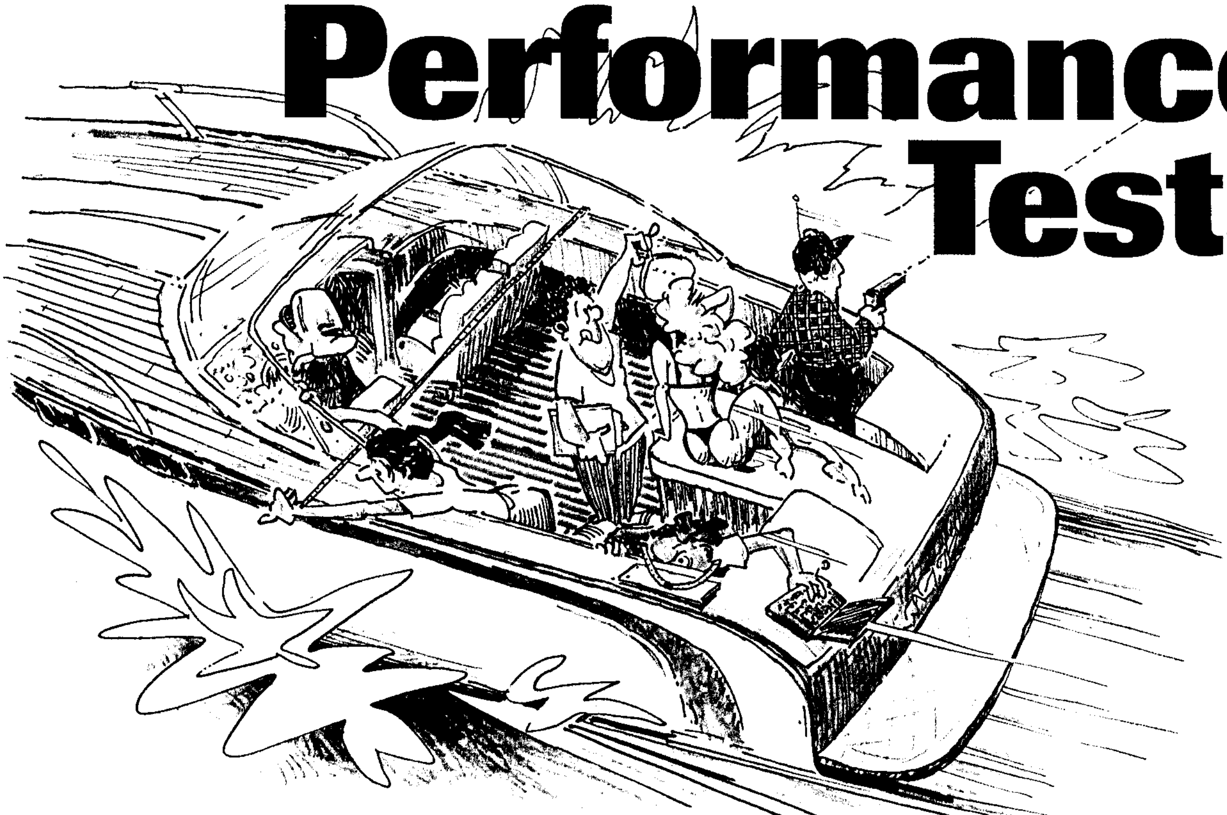
Powerboat Performance Tests



DOUGLAS COFFIN

Independent tests published in boating magazines can be a valuable source of data for designers, builders, and boat owners. Still, specific improvements would make any such test significantly more useful.

by Donald L. Blount and Douglas Blount

On the library shelves of our design office, we have a 6′-long shelf filled with notebooks containing boat-test articles from boating magazines—some from 25 years ago. We've collected much of the data on sportfishing boats from these articles in computer files for in-house use.

Boat-test articles serve the needs of several different groups. Magazine publishers get editorial content; boatbuilders get exposure to customers; and prospective owners get an objective look at the boats. The latter group may benefit the most, as they compare competitive boats. Builders, however, may experience a bit of a downside, since the test data provide a baseline for competitors developing their next generation. Many of these articles do a good job evaluating specific boats. One can also step back from individual boats' quantitative measurements and further analyze them collectively to yield useful diagnostic data and to indicate design trends.

Nevertheless, we feel that there are measurements that should be added to the typical published boat test that would make them even more valuable. In this article, we'll look at these parameters in detail, and make the case for more in-depth reporting.

At present, boat-test results are usually reported for a series of engine rpm's, and include speed, fuel-consumption rate, and range; noise level at one location; overall hull dimensions; engine make, model, and rating; tank capacities and condition during tests; personnel and optional equipment on board at the time of the test; and a boat weight (usually for an undefined condition). Acceleration (boat speed versus time) and trim are also reported in some instances. The weight of the boat during tests is seldom clearly defined.

We created a set of hypothetical boat-test data that's a bit more detailed than what's usually published, to make the case for more in-depth reporting. The additional information includes the depth of water under the keel at the test site, because it has significant influence on both the boat speed and acceleration results. To represent "deep" water, the test site should have water depth of at least 0.8 x LOA, or 3 x chine beam. Also, it would be good to know the specific gravity of the water to determine if it's salt, fresh, or brackish.

We also need a realistic boat weight. Understating or overstating weight benefits no one. Specifications often do not define the condition of the stated boat weight. We suggest reporting dry weight with standard equipment, unless the builder clearly defines the published weight. When no information is provided to help readers at least approximate the boat's weight, the value of the test data is greatly diminished.

We've included two other pieces of information in our hypothetical test results: change of trim with speed; and a few data points at cruise and top speed using trim tabs.

Analysis of Test Results

Our goal is to develop a power-versus-speed relationship from these boat tests. To do that, we need an accurate and direct measurement of shaft power. When installed, electronic monitors can be an invaluable source of fuel-rate data. Alternatively, fuel rates for diesel engines, based on characteristics curves from the engine manufacturer (see **Figure A**), can give power levels being delivered by the engine within approximately five percent.

We'll calculate a dimensionless speed (volume Froude number) in order to compare our Hypothetical 46

Boat-Test Example: Hypothetical 46

Specifications:
LOA: 46′ 0″ (14m) **BOA:** 15′ 3″ (4.6m) **Navigational draft:** 4′ 3″ (1.3m)
Transom deadrise: 20° **Dry weight with standard equipment:** 32,500 lbs (14,742 kg)
Fuel capacity: 650 U.S. gal (2,461 l) **Water capacity:** 150 U.S. gal (568 l)
Test engines: two inboard diesels, Generic Engine Co., Model 350, rated at 350 Bkw @ 2,600 rpm
Transmission: Marine Gear Ltd., Model XXX **Gear ratio:** 1.75:1
Propellers: Good Propeller Co., Style-Swift 24″ (61cm) dia x 28″ (71cm) pitch x 5 blades x no cup x 0.85 blade area ratio

Test-Site Conditions:
Atmospheric conditions: 75°F (24°C), 70% humidity, light breeze–4 to 7 mph (6.6 to 11.3 kph)
Seas: significant wave height, 0.5′ (.15m) **Water depth,** 50′ (15m), boat tested in salt water

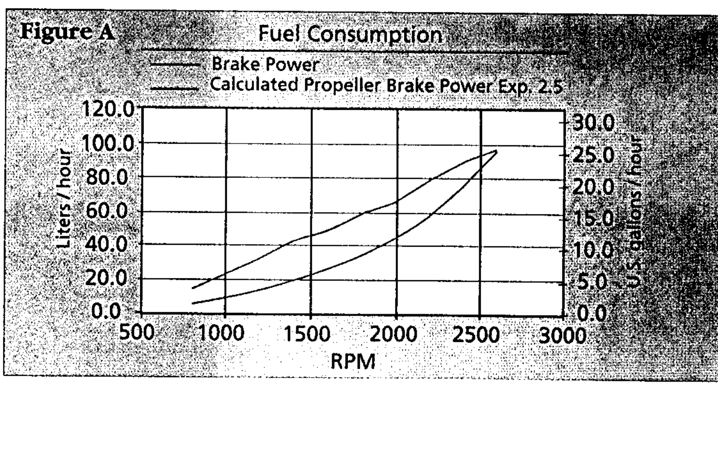
Test-Boat Condition:
Dry weight with standard equipment: 32,500 lbs (14,742 kg)
Fuel: 350 gal (1,325 l) 2,450 lbs (1,111 kg)
Persons: 5@180 lbs (82 kg) = 900 lbs (408 kg)
Water: 60 gal (227 l) 500 lbs (227 kg) **Test weight:** 36,600 lbs (16,602 kg)
Optional gear, teak, provisions: 250 lbs (113 kg)

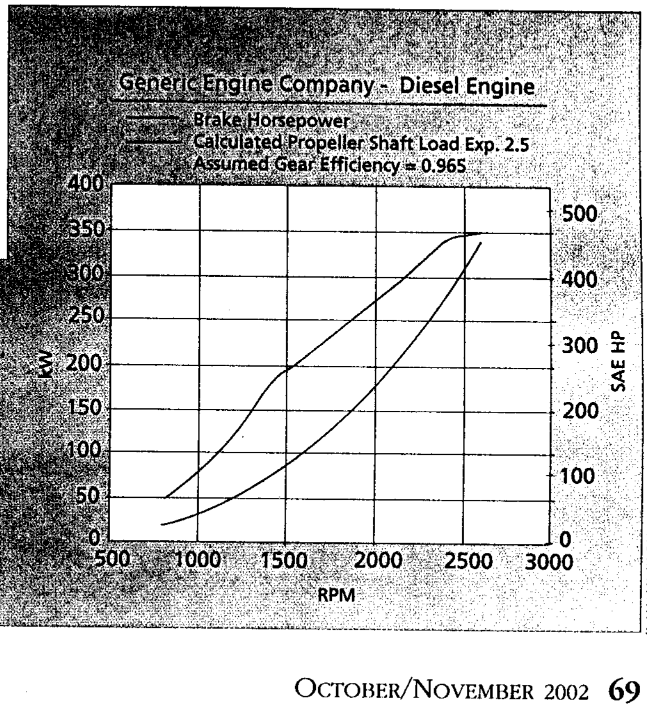
Test Results:

Engine rpm	Boat Speed MPH	Boat Speed Knots	Trim Degree	Total Fuel Rate GPH	MPG	NMPG	Range SM	Range NM	Sound Level
0	0	0	0	0	—	—	—	—	60
800	7.8	6.8	-0.7	3.0	2.60	2.27	1,521	1,323	64
1,000	10.1	8.8	-0.7	5.8	1.74	1.52	1,019	886	66
1,200	11.7	10.2	0.5	9.3	1.26	1.10	736	640	70
1,400	13.1	11.4	2.6	13.8	0.95	0.83	555	483	72
1,600	15.4	13.4	3.0	18.0	0.86	0.74	500	435	74
1,800	19.8	17.2	4.0	23.2	0.85	0.74	499	434	74
2,000	24.2	21.0	4.6	29.2	0.83	0.72	485	422	74
2,200	28.4	24.7	4.5	36.5	0.78	0.68	455	396	75
2,400	32.2	28.0	4.0	44.5	0.72	0.63	423	368	76
2,600	35.6	31.0	3.7	52.5	0.68	0.59	397	345	78
Trim tabs full down									
2,200	28.9	25.1	4.0	36.3	0.80	0.69	466	404	74
2,600	35.0	30.4	2.8	52.1	0.67	0.58	393	341	78

Notes:
1. Range calculated for 90% of fuel capacity.
2. Sound level measured at helm station.
3. For reference, the sound level of normal conversation is 65 dBA.
4. Boat-test weight includes optional gear of trim tabs and teak-trimmed deck.
5. Range calculations do not account for generator fuel, approximately 0.5 gph (2 lph).
6. Tests were conducted without using trim tabs, unless noted.
7. Speeds are two-way averages, measured with radar gun.
8. Fuel-consumption rate measured with engine manufacturer's monitoring system.

Above—*A sample powerboat-performance test, incorporating the additional information the authors would like to see in such tests: depth of water under the keel, a realistic boat weight, change of trim with speed; and data points at cruise and top speed using trim tabs.* ***Figure A***—*Fuel rates for diesel engines, based on characteristic curves from the engine manufacturer such as the ones shown here, can give power levels being delivered by the engine within approximately 5%.*





DONALD BLOUNT (BOTH)

to different-size twin-screw diesel boats, or to the benchmark for monohulls. We'll also include apparent slip ratio, to understand how well the propeller and gear ratio have been selected; brake and shaft horsepower; and transport efficiency.

• ***Apparent slip ratio.*** A good way to understand propeller slip is to compare the prop to a wood screw. A wood screw advances into wood with one revolution a distance equal to its pitch—there is zero slip. A typical boat propeller without cup, operating in water, will advance 80% to 85% of the propeller pitch with one revolution—that is, with 20% to 15% slip. A propeller with cup has an effective pitch somewhat greater than the nominal pitch and may have relatively low slip.

To achieve good propulsive efficiency, you need a very low slip ratio at design operating speeds, while the propeller is loading the engine at rated horsepower and rpm. A fairly high slip ratio indicates reduced efficiency and/or propeller cavitation. **Figure B** shows slip values from **Table 1** for a range of speeds for our test boat, compared to the maximum speed-versus-slip ratio of other boats. Our boat has a good match of gear ratio and propeller dimensions. If we reduced the drag of the hull and appendages, or improved the match between propeller and reduction-gear ratio, or just fit a propeller with better characteristics, then tests repeated under the same conditions would show a reduced slip ratio, and therefore improved propulsive efficiency. There are several ways to achieve better propeller characteristics: with cambered blade sections, rather than the flat-faced ogival sections common on most stock propellers; by varying pitch distribution from hub to tip for propellers on inclined shafts; or by polishing surfaces and refining blade leading-edge detail.

Be suspicious if the apparent slip ratio is negative. A negative reading could occur with cupped or cambered-section propellers, but it's more often the result of misinformation about the gear ratio or propeller pitch. (Boat speed and engine rpm are independently recorded by an objective journalist/tester.)

• ***Volume Froude number.*** One of the best ways to evaluate calm-water performance of different boats is by a dimensionless comparison. **Figure C** is the graph of the Hypo-

Table 1

Engine RPM	Boat Speed MPH	Boat Speed Knots	Volume Froude Number	Apparent Slip Ratio	Specific Fuel Consumption lb /(HP*hr)	Total Brake HP	Total Shaft HP	Transport Efficiency
0	0.0	0.0	0.00	---	---	0	0	---
800	7.8	6.8	0.70	0.378	0.420	50	48	15.8
1000	10.1	8.8	0.91	0.356	0.400	102	98	10.1
1200	11.7	10.2	1.05	0.378	0.380	171	165	6.9
1400	13.1	11.4	1.18	0.403	0.363	266	257	5.0
1600	15.4	13.4	1.38	0.386	0.351	359	346	4.3
1800	19.8	17.2	1.78	0.299	0.344	472	456	4.2
2000	24.2	21.0	2.17	0.228	0.341	599	578	4.1
2200	28.4	24.7	2.55	0.177	0.347	736	711	3.9
2400	32.2	28.0	2.89	0.144	0.364	856	826	3.8
2600	35.6	31.0	3.20	0.127	0.385	955	921	3.8
Using Trim Tabs Full Down								
2200	28.9	25.1	2.60	0.162	0.347	732	707	4.0
2600	35.0	30.4	3.14	0.142	0.385	947	914	3.7

Figure B

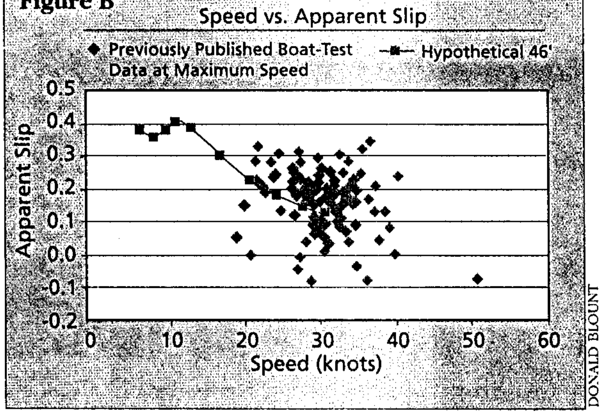


***Figure B**—Slip values for a range of speeds for the Hypothetical 46, compared to the maximum speed-versus-slip ratio of other boats. The H46 has a good match of gear ratio and propeller dimensions.*

Definitions

BHP	Engine brake horsepower (power input to gear)
BOA	Beam overall in feet
Diesel fuel weight	7 lbs/U.S. gal (838 kg/cu m)
ET	Transport efficiency, (W x V)/(Total SHP x 326) = η/(R/W)
$F_{n\nabla}$	Volume Froude number (dimensionless boat speed), $(V x 1.6878)/(g x \nabla^{1/3})^{1/2}$
g	Acceleration due to gravity, 32.15 ft/sec^2 9.8m/sec^2)
LOA	Length overall in feet
n	Propeller rotational speed in revs/sec, rpm engine/(gear ratio x 60)
P	Propeller pitch in inches
R	Bare hull resistance in lbs
SA	Apparent slip, 1-[V(1.6878)/(Pxn/12)]
SFC	Specific fuel consumption, lbs fuel/(BHP x hr)
SHP	Shaft horsepower (power out of gear)
V	Boat speed in knots
W	Boat test weight in lbs
η	Overall propulsive efficiency
η_t	Gear efficiency (about 96.5%)
∇	Volume of displaced water necessary to support the weight of the boat in cu ft - in salt water, ∇ = W/64 - in fresh water, ∇ = W/62.4

thetical 46's transport efficiency (ET) versus volume Froude number (F_{nv}). To construct this graph, we need shaft horsepower, test-boat weight, and speed—all of which can be gathered from boat-test data from various magazines, and from manufacturers' diesel engine characteristics. The performance of the Hypothetical 46 is typical of many current production boats, but below the benchmark that a limited number of very good boats have attained. The transport efficiency calculated from the test data is shown as points in Figure C, and is well below the benchmark line. At the highest test speed, F_{nv} = 3.2, the Hypothetical 46 is only 68% as efficient as very good hard-chine monohulls.

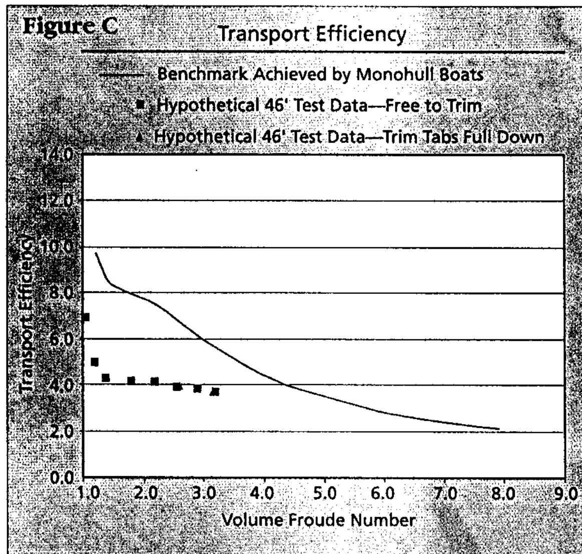


***Figure C**—The Hypothetical 46's transport efficiency is well below the benchmark line. At the highest test speed, it is only 68% as efficient as a very good hard-chine monohull.*

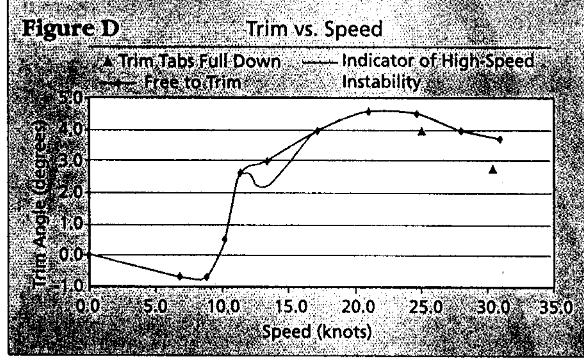


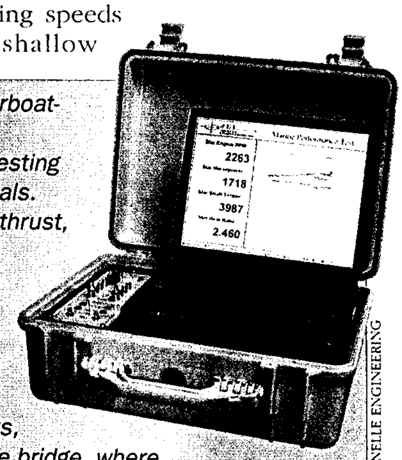
***Figure D**—A double hump in the speed-trim curve, shown by the green line, portends problems when the running-trim angle is reduced at higher speeds, whether by trim tabs or heavy items placed forward in the boat.*

• ***Trim measurements.*** Taking trim measurements during boat tests seems to have fallen by the wayside. We would encourage its return. Let's examine the trim data in **Figure D**. First, note that the trim gauge need only be set to zero when the boat, loaded for sea trials, is at rest. Trim measurements accurate to 0.1° to 0.2° are desirable. It's important to make trim measurements at steady boat speeds, beginning with low engine rpm and increasing in increments to maximum throttle. Select the rpm increments so that at least three boat speeds are run between 10 and 18 knots. The trim-versus-speed curve in this range provides a good indicator of potential bow steering and/or dynamic instabilities at higher speeds.

During tests on the Hypothetical 46, the boat was free to trim. That is, trim tabs were up (not used) for all but two runs. We know that trim tabs produce a bow-down moment, which can improve both ride quality in head seas and forward visibility. But, trim tabs can also give undesirable results. On some boats, they help increase speed; on others, they slow down the boat; and in some cases can induce unwanted bow steering. For our test boat, tabs improved cruise speed but hurt top speed. At cruise, the boat was running at a trim angle higher than optimum for minimum resistance; trim tabs lowered the running angle, which helped at that speed. At full throttle, the boat was near optimum trim. So, trim tabs at full throttle slowed down the boat, since the bow was lowered into the water, increasing frictional drag.

The running trim of a boat at semi-planing speeds is a good indicator of potential dynamic instabilities—bow steering and heeling—at high speeds. A double hump in the speed-trim curve shown by the green line in Figure D portends problems when the running-trim angle is reduced at higher speeds, whether by trim tabs, or heavy items placed forward in the boat.

• ***Acceleration.*** The acceleration test is generally accepted as a gauge of "time out of the hole"—that is, a measure of agility or response to the throttle. It is that and more. But, take note that the water depth at the test site can easily shade acceleration results. If the boat has little power margin between the propeller demand and the engine characteristics at low rpm, it might not accelerate to planing speeds in shallow



Portable yet sophisticated patent-pending powerboat-performance testing equipment from Janelle Engineering (Punta Gorda, Florida), capable of testing a boat's entire propulsion system during sea trials. Janelle's PowerMate system measures torque, thrust, horsepower, rpm, trim data, speed, voltages, current, pressure, heat, and GPS information simultaneously, with no restriction on vessel horsepower. During a sea trial, a Janelle engineer attaches wireless strain gauges to the prop shafts. The strain gauges communicate information to a laptop computer near the shafts, which in turn communicates with a laptop on the bridge, where the engineer conducts the testing. All the measured values are recorded simultaneously for graphical side-by-side comparisons of the engines' individual effect on the vessel's performance. In its report, Janelle provides a copy of the engine manufacturers' performance specifications, allowing for a new-versus-used comparison of the engines.

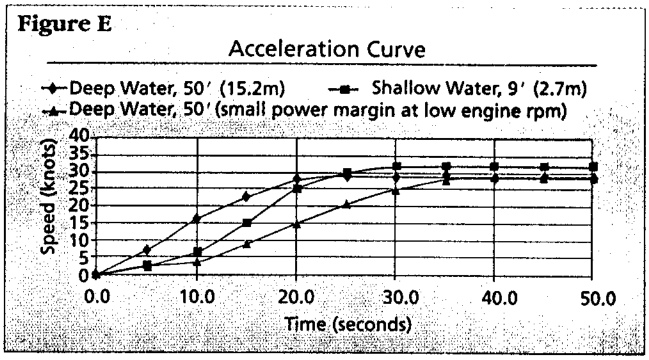


__Figure E__—The acceleration-test results for the Hypothetical 46 include two additional curves. One shows the likely differences due to conducting the test in shallow water. The other curve shows the sluggish response when there is a small power margin at low engine rpm.

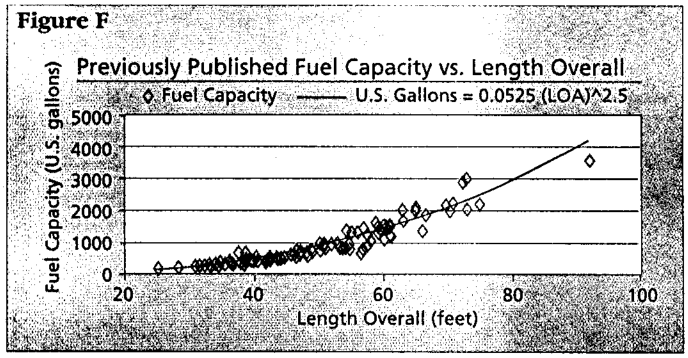


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__Figure F__—Boat tests collected over several years offer ways to study trends in boat characteristics. For example, the data here shows that the nominal fuel capacity in twin-diesel-engine sportfishing boats increases exponentially as a function of boat length.

water. For boat-to-boat out-of-the-hole comparisons to be equitable, they all need to be conducted in water depth of at least 0.8 x LOA.

The acceleration-test-results graph for the Hypothetical 46 given in **Figure E** includes two additional curves. One shows the likely differences due to conducting the test in shallow water: slower initial acceleration, but increased top speed. The other curve shows the sluggish response when there is a small power margin at low engine rpm. The fixes in the latter case may not be easy. Options are to change propellers and gear ratio, change engine turbocharger, change engine model, or reduce boat weight. If a boat exhibits very sluggish acceleration, then one or all of these changes must be made to produce a marketable craft.

Boat-test results collected over several years offer a number of ways to study trends in boat characteristics. Take, for example, **Figures F** and **G**. The first shows the nominal fuel capacity offered in twin-diesel-engine sportfishing boats. As expected, the

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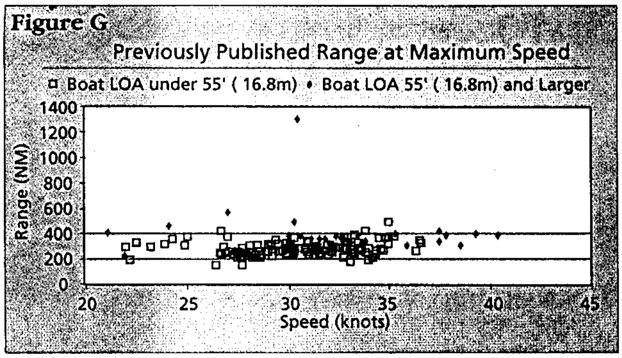

Figure G—*The great majority of planing, twin-diesel boats have, at maximum test speeds, ranges of 200 to 400 nm. Longer boats have the greatest range; their maximum speeds also tend to be higher than smaller boats. These trends support the conclusion that larger boats with high-powered diesel engines are more efficient load-carriers than smaller boats.*

fuel tanks' capacity increases exponentially as a function of boat length. **Figure G** illustrates that the great majority of planing, twin-diesel boats have, at maximum test speeds, ranges of 200 to 400 nm. Longer boats have the greatest range; their maximum speeds also tend to be higher than smaller boats. These trends support the conclusion that larger boats with high-powered diesel engines are more efficient load-carriers than smaller boats.

Another trend that boat tests can reveal is sound levels. Are noise levels at the helm increasing or decreasing, considering the offsetting effects of emerging acoustic treatments versus increasing engine power?

We applaud the boat testers. Con-tinue the wonderful service. But, may we greedily ask for a bit more detailed information that would add greatly to the value of the tests? Clearly define the condition of boat weight in the specification, so there is a realistic value for boat weight as it is tested. Measure and publish the water depth at the test site; indicate whether it's salt, fresh, or brackish water; and remember that speed-trim data is most useful.

The message for magazine readers is, save all your boat-test articles. Boat tests collected over several years build an informative design-and-trend data base. Turn your creative thoughts loose and squeeze more from these boat-test articles. PBB

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