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Sailing Yacht Design for Maximum Speed

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ABSTRACT

This paper reviews the performance of ice and land yachts and the factors that determine their top speeds. The data clarify a century of misunderstanding about top iceboat speeds and serve as background for discussing the design and performance of the author's land yacht, the Iron Duck. This yacht was built as an amateur project and holds the
world record for speed in a land yacht at 116.7 mph. It appears that it is, currently, the fastest sailing yacht on any surface. Finally, the paper provides perspective on a variety of aspects of speed sailing on dirt and ice.

NOTATION

a Angle of attack of the wing or sail

β Angle between the apparent wind and the

	yacht travel direction
γ	The angle between the true wind and the yacht's travel
Cd	Coefficient of drag
Cross Flow Drag	
	Drag associated with sailing when β is higher than a few degrees.
Drag:	The forces operating opposite to the direction of the yacht's travel.
Dirt	Typically a dry lake surface suitable for sailing on wheels.
Drive	The force from the sail or wing acting in the direction of the yacht's travel.
Effective Frontal Area	
	The frontal area of the yacht, other than the wing, normalized to a Cd of 1.0.
FISLY	Federation Internationale De Sand Et Land Yachting
NALSA	North American Land Sailing Association
Pilot	Land sailor speak for skipper
Speed Yacht	A yacht designed primarily for top speed
Va	Apparent wind velocity
Vb	Yacht velocity
VMG	Velocity made good, up or down wind
Vt	True wind velocity
Wing	Used instead of a soft sail on some yachts
Units	Mph, ft, lbs

INTRODUCTION

Ice and land yachts occupy one end of the sailing yacht performance spectrum. Their very low 'hydrodynamic' or rolling resistance while resisting the considerable lateral force these yachts develop allows them to sail at speeds well over twice that of the fastest watercraft. Particularly on ice, their top speeds have been more a matter of speculation than science.

While many sailors of these yachts have had ideas about setting speed records, most have focused their considerable ingenuity on being fast on the racecourse. Racing has a very objective measure of performance: whoever gets to the finish line first is fastest. Racing allows sailing in a wide range of conditions. There is a reasonable ratio of sailing time to the amount of time a sailor has to spend preparing to sail (building, maintaining, transporting and waiting for the right sailing conditions).

Speed sailing, on the other hand, has a number of drawbacks. It has a particularly low ratio of sailing time to preparation time. It is common to wait weeks for the right sailing conditions. Making accurate speed measurements is a much more involved process than setting two marks to race around. Finally, widely accepted speed claims on ice reached 143 mph in 1938. Any scientifically sound measurements gave much lower values, which made the prospect of going faster than 143 daunting. Efforts by iceboating authors Calhoun Smith[1] and Jack Andersen[2] to provide a more realistic perspective on top speeds has done little to dampen the acceptance of the prevailing claims. The result of all this was that by 1990 no one had built a yacht that was truly optimized for top speed.

A LITTLE HISTORY

Land yachts in particular have been around for a long time. The remains of a sailing chariot were found in the tomb of Egyptian king Amenenhat III (1844-1794 BC)[3]. Around the turn of the century the sport gained interest on beaches in Europe. Land yacht racing became organized in the United States in 1972[4]. The open land yacht classes essentially have no constraints on design. This has resulted in a particularly diverse range of solutions to getting around the racecourse. There has been considerable experimentation with wings and very wide masts as well as a wide range of construction materials.

Ice yachting started in Holland in the mid 1600's. By the late 1800's in North America, boats as long as 60 feet with up to 1000 square feet of sail were sailing on the Hudson River and elsewhere in the ice belt that runs across the northern part of the US and southern Canada. As was typical of sailboats of the day, the yachts did not benefit from a proper understanding of aerodynamic drag. The sails were lateen or gaff rigged and the steering runner was at the stern. This configuration allowed the pitching moment of the sail to un-weight the steering runner as the yacht powered up. The angular momentum associated with the rear steering action further loads the steering runner. This same action can be seen when driving a car backwards with some speed. The result was often a spin at near top speed called a 'flicker.'

There is a lot of folklore from this period. These yachts were said to be the fastest means of conveyance of the day. Without an easy way to accurately measure speed, exuberant speculation dominated speed discussions. Claims built on previous claims. One hundred-plus mph was claimed by the late 1800's. In 1908 the unremarkable lateen rigged 'Carel' claimed 140 mph. A 1938 claim of 143 mph for the rear steering yacht 'Debutant' in the "Guinness Book of World Records" is the most well known.

In 1931 Joys Brothers Sail makers (Milwaukee) made a small front steering yacht that did not have the flicker problem. With the steering runner in front, the pitching moment increased steering control as the yacht built speed. Over the next two years Wisconsin sailor Walter Beauvois, working with Joys, developed a 13-foot long, 9-foot wide, front steering yacht with a single 75 square feet sail. It was a faster race boat than all the much larger rear steering yachts. This design has evolved into ever-faster racing yachts on both ice and dirt.

OVERVIEW OF MODERN RACING YACHTS

The DN is the most popular iceboat in the world. It is 8 feet wide, 12 feet long with a 67 square foot sail on a 16 foot mast. It weighs about 150 lb. It started as a home building project in 1936 and has evolved into a well-balanced racing machine. It is surprisingly undiscriminating about who is successful: light and heavy, young and old, all have had their day as champion of the class.

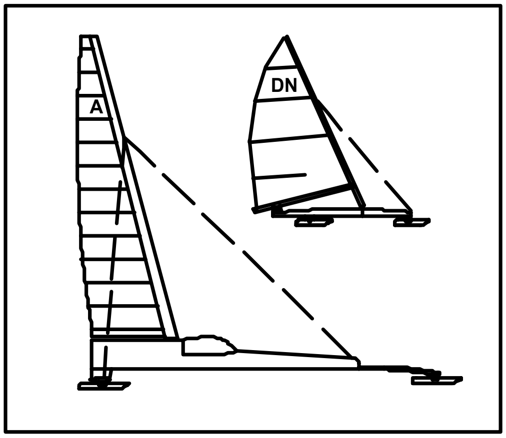


Fig 1 Side view of a Skeeter and DN iceboat

The Skeeter is the fastest iceboat. The class is based largely on a single rule: the sail triangle can be no larger than 75 square feet. This does not count the mast, boom, and roach. The maximum propulsive area is about 140 square feet. They are typically around 30 feet long, 25 wide and have a 27-foot mast. Weights are 500-600 lb. There are presently two popular styles of Skeeters. The 'Bubble Boat' design is shown in Fig. 1 with the skipper under a canopy in front of the mast. The design was developed by Tom Nichols and Dan Clapp and is popular in the East. In the Midwest, the skipper usually sits behind the boom in what is known as a 'Rumble Seat' configuration. In most other iceboats the skipper sits or lies under the boom.

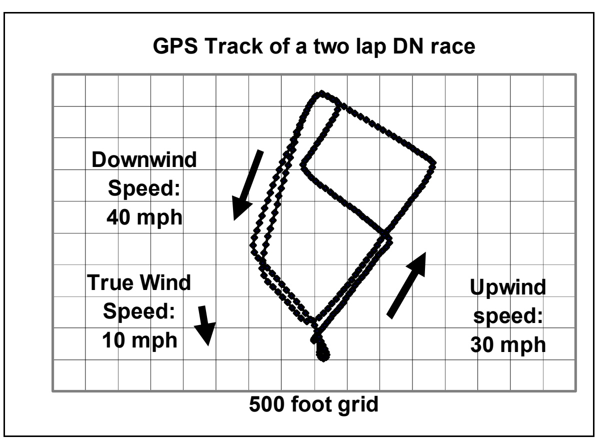


Fig 2

These yachts almost always sail in a 'close hauled' condition, as ß (the angle between the apparent wind and the yacht travel direction) is rarely more than 20 degrees. Iceboats race only on windward-leeward courses, allowing them to use their closeness to the true wind to depower quickly in windy conditions (by heading up or down a few degrees, as appropriate). This allows them to carry their largest sails in all wind conditions.

Land yacht racecourses often have long reaching legs and the yachts have evolved a variety of ways to allow them to sail fast on beam reaches in high winds. These include the use of small sails for windy days, mainsheet travelers, wide masts with mast rotation controls, and the use of flapped wings instead of sails.

TOP SPEEDS OF RACING YACHTS

Until the advent of the inexpensive GPS, iceboats have not had an easy way to measure their speeds (unlike land yachts that can easily incorporate a speedometer on a wheel). As previously mentioned, there has been no shortage of speculation on the matter of iceboat top speeds. To get a better understanding of true performance, in 1992 I bought a good radar gun and started taking it to iceboat regattas. The following graph is from many hundreds of measurements of DNs.

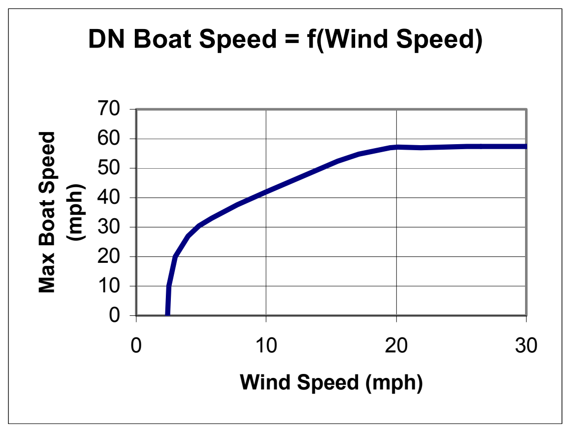


Fig 3

Ice yachts on good ice will not start in winds less than 2.5 mph. In very light winds they sail fastest up wind in a tight reach. From 4 to about 12 mph they sail well on any point of sail. Above 12 they are fully powered. By 20 mph they are overpowered and are relegated to pointing and broad reaching to control the yacht. The flatness of the curve in winds above about 18 mph was somewhat of a surprise. Sailing a boat in 30 feels much faster than in 18 as a result of the greater difficulty of controlling the yacht.

The vector diagrams used to describe the performance of these yachts predict higher top speeds than they are able to achieve. I am in the midst of an empirical study of sailing angles in various wind and surface conditions to try to sort this out.

The DN class recently permitted the development of high flexibility fiberglass masts, which has allowed top speeds to increase a few mph since this data was taken. These masts are sailed with up to 15 inches of bend in the 127 inches between the hound and the base. The bend flattens the sail and eases the leach for less drag and moves the center of effort down allowing more drive.

The same graph with data from Skeeters and selected land yachts is shown below.

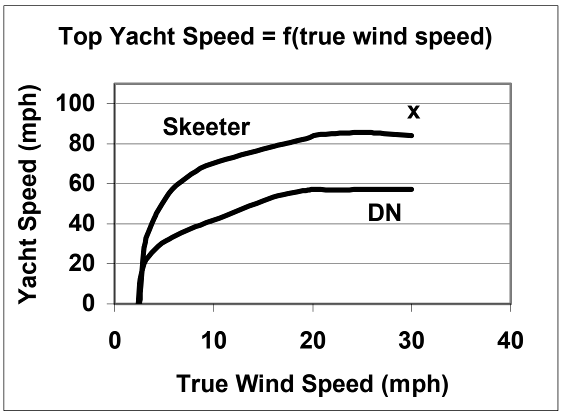


Fig 4 ('X' = Rothrock Winged Land Yachts)

The Skeeters and the fastest soft sailed land yachts have similar maximum speeds (in the upper 80 mph range). In significant part, their speed is limited by their inability to sail at high speed on a beam reach. This is a function of two things:

- At high apparent wind speeds sails have to be nearly fully sheeted to avoid excessive luffing drag and its attendant negative pitching moment.
- Center sheeting is universally used in ice boating as it works very well on windward leeward courses. On a beam reach in 30 mph wind with an 80 mph boat speed, ß is about 20 degrees which creates too much lift with a well sheeted sail. Center sheeting does not allow reducing the angle of attack without releasing the sail so much that it luffs excessively.

The winged land yachts do not have the luffing problem and a couple of the yachts designed by the Rothrock family have gotten to nearly 100 mph. Unfortunately, they never went this fast during an official speed trial.

The true top speed performance of the old rear steering yachts with their 100+mph claims is, to a large extent, lost to antiquity. While a few of these yachts are still sailing, they are now much loved antiques and they rarely get sailed hard. On the racecourse they have speeds similar to DNs in lighter winds and they tend to stay on shore when it gets windy. In the hearts of many iceboaters these wonderful old yachts will always be the fastest.

Boat Speed to Wind Speed Ratio

Figure 5 shows the speed data for DN's and Skeeters arranged to show the boat speed to wind speed ratio. Although this is a difficult measurement to make accurately, especially in light winds, I am reasonably confident in this data.

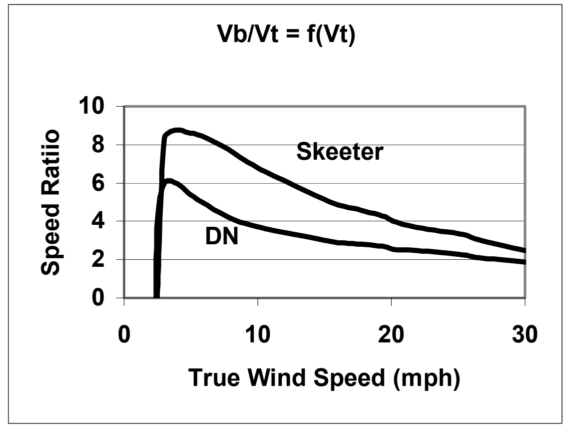


Fig 5

The highest Vb/Vt ratios occur at the low end of the wind range. In very steady, light winds on smooth, warm salt ice Vb/Vw ratios as high as 8:1 or 10:1 are possible in the Bubble Boat Skeeters. This corresponds to a ß of only 7 or 6 degrees. The most efficient land yachts are capable of about 6:1 in a steady 5 mph wind. In 30 mph winds the ratio drops to about 2:1 for the DN and just under 3:1 for Skeeters and soft sailed land yachts.

For perspective, on water the average keelboat is capable of roughly 1:1 in light winds. Sailboards do slightly better than 1:1 at their highest speeds. The A Class and similar catamarans are capable of about 2:1 in light winds. The last round of C Class cats were able to do about 3:1 in 4-6 knot winds. More impressive, the Australian speed yacht, Maquarie Innovation has achieved 43 knots in 14 knots (3:1). This is getting into the realm of ice and land yachts.

In summary, racing yachts are specialized for the single goal of getting around a racecourse first. They need to perform well in winds from 3 to 30 mph. This leads to lighter weights and more powerful rigs that can be depowered as needed. They need to sail well on all points of sail with emphasis on VMG both up and down wind. A speed yacht needs to sail at it's fastest on one tack , at one sailing angle (γ) and only in high winds. This is a more straight forward design problem.

DESIGNING FOR TOP SPEED

The design process for the Iron Duck was piecemeal and iterative in an effort to find effective but reasonable to implement solutions. The design focused on minimizing drag first and then optimizing the platform and wing to provide enough drive at speed. Sighard Hoerner's book "Fluid Dynamic Drag"[5] was particularly helpful with his practical presentation of the many factors that contribute to drag. Most of the science that allowed us to be successful was developed in the 1930's or earlier.

Drag

At high speeds, aerodynamic drag accounts for about 70% of the total drag on the boat. The majority of that is parasitic drag on which the designer has considerable influence. The following chart shows the estimated relationship between top speed and effective frontal area (at Cd =1). This is based on a simple velocity prediction algorithm adjusted for actual yacht performance.

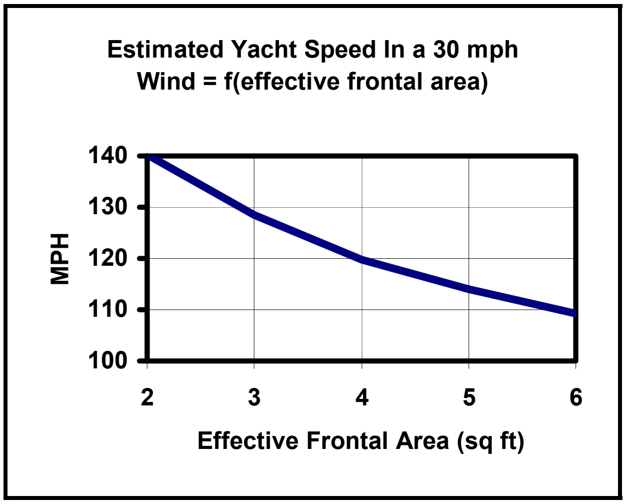


Fig 6

Fairing everything and using an asymmetric layout are keys to reducing parasitic drag. Asymmetry minimizes cross flow drag at speed by making all the fairings point into the apparent wind on port tack at the design Vb/Vt ratio. I expected to be able to achieve about 4:1 so the fairings were pointed about 14 degrees to the left of the yacht travel direction. Port tack was chosen based on the places we expected to sail. Interference drag was minimized with fillets at junctions and sufficient separation of nearby surfaces. A full roll of duct tape was required to cover seams, gaps and irregularities.

Estimated Drag Budget: Iron Duck at 120 mph

Drag Source	Percent of Total
Parasitic/Interference	60%
Profile (wing)	10%
Induced	3%
Rolling	27%
Total	260 lb

Fig 7

A wing has several advantages over a sail. It has less drag than a sail and at high speeds it can be operated at very low angles of attack without luffing drag. This makes up for its higher weight and greater difficulty in starting and accelerating the yacht. The wing on the Iron Duck has an aspect ratio of 8:1 with a good seal at the deck resulting in an effective aspect ratio of nearly twice that amount.

Wheel drag is minimized by the choice of tire size, tread compound, and inflation pressure. We used 24" diameter car tires on 15" rims. We tried everything from very sticky dirt track tires to high performance street tires. We went fastest on the street tires but subsequent testing indicates the moderately sticky racing tires we are presently using are probably the best choice.

Drive

The amount of power required at top speed is impressive, on the order of 80 hp. Drive is limited by either tip-over stability or lateral traction. Balancing weight, width and sail height against their associated drag costs is the basis of a good yacht design. The sail plan only needs to be large enough to start the yacht in enough wind to set a record.

After many hours pouring over Abbot and Doenhoff[6] looking for the optimum wing section, a slightly thickened NACA 0012 section was chosen. A fast run requires a sustained 27+ mph wind, good entry speed and the right sailing angle. Having all three on the same run requires a significant amount of luck. A cambered section would be a little more efficient on the fast tack, however the NACA 0012 section allowed powerful sailing on both tacks. This allows sailing laps on our 1.5mile long course in about three minutes. Many runs maximize the chance of being lucky.

Experience by other land sailors had shown that the potential benefits of laminar sections are not easily realized given the amount of vibration in the yacht and the turbulence of the gusty wind. In addition, their pointy nose prevents them from generating the desired high lift coefficients at low yacht speeds.

The optimum weight is hard to predict. The velocity prediction algorithm suggests higher weights will yield higher speeds. The algorithm does not account for the benefit of accelerating to high speed quickly so the yacht is ready to take advantage of each gust of wind. Typically a 1.5 mile run will pass through multiple gusts. The Iron Duck appears to be a bit on the heavy side for the courses and winds we have had.

CONSTRUCTION AND TRIALS

We built two iterations before we were successful: the Wood Duck in 1994 and the Iron Duck the following year. In the following discussion, most of the data relate to the Iron Duck. We had the use of Bob Schumacher's canoe repair shop and basic machine tools (welder, lathe, milling machine and bandsaw). The project has been a proper amateur effort without the distraction of seeking sponsorship. The overall material cost of the two yachts was about $6,000.

The fuselage of the Wood Duck was a fiberglass covered wood strip tube with a fore and aft seating configuration. The pilot steered and the crew managed the wing. Struts were used to support the wing to avoid the inherent floppiness of a wire-stayed system. The yacht was steered with the front wheel, actuated with foot pedals through a cable system. The 27-foot wheelbase kept the steering slow enough to be manageable at high speeds. The front tire was a 5x5 airplane tire. The side wheels, hubs and spindles were from old Volvos.

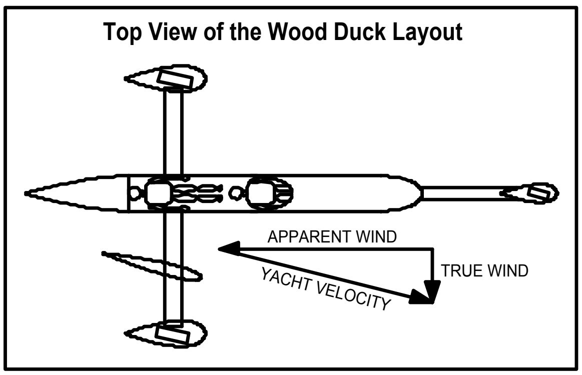


Fig 8

The Wood Duck incorporated most of the drag reducing elements discussed above but suffered from an under appreciation of the importance of cross flow drag during start up when the yacht is sailed at high angles to the apparent wind (ß). The long fuselage and struts were efficient when ß got below 15 degrees, but this only happens at high speeds or by starting pointing close to the true wind where drive is limited.

More importantly the wing control system was not designed to allow it to immediately depower (as any sailboat will when the main sheet is released). The wing was run by a hydraulic system that held the angle of the wing until it was changed. It took several seconds to move the wing through 90 degrees.

Like the Titanic, I considered the mighty yacht far too big to tip over with its tiny 80 square foot wing and hefty 1400 lbs. We did not even put in seat belts! The Wood Duck seemed to have a hard time getting hooked-in the first time we sailed it in 15-30 mph winds on Ivanpah Dry Lake near Las Vegas in the fall of 1994. I had not diagnosed the cross flow problem, and spent the night pondering the merits of a thorough 600 grit sanding. The next day no sandpaper was required: in 40 mph winds it had no trouble getting going. On our tentative first run we hit 71 mph.

Shortly afterward, while sailing the yacht slowly to windward to get in position for a proper high speed run, a 55 mph gust started to tip the yacht over. Seatbelts were suddenly looking like a very good idea. With the wing mounted toward the windward end of the plank, as the yacht started to lift, the center of effort went up especially quickly, making capsize almost inevitable after it passed a relatively low heal angle. Bob tried to steer out of the hike but our low speed prevented that from being effective. I was not able to depower the wing quickly enough either. In a few long seconds we skidded to a stop, upside down.

Fig: 9
The Wood Duck-Feeling a little too frisky

With a newfound appreciation of what my land yachting friends had been telling me about wing control systems, I built the Iron Duck the following year.

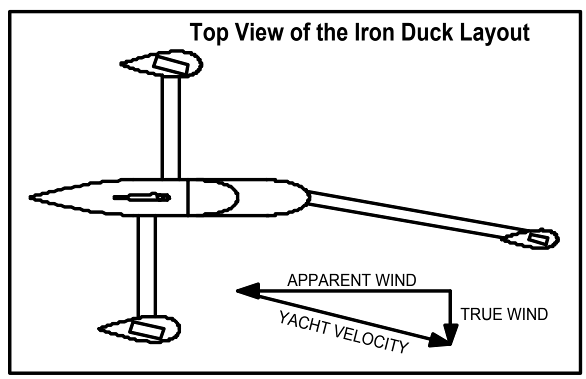


Fig 10

The yacht is nearly 40 feet long and 22 feet wide with an all up weight of 1800 lb. The fuselage is made of fully triangulated 1.5"OD, 0.120" wall DOM steel tubing and is very strong. It has five seat belts for a single pilot and three levels of roll over protection. It is driven by a high aspect ratio, 70 square foot wing. The wing is cantilevered to eliminate the considerable drag of stays or struts. The angle of the wing is controlled by a chain system that allows the wing to 'feather' immediately when the control wheel is released. The front of the yacht is 'bent' to keep the three wheels in an isosceles triangle to better balance the weight distribution and to keep the fuselage out of the wake of the front wheel fairing.

TUNING

It took 4 years of trials and modifications to get the yacht and pilots dialed in. The first trials in 1995 with an un-flapped 58 square foot wing found the yacht very hard to start in less than a 25 mph wind. Once started however, the yacht accelerated nicely. In 1997 the yacht sported an elliptical wingtip extension and a 20% follower flap. This allowed the yacht to start in about 15 mph and, once moving, to continue to sail in winds down to about 10 mph.

The pilots in particular required considerable seat time to learn how to handle the yacht in high winds at high speeds. Winged land yachts have a well-deserved reputation for instability in these conditions. Wings on land yachts are seldom mass or aerodynamically balanced. When β is very small, the wing may start to oscillate at 2+ hertz generating a large negative pitching moment. This is similar to flogging a sail but more violent. Typically, this tips the yacht backwards on its tail. As the yacht slows, it falls forward hard enough to break the fuselage in half. At speed in the Duck this might result in a high-speed forward cartwheel. This was not something we wanted to experience.

Once the yacht reached 70 mph in winds over 20 mph it REALLY wanted to go faster and it was far from clear that it would be stable or that we would be able to stop it before running out of lake bed. At 70+ in the overpowered yacht the warm thoughts of success that filled my head during the design and building phase were replaced with all the ways things could come to a bad end. Bob said it best as he climbed out of the yacht after an early run: "I am sure this thing will go faster, I am just not sure it will be with me in it". Having two pilots was helpful as it gave each of us a little time out of the boat to regain enthusiasm for pushing a bit further. Over time we learned that the yacht did have a top end, that it would not do anything untoward at speed and that we could stop it reliably from high speed either by backing the wing or throwing the yacht into a slide.

Early in 1998 the English speed yacht Windjet came to our attention. It was a professionally designed and built machine that had many of the features of the Duck. It appeared eminently and imminently capable of exceeding our goal: Bertrand Lambert's 1992 land sailing speed record of 94.7 mph. In the fall of 1998 we spent two weeks on the desert and had almost enough wind. We got to a tantalizing 92 mph and left with certain knowledge that with a bit more wind 95 mph or even the coveted 100 mph mark could be achieved.

RESULTS

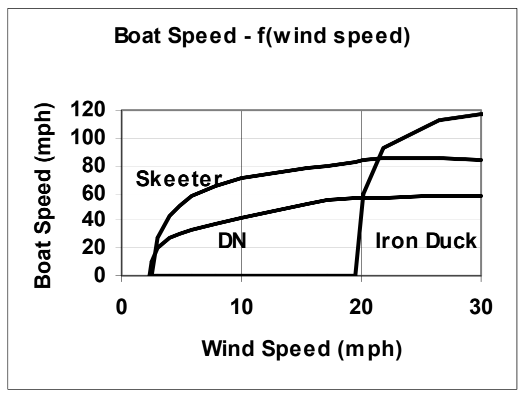
In March, 1999, on Ivanpah Dry Lake near Las Vegas, over two days with 25-32 mph winds, everything came together. On the first day we got the yacht to 108 mph with the flap on the wing. On the second day, without the flap we reached 116.7 mph (Bob was in the seat at the time, my best run was 112.4). The top speed on our secondary GPS measurement was 119 mph on the fastest run. The difference resulted form the yacht sailing at a moderate angle to the radar gun at its top speed.

Over the two days 81 runs were sailed: 60 of them over the existing record and 40 over 100 mph. Representatives of the North American Land Sailing Association oversaw the trials. After a review of the Final Report from the trial, NALSA ratified the record.

In several subsequent trials, in less than optimum winds, we have achieved speeds between 110 and 114 mph several times. Further trials are planned. The velocity prediction algorithm suggests a goal of 125 mph (200 km/hr) is realistic.

The following charts compare top speeds of racing yachts with the performance of the Iron Duck.

Fig 11 Top Speeds



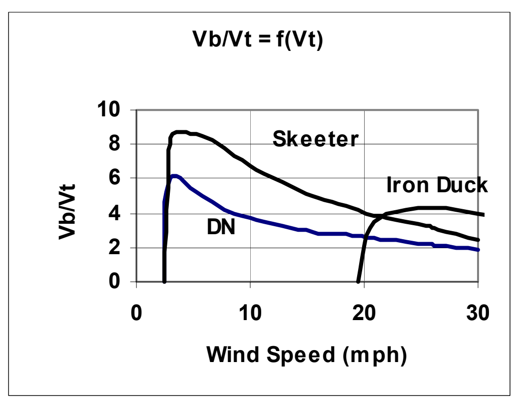


Fig 12 Boat Speed to Wind Speed Ratios

POTENTIAL FOR NEW DESIGNS

Based on what we have learned there are a number of refinements of the current design that will yield higher speeds. Reducing the total surface area of the yacht, improving the effectiveness of the fairings, and spending a few months waiting for the required wind should yield a top speed of about 140 mph.

RULES OF THE SPEED GAME

The rules for land sailing records in North America and Europe require that the craft be powered by the wind alone with no contribution from stored energy or gravity. They require a measurement procedure that assures that measurements are both scientifically and ethically valid. The NALSA Regulations for Speed Record Attempts can be found on www.nalsa.org.

The NALSA rules do not require a specific measurement method as long as it meets their accuracy criteria (0.25 mph measurement uncertainty) and can be demonstrated to be scientifically sound. One of the concerns is that any method can give spurious data. To protect against this risk, NALSA requires a careful analysis of this potential and the use of at least two secondary measurements to verify the primary measurement.

Timing traps have been the traditional primary method. These work very well for motor sport tracks but they are problematic for land sailing. Sailing at a measurement station from over a mile away at these speeds is difficult and dangerous for everyone involved. Radar is a better method but it still requires the yacht to pass relatively close to the measurement station.

Data logged GPS is by far the best method. It allows the yacht to sail well away from people and obstructions. We have been using a Trimble AG 132. The measurement uncertainty is 0.03 mph at zero speed (fixed position) and is directly measurable with the unit's filtering software turned off. The velocity measurement is made by a doppler calculation on the GPS signal. The AG 132 provides position data that can be checked against the doppler velocity. It also provides signal quality and satellite position data. We have found that differential correction on the AG 132 reduces the position uncertainty significantly (from about 2 meters to less than 1) but the velocity uncertainty is not affected.

Secondary measurements used for record setting include: inexpensive GPS's with data logging, bicycle speedometers, radar from afar with cosine error correction using the GPS position data, and video tape assessment. We typically use from 5 to 7 secondary measurement instruments.

NATURAL SURFACES: ICE AND DIRT

One would think that ice would be the preferred medium for speed. On good ice, an iceboat has runner drag of 0.8% of its weight based on low speed coast down tests. A land yacht on a dry lake has about twice as much rolling resistance. At top speeds, on the other hand, the dominant drag force is aerodynamic so the incremental difference in ground contact friction is a small factor in the overall drag budget. In the end, ice may be faster but the difference will probably only be a few miles an hour.

There is another more practical side to this: Dry lake surfaces tend to stay the same for long periods of time. Ice is far more fickle. An obstruction free ice sheet that is hard, big, thick and smooth enough for a record attempt is relatively rare and usually short lived. Setting a record requires a confluence of having the yacht ready to go, having observers on site, and the right wind, in addition to having a suitable sailing surface. Pulling all of this together is far more likely on dirt than ice.

With the greater difficulty of getting proper conditions on ice there can be considerable pressure on the team to make attempts when ice conditions are not as safe as they should be. Iceboat racers make these kinds of decisions regularly. The worst consequence for them is usually getting wet or breaking a boat. In a heavy speed-yacht at much higher velocity a bad outcome is likely to be more dramatic.

UNNATURAL SURFACES: PAVEMENT AND RAILS

Both the European and North American governing bodies for land sailing (FISLY and NALSA) have stipulated, one way or another, that records should be set on natural surfaces. Dry lakes and ice are the flattest natural hard surfaces in the world with relief of less than a foot/mile.

Paved surfaces are almost never this flat. Depending on how the down slope portion is used by a yacht, it can provide a gravity assist either for getting the yacht started or as a boost at top speed. Additionally, paved surfaces large enough to sail on invariably are heavily regulated making access to them unavailable to most people.

If there are no rules other than the machine be a purely wind driven sailing device, it is easy to design a rail constrained configuration that should be capable of over 200 mph. At some point the exercise moves beyond the reasonable realm of sailing. It is the contention of FISLY and NALSA that natural sailing surfaces define an important part of that realm.

RECENT HISTORY OF SPEED RECORDS, ATTEMPTS, AND HOPES.

On dirt, there have always been good speed measurement methods and a long history of scientifically sound speed trials. On ice, without such measurements, reality has been obscured by folklore. The following provides some perspective on recent efforts to go fast on dirt and sand.

In 1976 Nord Embroden sailed a Freedom land yacht to 88.4 mph. The Freedom is a commercial fiberglass yacht designed and built by Nord. The Freedom was generally not the fastest yacht on a race course but this speed record held until 1992.

In that year, Bertrand Lambert sailed to 94.7 mph on sand on the French Coast. His yacht was a modified racing yacht. It had an asymmetric, single element wing and had a canopy over the pilot. His record held for seven years.

Following his success several French teams developed a variety of exotic designs. They were fully faired and highly asymmetric. They were built as a competition between engineering schools with the primary constraint being that the yacht had to fit into a 7 meter cube. In June of 2000 at Saint-Brieuch on the French coast, Tadeg Normand, sailing one of his versions of the $7m^3$ design, exceeded Lambert's speed by 0.2 mph and now holds the record for sand. Interestingly, Normand's yacht was a relatively conventional, symmetric design. He had a single element wing on a medium sized platform.

In the mid 1990's, Australian Bill Finch built a relatively small single element wing powered speed yacht. He sailed it to 90 mph in 30 mph wind at Kambala, in Western Australia. Although he was confident he could beat Lambert's record, given the right conditions, he was unable to do so before the Iron Duck put the record out of his reach in 1999.

The Rothrock family has been building aluminum skinned, two and three element winged racing yachts for two generations. Two of those yachts have gotten close to 100 mph. Clarance Rothrock sailed his yacht Scorpion to 94 mph in about 30 mph winds on the Black Rock Desert in 1996. Robert Measures sailed Phil Rothrock's yacht Bliss to 99 mph on Alvord Dry Lake in Oregon in 1998 (also in a 30 mph wind). The speed measurements were carefully made but unfortunately they were not done at an official speed trial.

Dan Kampo and a team from the Experimental Aircraft Association built a very large, soft sailed ice/land yacht now called Miss Wisconsin. It has seen a little ice time and has spent several years on the Black Rock Desert in Nevada undergoing trials and modifications while waiting for the right sailing conditions. Definitive data on the yacht's performance have not been available. They have a website describing the yacht, its history and their expectations.

The Ghinn brothers in England have been working on a craft they call WindCat. It is a two hulled affair with a wing on each hull. They have been held back by financial constraints but are hoping to complete the yacht soon. They also have a website.

WindJet is the only yacht that presently appears capable of exceeding 116 mph. They have gone as fast as 113 mph on a runway at the RAF's Waddington Airfield in Lincolnshire UK. The yacht was conceived by Peter Whipp and English composite yacht builder Bill Green in the early 1990's. Whipp commissioned seaplane designer James Labouchere to design the yacht. It is a fully faired, symmetric, 'pilot in front of the wing' configuration. The wing is single element (no flap), cantilevered, and has three sections to put in twist. The overall size is similar to the Iron Duck but its weight is 60% of the Duck and it has 50% more wing area. Bill Green built the yacht out of the usual composite materials for a reputed cost of over $100,000. It is an impressive looking machine and there is no duct tape in evidence in any of the pictures on their extensive website.
Richard Jenkins took over the program in the mid 1990's. The team recently built a new yacht for ice utilizing a similar configuration. At last report (early January) it was being campaigned on a lake west of Calgary Alberta. They have been working through the vagaries of a new yacht and learning about sailing on ice. They had reached 87 mph.

Record seeker, Steve Fossett and his team may tackle this problem after having a go at some of the other records on his list. If they bring the money, intelligence and design skill that they brought to efforts like Play Station or his round the world balloon effort, Spirit of Freedom, they are likely to be successful. They will probably push the technology to levels that will diminish the opportunity for future amateur projects. If anyone wants to make another go at this record on a garage basis, now is the time.

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Websites mentioned in the paper can be found using Google and the following key words: NALSA, FISLY, Miss Wisconsin+ice, Windcat, Windjet, Hoerner+drag, Bob Dill+articles, Pictures of some of the French '7 m^3' yachts can be found in the photo section of the WindCat site or by using www.web.archive.org and the now defunct address: www.oceannet.fr/Associations?vgv/

Photos: Fig 1 and 13: Bob Eustace, Fig 9: Bob Dill

Fig 13: The Iron Duck at speed, March 1999
View Direction: Nearly parallel to the apparent wind