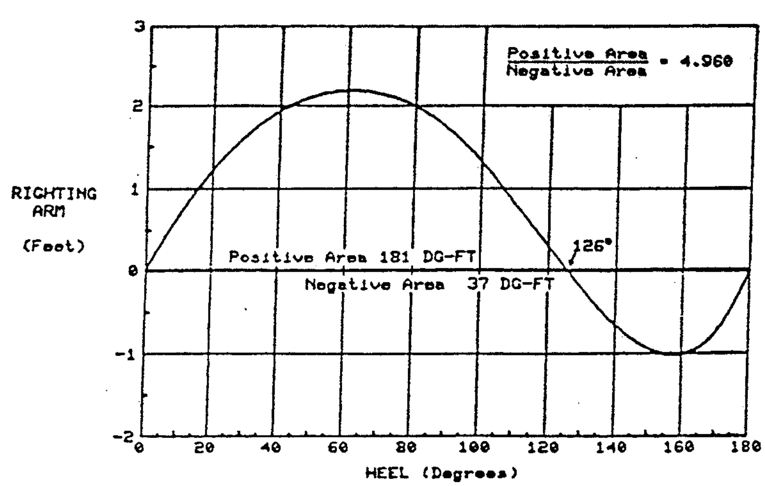
The joint USYRU/SNAME* Capsize Committee is working to improve the understanding and appreciation of these complex factors, and will keep you informed of future work in this important area. In the meantime, the theoretical stability parameters which have been computed for your yacht provide a means for a qualitative assessment we urge you to make.

IMS FLEET DISTRIBUTIONS OF STABILITY LIMIT AND RATIO





CALCULATED STATIC STABILITY FOR REPRESENTATIVE 41' BOAT



* SNAME is the acronym for the Society of Naval Architects and Marine Engineers

POLAR DIAGRAM

BOAT SPEED AS A FUNCTION OF
TRUE WIND VELOCITY & ANGLE

Yacht

CAT38
Masthead Sloop, 150% Jib, Keel
Folding Exposed Prop

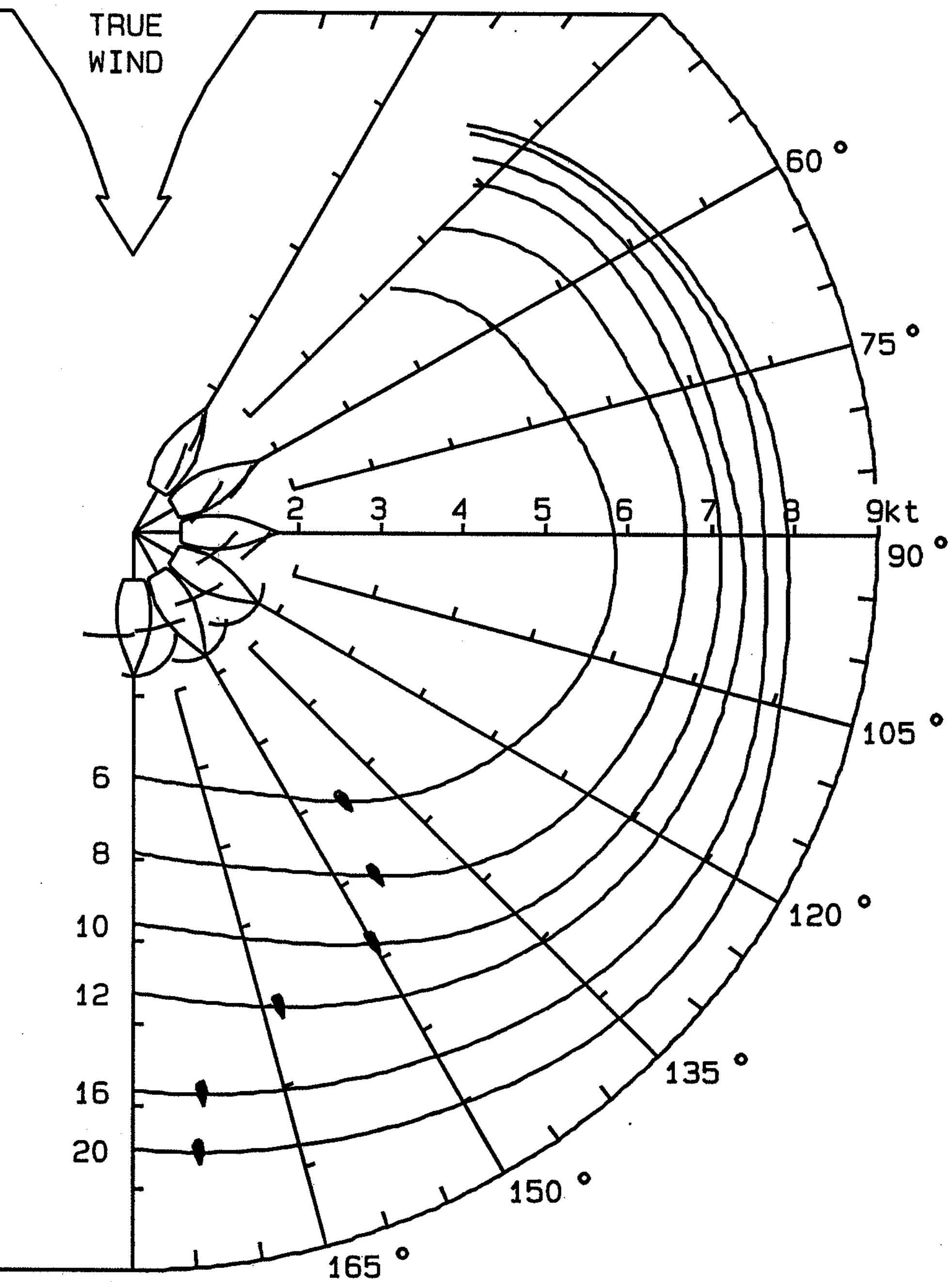
WIND	OPTIMUM VMG BEAT	OPTIMUM VMG RUN	OPTIMUM RUN ∠
6kt	3.001	3.293	142°
8kt	3.724	4.192	145°
10kt	4.263	5.020	150°
12kt	4.571	5.787	163°
16kt	4.877	6.846	173°
20kt	4.975	7.549	174°

Notes:

Boat-speed curves are given at six different true wind velocities as shown at right:

(boat symbol) = optimum run angle.

Run: 5/21/90 11:44: 4 Cert 26265



POLAR DIAGRAM

BOAT SPEED AS A FUNCTION OF TRUE WIND VELOCITY & APPARENT ANGLE

Yacht

CAT38
Masthead Sloop, 150% Jib, Keel
Folding Exposed Prop

WIND	OPTIMUM VMG BEAT	OPTIMUM VMG RUN	OPTIMUM RUN ∠
6kt	3.001	3.293	114 °
8kt	3.724	4.192	107 °
10kt	4.263	5.020	119 °
12kt	4.571	5.787	147 °
16kt	4.877	6.846	167 °
20kt	4.975	7.549	171 °

Notes:

Boat-speed curves are given at six different true wind velocities as shown at right:

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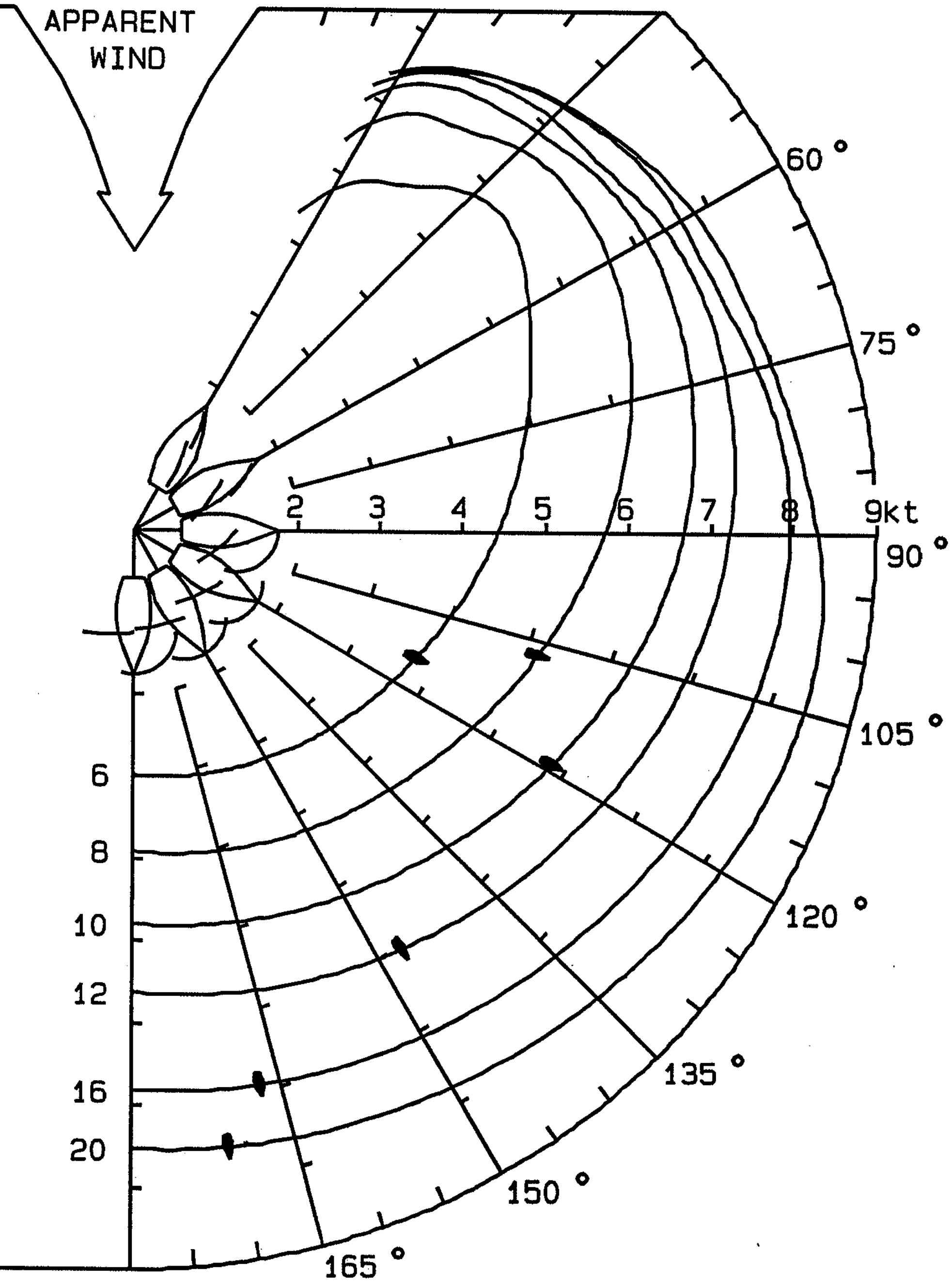
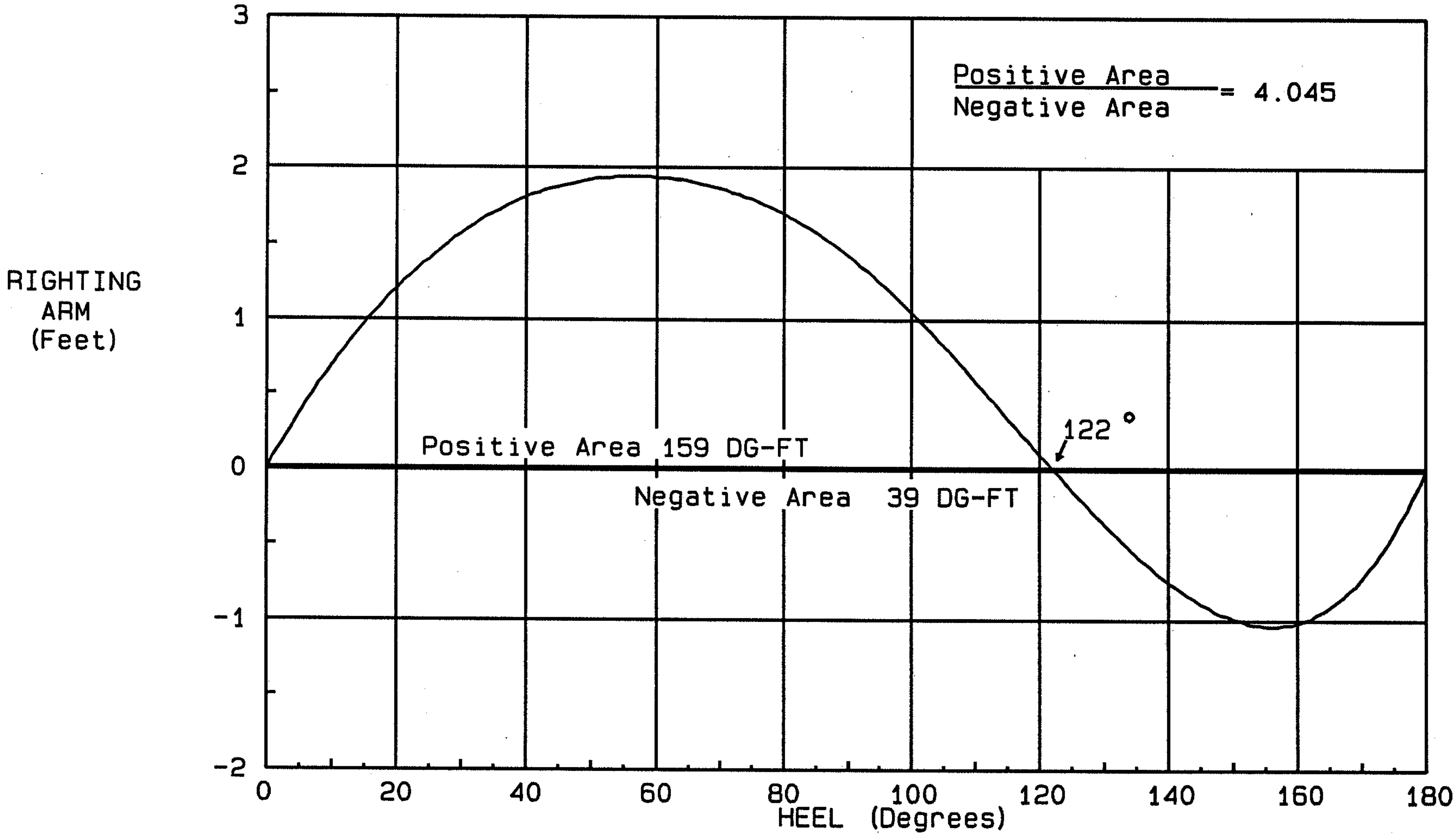
Run: 5/21/90 11:44: 4 Cert 26265



CALCULATED STATIC STABILITY

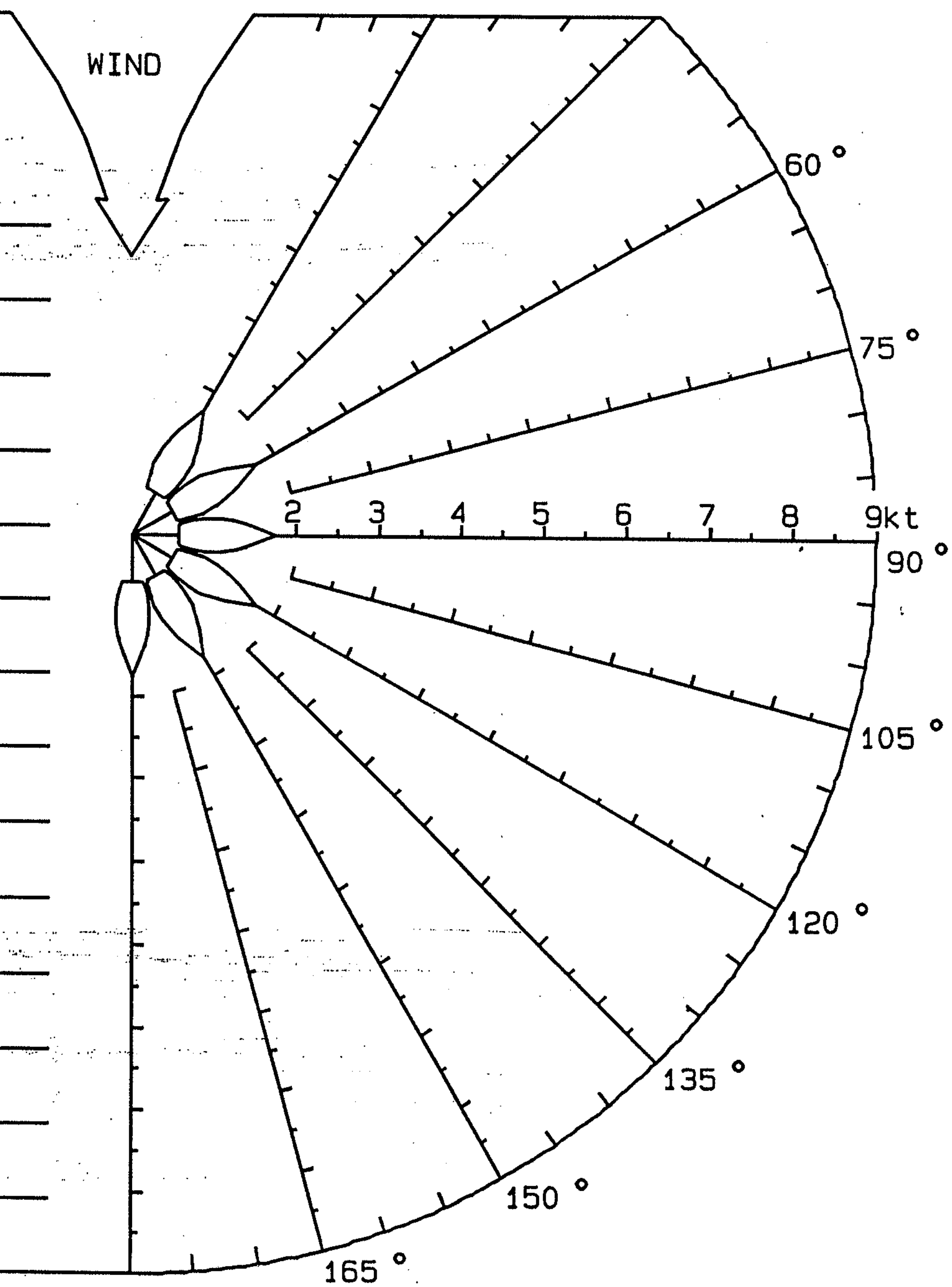


Yacht CENTAURI

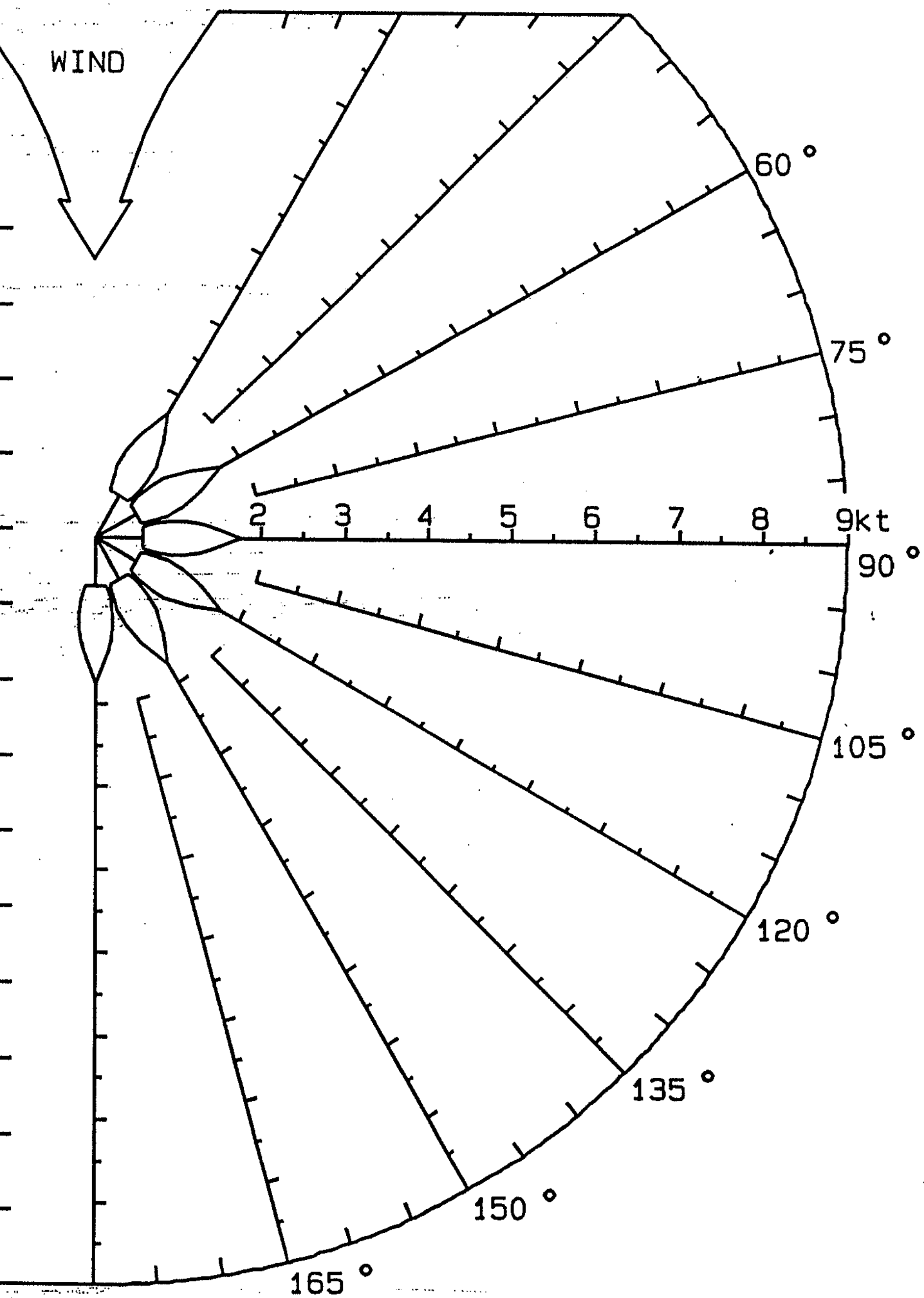
CAT38 US-30293

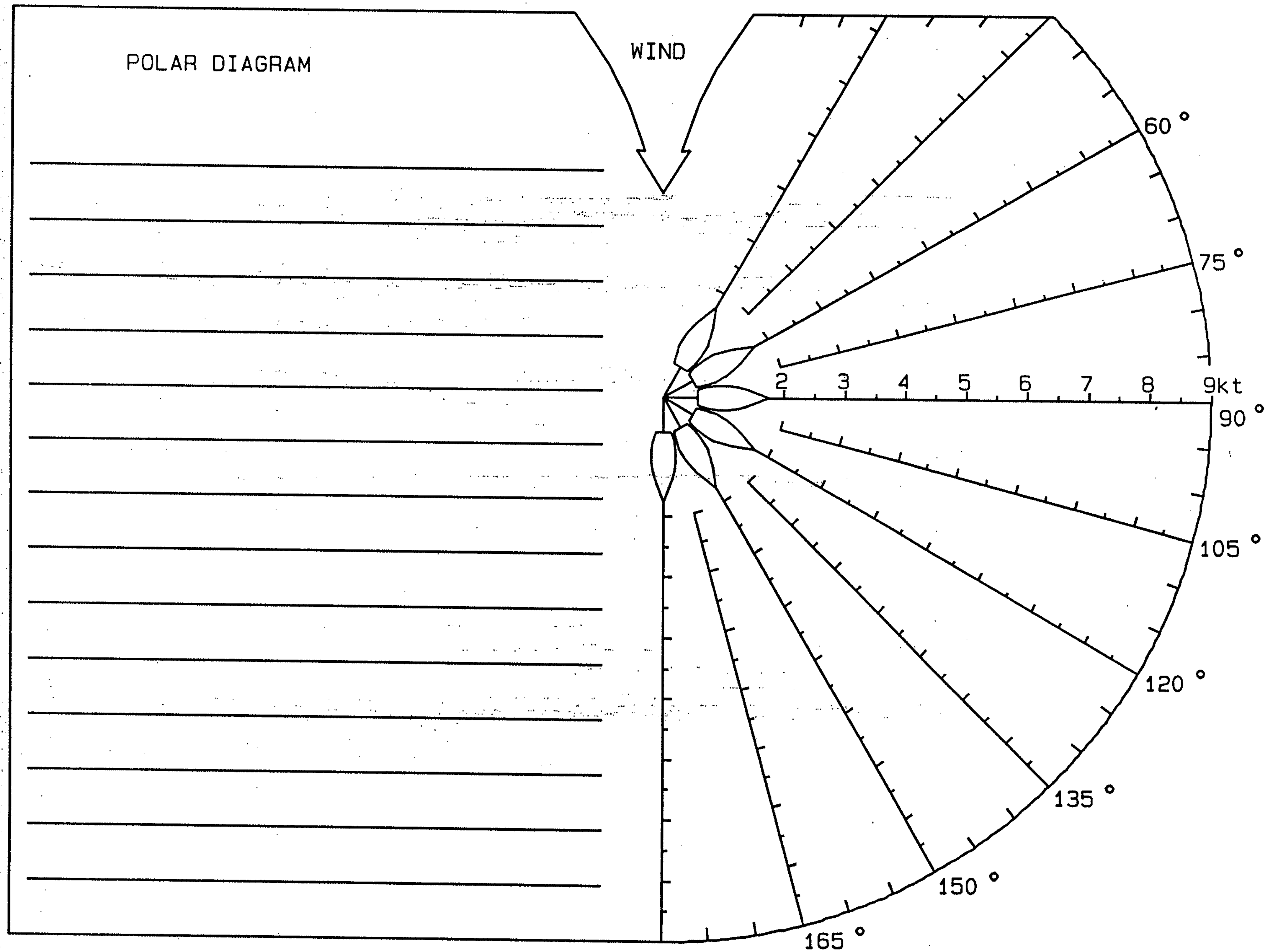
Run: 5/21/90 15: 26: 32 Cert 26265

POLAR DIAGRAM



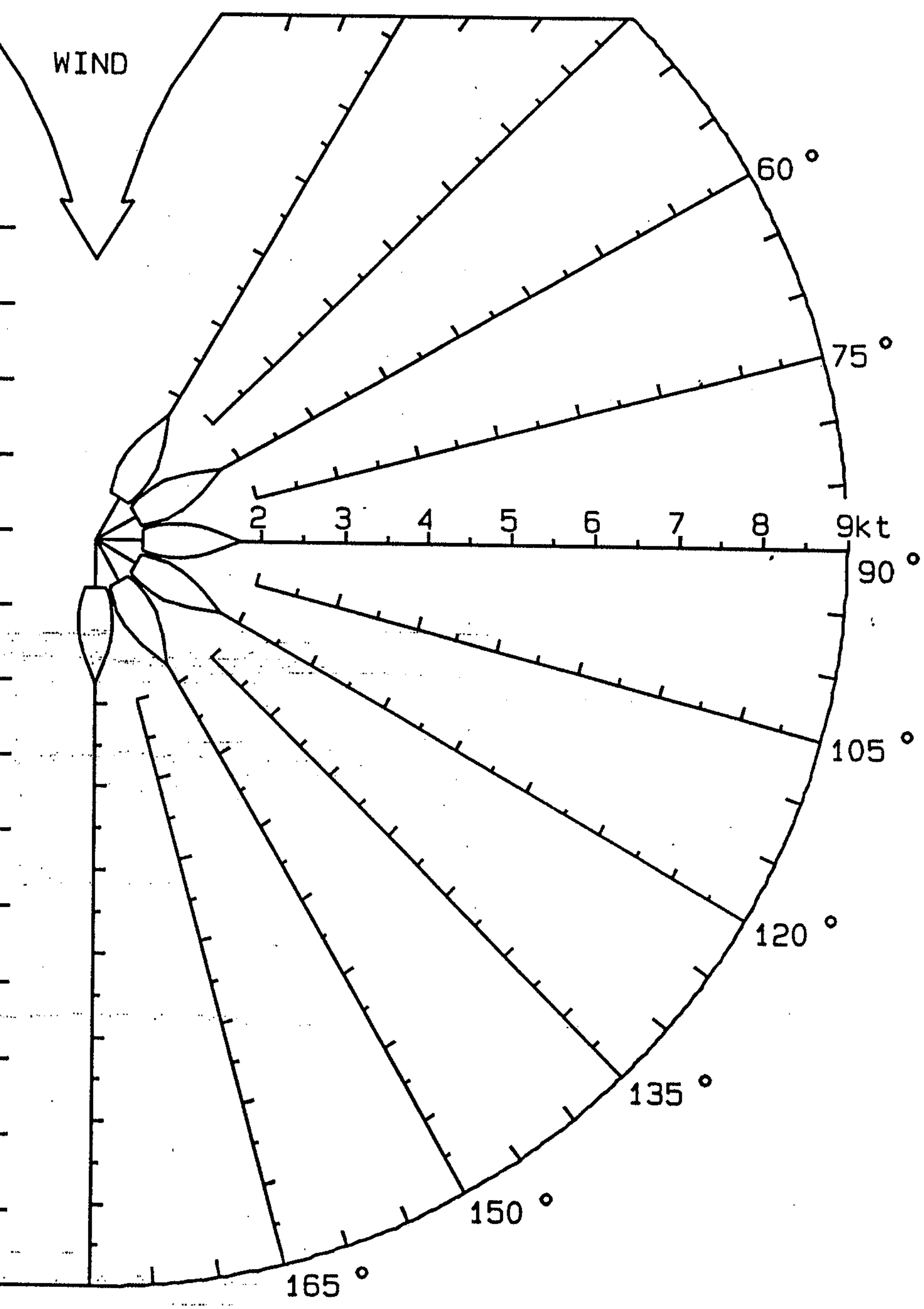
POLAR DIAGRAM

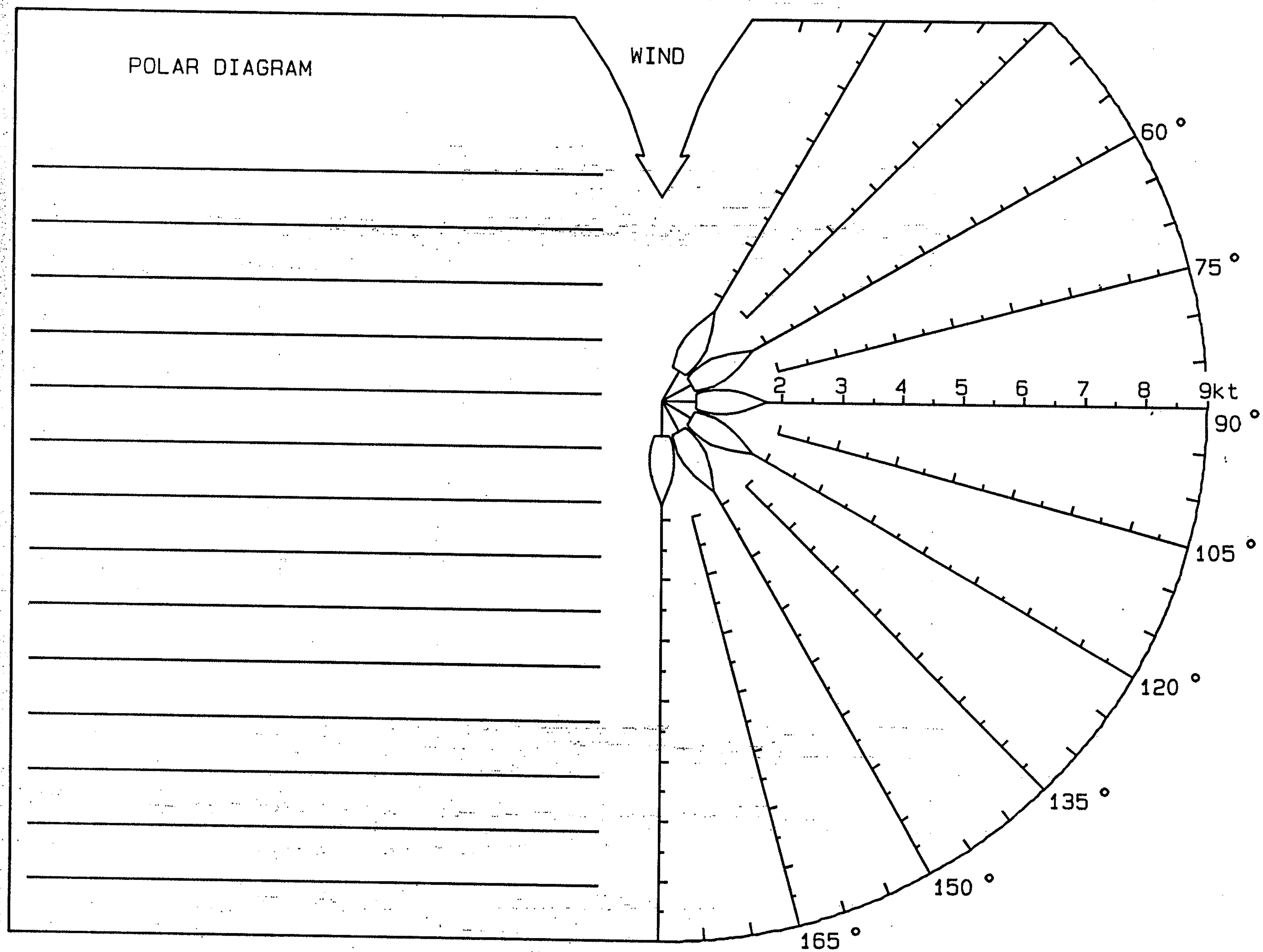




POLAR DIAGRAM
WIND
2
3
4
5
6
7
8
9kt
60 °
75 °
90 °
105 °
120 °
135 °
150 °
165 °

POLAR DIAGRAM





POLAR DIAGRAM
WIND
60 °
75 °
2
3
4
5
6
7
8
9kt
90 °
105 °
120 °
135 °
150 °
165 °

PERFORMANCE DATA FOR CATALINA 38