International Hydrofoil Society Correspondence Archives...

Hydrofoil, Rudder, and Strut Design Issues

(See also links to design texts and other technical information sources on the IHS Links Page)

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Correspondence

Where is Foil Design Data?

[11 May 03] Where do I go for specifics about foil design? As in how do I determine the size, aspect ratio, need for winglets, shape, (inverted T vs. inverted Y vs. horizontal V), NASA foil specification . My plan calls for a single foil fully submerged with all control being accomplished with above water airfoils (pitch, roll, direction). Everything above water is conceptually set, but I have limited understanding / knowledge about foils. I understand that there are arrangements combining a lower speed and higher speed foil on the same vertical column, with some type of grooving on the higher speed foil to prevent cavitation at limited angles of attack. With respect to the website http://www.supramar.ch/ there is an article on grooving to avoid cavitation. I anticipate a limited wave surface (off shore wind) so elevation could be limited, and the initial lifting foil would be unlikely to be exposed to resubmersion at speed. Supramar is willing to guide/specify the grooving at no charge, but I need a foil design for their review or at least that seems to be the situation. I have not actually asked for a design proposal. Maybe I should. Actually it is hard to know if my request would even be taken seriously. They did communicate initially but subsequent emails have been unanswered. Any instruction, constructive criticism, or guidance would be appreciated. Of note the current land speed record for a kite/sail powered tricycle vehicle is just a touch over 72 mph in 40-50 mph winds. -- Duncan Coolidge (jcoolidg@tds.net)

Response...

[11 May 03] We frequently get requests like this. The answer is not simple, but there is a lot of help within the organization and on the website. I advise first checking out the site, and at the same time order a copy of the Advanced Marine Vehicle (AMV) CD-ROM #1 announced on the site. This CD has a lot of foil design info. -- John Meyer (jmeyer@erols.com)

What NACA Series is Best?

[15 Mar 02] I am studying in Naval Architecture Department, Ocean Engineering Faculty, Sepuluh Nopember Institut Of Technology, Surabaya Indonesia. Before I complete my studies, I must do experiments as requirement from my college. I want to experiment with about lift and drag for a foil of a Hydrofoil Craft. This experiment is using Computational Fluid Dynamic (CFD) with ANSYS 5.6. But I am confusing about what NACA Foil Series is suitable for Hydrofoil Craft, and what the principal reason for choice this NACA Series. -- Hot Pungka Purba (pungka@yahoo.com)

Response...

[15 Mar 02]You haven't said what the requirements are for your section. Since you mention NACA foils, I assume that you are interested in the subcavitating speed range. You need to have some idea of the range of lift coefficients are required of your foil - this is driven by the load the foil has to carry and the variation in angle of attack the foil will experience as it goes through waves. Something like Cl = 0 to 0.6 with a design Cl = 0.3 would be typical. The intended speed range for the vessel is critical - what are the takeoff, cruise, and dash speeds? And you need to know how the craft will be controlled - will the foils be surface piercing or fully submerged, and will they change incidence or have flaps?

I believe there are four key problems in subcavitating hydrofoil section design. First, you want to avoid separation because this invites ventilation as well as causing drag. Second you want to avoid cavitation. Of course, you also want low drag, and fortunately the things you do to get a high cavitation speed and avoid separation are also good ways to minimize the drag. Finally, the section may be operating close to a free surface, and this modifies the velocity distribution about the foil.

Since cavitation begins when the lowest pressure anywhere on the foil drops below the local vapor pressure of water, you want to minimize the maximum velocity. That means no sharp pressure peaks allowed! At the same time, you want the average velocity over the top surface to be as high as possible so as to produce the most lift. This drives the design to shapes which have long, flat pressure distributions - shaped like building with a flat roof.

The NACA sections which have this type of rooftop velocity distribution are the 6-series laminar flow sections and the earlier 1-series (i.e., 16-012, etc). The 1-series sections have a shallow favorable pressure gradient back to 60% chord, but they have a highly convex pressure recovery that is not necessarily a good characteristic if one wants to avoid separation at the trailing edge. So a comparable 6-series section (say, 66-XXX) would probably be a better bet than the corresponding 16-XXX section.

There are other more modern hydrofoil sections, such as the Eppler designs. Try to get his book, "Airfoil Design and Data". It is out of print, but your engineering library should be able to find it. He talks about the philosophy of hydrofoil design and has several sections specifically designed to be hydrofoils.

You can also design your own hydrofoils using XFOIL, which you can download for free. XFOIL is more modern code than the Eppler code, but you can still design sections like Eppler's using XFOIL. This would be a good start to analyzing with ANSYS because ANSYS doesn't have the inverse design capability of XFOIL but it does have a more powerful analysis capability. So you would be able to compare the experimental results, the inviscid + integral boundary layer results, and the Navier-Stokes CFD results, at least for subcavitating flows.

Simulating the two-phase flow that results from cavitation would be a difficult challenge! But it has been done, and this makes a Navier-Stokes method worthwhile. Unfortunately, much of the research has been done using NACA 4-digit sections (like 0012, 0015), and I suspect this is either out of ignorance as to what makes a good hydrofoil, or perhaps because these are bad hydrofoils and cavitate more easily!

Say you are concerned with a fully submerged hydrofoil with flaps to control the height of the vessel. As the boat flies through waves, the orbital velocity of the waves will change the angle of attack on the foil and thus the lift. The control system will try to compensate for this by moving the flap. If the boat is flying along perfectly level, a good approximation of a perfect control system would be one that maintained a constant lift coefficient on the foil as the angle of attack changed. Thus you need to consider three cases: zero angle of attack with the flap at neutral, positive angle of attack with the flap deflected up, and negative angle of attack with the flap deflected down. The larger the flap deflection, the greater the angle of attack change that can be tolerated while still maintaining the same lift coefficient, and the higher the sea-state in which the ship can operate. For each of these three cases, the peak velocity will occur on a different part of the foil. You would want to design the foil so that the value of the peak velocity is the same in each case. This will give you the highest speed without cavitating. But larger flap deflections and a greater angle of attack range means higher maximum velocities and thus a lower operating speed without cavitating, so there's a tradeoff between the ability to operate in rough seas and the vessel's maximum speed. It's an interesting design problem! But one that comes back to knowing the original requirements in order to design (or select) the appropriate section.

Take a look at ...

- http://cavity.ce.utexas.edu/kinnas/
- http://cavity.ce.utexas.edu/kinnas/cavphotos.html
- http://cav2001.library.caltech.edu/view/subjects/
- Krishnaswamy, P., and P. Andersen Technical University of Denmark S.A. and P. Kinnas, University of Texas at Austin. "Re-Entrant Jet Modelling for Partially Cavitation Two-Dimensional Hydrofoils," presented at CAV2001: Fourth International Symposium on Cavitation, http://cav2001.library.caltech.edu/archive/00000160/00/final.pdf
- http://www.tev.ntnu.no/vk/personer/gbdip.pdf *[this document moved or removed on NTNU site - Editor]*
- http://www.cfd.eng.wayne.edu/research/cavitation.htm
- http://www.sw.nec.co.jp/hpc/sx-e/sx-world/no26/e6.pdf
- AN EXPERIMENTAL INVESTIGATION OF PARTIAL CAVITATION ON A TWO - DIMENSIONAL HYDROFOIL Jean-Baptiste Leroux, J. Andre Astolfi & Jean -Yves Billard Institut de Recherche de l'Ecole Navale, 29240 Brest-Naval, FRANCE, presented at CAV2001: Fourth International Symposium on

Cavitation, http://cav2001.library.caltech.edu/archive/00000070/00/cav2001-B1002.pdf

-- Tom Speer (me@tspeer.com) website: www.tspeer.com

Just after I pushed the "Send" button for the preceding email, I found a good link about using Fluent to calculate cavitating flows, but I didn't save the link. I can probably find it again if anyone is interested. I've also thought some about why the 16-XXX sections are so popular for hydrofoils over the 6-series, and I think it must be because they have a much thicker and stronger trailing edge. So perhaps I was too hasty in recommending the 6-series because they may not be practical for the very high loadings of hydrofoils. Flexing of the trailing edge can lead to singing, too. By the way, there are some interesting papers at U. Mich. on their large-scale hydrofoil (8' chord!) test. -- Tom Speer (me@tspeer.com) website: www.tspeer.com

Foil Design Guidance Needed

[4 Feb 02] I am restoring and optimizing a 1969 Irwin 24. Its keel has an "L" design fin and ballast torpedo. The foil consists of a one inch thick steel plate encased in fiberglass and faired to a section that is similar to NACA 00-series sections through station 6; then tapers to a blunt trailing edge. I have some experience with symmetrical foil optimization; however always with sections in the 8% to 12% thickness range (and no data on less than 6% thickness). I have never implemented a foil less than 7% (even when strength and ballast were not considerations) and I am contemplating taking one of two options:

1. Maintaining the thin section, leaving the foil in tact (excepting minimal fairing) through section 6, tapering the trailing edge to 1/16th inch and squaring off (this may require increasing the span ~3 inches); making the foil a very close approximation of a NACA 00-series section with 4% thickness.
2. Building up the existing foil section to a NACA 0006 or NACA 0008 section (this may require increasing the span ~1 inch and add approximately 100 pounds to the displacement).

Option 1 is far less work, but would change the plan form design slightly. I am not particularly worried about moving the center of lift slightly back because I have removed a 6 inch deep skeg that was a retrofit between the keel and rudder. In any event I am keen on cleaning up the trailing edge. Option 2 would be a good deal of work that would require some benefit to justify undertaking. The plan form data on the keel is as follows: Span = 24 inches, Chord = 45 inches, Max thickness = 2 inches, Sweep Angle = 45 degrees. The torpedo height is 12 inches, the torpedo is V shaped where it meets the foil (120 degrees at the foil interface and the at the bottom) and has a total length of 58 inches. Total displacement is 3000 pounds. Thanks for any guidance you can afford me. -- Tom Graham (TGraham@entergy.com)

Response...

[6 Feb 02] Paul Bogataj had an article in Sailing World a while back concerning keel sections and leading edge shapes. I'd download XFOIL and use it to look at different sections. You can put in your section as it is, NACA sections for comparison, and use it to make modifications to either. -- Tom Speer, F-24 *AMA DEUS* (me@tspeer.com) website: www.tspeer.com

Rudder Cavitation Design

[3 Feb 02] The rudder cavitation article in the Winter 01-02 Newsletter got my interest. The hydrofoil strut has a similar sea state problem. We tailored the strut section pressure distribution along the strut to reduce its cavitation sensitivity. If you are interested I would be glad to talk with you about the work we did. My comment is based on the ongoing research effort we had at Boeing Marine Services (BMS) relating to hydrofoils. The research combined our hydrofoil experience with the aero capability imported from our airplane organization. The work was reported in Boeing documents and IRAD reports-David Taylor was always on the distribution list. We presented a paper at the 19th Tow Tank Conference giving a brief report on the Jetfoil forward foil. -- Bob Dixon (dixon.bob@comcast.net)

Responses...

[3 Feb 02] I'd like to hear more about it. I wonder if many strut "cavitation" problems are really ventilation problems, and if what one would do with the pressure distribution would be somewhat different in the two cases. To prevent cavitation, did you try to cap the peak velocity by using a roof-top pressure distribution, carried as far aft as possible? This would also be consistent with natural laminar flow control. -- Tom Speer (me@tspeer.com)

[3 Feb 02] Thanks for the info. All of the Boeing reports are in the Advanced Ship Data Bank at NSWCCD (David Taylor). Do you have a copy of the paper from the 19th Towing Tank Conference? That may not be in the Data Bank. If you could send it, I would copy it and send it right back. It may be good to include in the next AMV CD we may be putting out at IHS. -- John Meyer (jmeyer@erols.com)

Turning Circle Explanation

[25 Nov 01] I need a brief explanation about measuring the turning cycle of a ship (HSLC). -- Yuksel UNAL (yunal@ssm.gov.tr)

Responses...

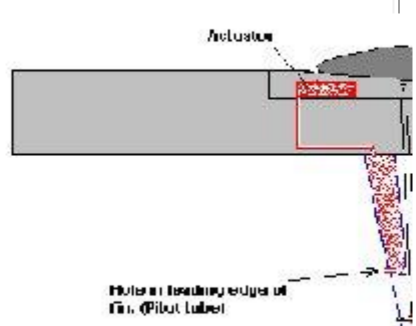
[25 Nov 01] The answer to the question can be found in Vol. III of SNAME's Principles of Naval Architecture, pp.316 and Fig.157. -- Bill Buckley (wbuckley@erols.com)

[25 Nov 01] You have asked about the measurement of the 'turning cycle of a ship' and I presume this is a reference to the Turning Circle performance. A ship's turning performance is defined by parameters such as the advance, transfer, tactical diameter and steady turning diameter and speed. These are defined in naval architecture text books. For any particular ship, they are a function of the initial speed and the angle of the rudders (or waterjet) that is applied. The distances are often defined relative to the length of the ship itself, so for instance a ship may have a tactical diameter of 5 ship lengths after applying full rudder angle while at maximum speed. In the past, such parameters were measured by taking position fixes to nearby stationary objects or by the use of radio ranging equipment. It is more common practice these days to measure such maneuvering parameters on trials by using Differential GPS equipment reconnected to a data logger. More information on the conduct of maneuvering trials is available in such documents as the "Guide for Sea Trials" that can be purchased from the Society of Naval Architects and Marine Engineers (SNAME) who's website is at www.sname.org. Details of that publication extracted from their website are as follows: *Guide for Sea Trials*: Covers sea trials of self-propelled surface ships displacing 300 tons or more, powered by fossil fuel and driven by steam turbine, gas turbine, diesel engine or electric motors. It does not cover dock trials or tests or demonstrations which can be conducted dockside, which are covered in T&R Bulletin 3-39, Guide for Shop and Installation Tests. [3-47] 1989, 95 pp. List Price: $38.00; Member Price: $19.00. Available by photo reproduction only. -- Martin Grimm (seaflite@alphalink.com.au)

[26 Nov 01] Are you talking about "tactical diameter", "advance and transfer" as explained in any seamanship textbook like Crenshaw's? -- CAPT Peter Squicciarini (Dsquicciarini@acu4.spear.navy.mil)

Taig's *ALF*...

[11 Nov 01] Here are pictures of a friend's foil sailboat called *ALF* by Alistair Taig. Mr. Taig has a unique solution to automated attitude control using dynamic pressure rather than a surface skimmer. Click Here to view an article (in Adobe Acrobat format) that he wrote about that. -- Ron Drynan (info@humanpoweredboats.com) website: www.HumanPoweredBoats.com



Response...

[11 Nov 01] I liked his analysis of the steady state gain in his feedback control system. I wish more amateur designers did analyses of this kind. A fully submerged foil that operates at constant lift coefficient is basically one that maintains its angle of attack, much like a fixed foil would if the craft were flying with a constant pitch attitude. However, the effect of his spring would be to modify this relationship. A spring which applied a nose-up moment on the foil would result in a larger lift coefficient at low speed and a lower lift coefficient at high speed, which is in the direction necessary to trim the craft. With the right spring constant it would act like a feedforward term in his control system to trim the foil and reduce the dependence on his pitot tube feedback. This is a spring which acts in the opposite direction that he suggests. Personally, I would be more concerned about sizing the spring for after takeoff and less concerned about speeds below takeoff. The pilot can manually override the system to get low drag hullborne, and then release it for takeoff. I think he's going to be in for an interesting time when he gets it flying! Tuning the lag in the pitot-tube feedback will be tricky - it has to be enough to put the break frequency below the wave frequencies he's trying to reject, but the bandwidth still has to be high enough to stabilize the heave of the boat. And if the lag is too much, the phase lag will destabilize his system. However, the idea that the roll-off in vehicle response will attenuate the wave disturbance is valid. His pitot-tube will act rather like a bang-bang system as it dips in and out of the water, and this may lead to a limit cycle oscillation. However there may be enough dithering from wave action to smooth this out. -- Tom Speer (me@tspeer.com); website: www.tspeer.com; fax: +1 206 878 5269

Yawl Leeboard Foil Design Recommendation Needed

[9 Nov 01] I have a 28 ft Shearwater yawl build by Edey& Duff in 1987. It is designed to have a pair of pivoting leeboards suspended outboard on each side instead of a centerboard or fixed keel. The standard leeboards measure about five ft long and 32 inches across the lower end. they are flat in section with a rounded leading edge and a tapering trailing edge. One of my leeboards fractured rolling in big seas on lake Michigan, and instead of purchasing a replacement from E&D I want to make a new pair exhibiting improved performance. Both the designer and builder favor simple, low-tech, short and flat leeboards for sailboats, claiming that foil sections are not worth the bother. However, another owner of a boat like mine, a friend in Barnegat, NJ, did construct a pair of custom leeboards for his boat and their performance is remarkable. His boat is considerably faster than mine, and makes much less leeway when sailing to windward. Proof enough for me! Of course he is also a very good sailor. Rather than copy his work line for line, I am trying to search out as much about underwater foils as I can, and am finding this a daunting task. I know, for instance that a few of today's high performance scow sailboats and catamarans are using foil bilge boards for lift to windward by virtue of the fact that only the leeward board in in the water while the windward has lifted above the water due to heel. Two specific questions I have are:

First, what NACA foil section would be appropriate?

Secondly, what angle-of-attack would be most effective for that section? The top speed of a Shearwater in a fresh breeze over smooth water is about seven ot eight knots on a reach and five knots to windward, which is slower than high-performance scows and catamarans.

I have found advice recommending the NACA-0012 foil as being very good for symmetrical foils with zero- angle-of-attack. I have also found information indicating that when a foil that thick has its pitch increased, that trailing portion of the windward side might exhibit flow separation. I know that my friend has thinner foils than a NACA-0012, measuring 1 1/2 inches thick with an 18 inch chord and that they are asymmetric, with a chord ratio of 60%/40%. I do not know what positive angle-of-attack he has used (only the leeward board is used on these boats, while the windward one is drawn up out of the water), only that there is a small amount of "toe-in". I would very much appreciate any guidance you might provide. -- Nichilas "Moby Nick" Scheuer; Rockford, IL; (mobynick@juno.com)

Response...

[4 Dec 02] I am currently building a Bolger/Storey Chebacco 25 origionally designed with a centreboard , however "fools rush in ... etc. " and I've gone with a change to leeboards. How is your project going? and would you have any info that I might find useful ? Your response anticipated and appreciated. -- Simon Jones (sjones@sa.Apana.org.au)

Hull Drag Characteristics at Take-Off

[22 Oct 01] I am presently dealing with the design of a hydrofoil boat with fully submerged hydrofoils. The foil section design as well as the strut design are already well established but the hull design is still under development. Since the craft will be powered by a water jet system very similar to the Jetfoil propulsion system, the hull resistance near take-off speed seems to be critical for the overall power requirements according to my calculations (hump speed power). I have not found any reliable literature information regarding the hull resistance characteristics from standing to take-off speed. Of special interest is the hull resistance decrease when lifting the hull off the water near take-off speed. An article from Charles G. Pieroth/Grumman Aerospace Corporation dealing with 'hydrofoil hullform selection' published in *Hovering Craft & Hydrofoil* in 1977 does just give general recommendations. Also on the IHS-homepage I could not find further useful information. Can anyone provide me with more detailed information? -- Sebastian Muschelknautz (Sebastian.Muschelknautz@Linde-VA.de)

Responses...

[22 Oct 01] I don't know if the following will be of assistance, but you may like to look at these papers:

Sakic, Prof Dr Vinko (Maritime Institute, Split); 'Approximate determination of the propulsive power of small hydrofoil craft', High-Speed Surface Craft, March 1982. (This discusses resistance in hullborne mode and transfer into foilborne mode but only over about two pages).

Latorre, Dr Robert; 'Hydrofoil Craft Performance Calculation', Naval Engineers Journal, March 1990. (again, this addresses performance on take off).

Finally, the Maritime Research Institute Netherlands (MARIN) once offered for sale a program for the hydrodynamic design and analysis of hydrofoil craft in calm water called 'HYDRES'. This included "the calculation of the resistance for hullborne, take-off and foilborne speeds". It was apparently based on the use of Series 65 hard chine planing hullforms. Further details may be available via the MARIN website but I have not checked that. -- Martin Grimm (seaflite@alphalink.com.au)

Source of Foil Profiles

[3 May 01] Je fais partie d'un groupe d'élèves ingénieurs qui étudie l'hydroptère. Je recherche des données sur le profil EPPLER817 que nous avons utilisé pour réaliser le foil de notre maquette. Je ne parviens notamment pas à trouver les courbes de Cz et Cx en fonction de l'incidence pour ce fameux profil. Je vous serais donc très reconnaissant si vous pouviez m'aider dans ce domaine. (I am part of a group of students engineers that studies l'hydroptère. I look for the view of the profile EPPLER817 that we used to realize the foil of our maquette. In particular, I do not find the curves Cz and Cx incident to this fine profile. I am therefore very appreciative if you could help me in this area) -- Elie Daguet (Elie.Daguet@etu.enseeiht.fr)

Response...

[3 May 01] The data may be found at www.nasg.com/afdb/index-e.phtml. There you'll find data for the following hydrofoil sections:

- Eppler E817(E817)
- Eppler E818(E818)
- Eppler E836(E836)
- Eppler E837(E837)
- Eppler E838(E838)
- Eppler E874(E874)
- Eppler E904(E904)
- Eppler E908(E908)

- Speer H105(H105)

The most complete database of section coordinates is at the UIUC Airfoil Data Site. With the coordinates from there and XFOIL (http://raphael.mit.edu/xfoil/), one can generate the data for precisely the conditions desired. -- Tom Speer (me@tspeer.com); website: www.tspeer.com; fax: +1 206 878 5269

Paravane Questions

[3 Sep 01] I read Phil Morris' comments about a paravane. I have had the same idea myself, as mentioned at Jon Howe's forum at the speedsailing pages. It appears his foil is a supercavitating one. Also an interesting (and pretty) approach is the "jellyfish foiler", although what will happen when the luff-ward foil slips? I suspect the pivot point will now be the lee-ward foil, and the whole craft may bury or make a judo. I would like to know from Phil Morris if he has had any progress in his research on making a "water-hook". Also I have read somewhere that it has been tried (as I understood it) in combination with a wakeboard and a kitesurfing kite (by whom, I don't know, I think it was one of the foil-chair or -ski manufacturers), but they couldn't control it in high speeds. No details on the setup were given. -- Sigurd Grung (mermade@frisurf.no)

"Glide Ratios"

[3 Apr 01] I'm assessing high-speed sailboat designs, using the expression for maximum wind-factor asymptote, 1/((1/Ga) + (1/Gh)). This requires reasonable values for aerodynamic and hydrodynamic glide ratios, Ga & Gh. I have no trouble finding glide ratios for airfoils, subcavitating foils, and planing steps, but where do I find data relating aspect ratio and angle of attack to glide ratio for supercavitating foils? I need reasonable, but not exact values, within 20% or so. Some suggest using one-third the glide ratio of a subcavitating foil, but... is the planing step glide ratio a better approximation? -- Phil Morris (phil.morris@alum.mit.edu)

Responses...

[4 Apr 01] The reference to 'glide ratio' is unusual but it actually corresponds to the overall lift-to-drag ratio of the airfoil / hydrofoil (or aircraft / boat) in question. For instance, a high performance glider has a glide ratio of 1:40, i.e. in still air, it will drop 1 metre in altitude for every 40 metres in horizontal travel. To achieve such a good glide ratio, the drag of the whole glider has to be no greater than 1/40 of its lift (which is equal to its weight). A lot of work was done on supercavitating hydrofoil sections for US Navy hydrofoil projects in the 60s and 70s timeframe. You would find some of it published in the Society of Naval Architects and Marine Engineers (SNAME) journals such as Journal of Ship Research. One main researcher in the field was Marshall P. Tulin. You are right that the glide ratio (lift to drag ratio) of supercavitating foils is not generally as good as fully wetted foils so your use of 1/3 of the glide ratio is at least tending in the right direction. The glide ratio will vary considerably as a function of the angle of attack of the foil. The greatest glide ratio is achieved for relatively small angles of attack on typical airfoils such as on gliders. -- Martin Grimm (seaflite@alphalink.com.au)

[3 Apr 01] I believe by glide ratio you means the lift/drag ratio. A sailplane's glide ratio is the same as its L/D. The equation you listed is the correct performance relationship for a sailing vehicle, but you have to ensure that the lift and drag you plug in is the lift to the side (in the horizontal plane and perpendicular to the oncoming flow direction) and the total drag. The vertical L/D is irrelevant except that it dictates the drag that will be added into the total. With hydrofoils it's easy to get confused, because the L/D one has to use in the performance equation is really the lift of the strut divided by the total drag. Since you didn't ask about the strut, I will not get into a long discussion on the topic. I also don't have the parametric design information for which you're asking! Here's what I have been able to put together on the feasibility of high speed supercavitating sailing hydrofoils.

- The best supercavitating foil performance I've found (and admittedly I don't have much to draw from) was a T-foil and strut designed for operation at 60 kt and tank tested at the Lockheed Underwater Missile Facility. Aspect ratio was 5, taper ratio was 0.5, and the foil was swept back so that the trailing edge was straight. The section was 7% - 7.5% thick. That foil's design takeoff speed was 35 kt, where it had an L/D of 13 at a lift coefficient of 0.5 based on the wetted section. At high speed, the chord was effectively less due to the aft 20% or so on the lower surface not being wetted (the structural annex portion). It required a lift coefficient of at least 0.2 to avoid wetting of the upper surface at high speed. It achieved an L/D of 9 at a speed of 65 kt and a depth of one chord. An 18% thick parabolic strut tested for side force at 70 kt had a maximum side force coefficient of 0.1 at one chord depth and a leeway angle of 4 degrees. Strut chord is typically 50% bigger than lifting foil chord due to the taper in the latter. So adopting this same design to support a sailing hydrofoil, at high speed, the maximum sideforce is 15% of the lift. L/D for sideforce is probably around 5 at best. The total drag divided by the sideforce gives a ratio of 1.06, for a "drag angle" [arctan(D/L)] of 46 degrees. Even if the aerodynamic L/D were 10 (which is probably twice current practice), this results in an apparent wind angle of 52 degrees and a top boatspeed/windspeed ratio of 1.3, so the required wind speed would be 46 kt to achieve the 60 kt the design speed of the foils. At a depth of 3 chords and assuming the lateral L/D also went up to 9, the achievable sideforce is 90% of the weight, the transverse drag angle of the foils is 13 degrees and the apparent wind angle is 19 degrees, for a boatspeed/windspeed ratio of 3 and a true wind speed of 23 kt. This is about the same performance as a competitive land yacht in these winds, operating on a smooth flat surface. So these numbers have to be considered as highly optimistic at best and the feasibility of the supercavitating hydrofoil is a long shot.
- Here's another example of supercavitating hydrofoil design that shows how sophisticated one's design capabilities have to be. One can make a guess at possible performance, as I've done above, but to actually achieve those numbers requires the ability to accurately compute the details of the drag components. Hydronautics designed a helicopter-towed minesweeping sled that had 4 ladder foils at the corners. Each ladder had three foils - one subcavitating, one base-ventilated, and one supercavitating. The central strut was a modified parabola (parallel surfaces at the trailing edge) canted 25 deg from the vertical. The top

rung and a diagonal strut were a 16(35)04 section (4% thick subcavitating NACA design), the base ventilated rung looked to be a cambered parabola with nearly a delta planform, and the bottom rung was a tapered, swept-back planform with a sizeable annex (rectangular structural addition) behind the wetted supercavitating portion. At light weight (27,000 lb), takeoff was around 22 kt and the drag was nearly constant out to 80 kt with a bit of a rise from there to 100 kt. At heavy weight (40,000 lb), takeoff was around 25 kt and the helicopter had enough thrust to pull it to 70 kt. L/D was 7.5. "The most significant problems which had to be overcome related to achievement of full ventilation of the strut, base ventilated, and supercavitating foil. Positive air channels were finally provided at the strut base in the vicinity of the upper and and middle foil-strut intersections. These changes which were necessary to insure the ventilation assumed in the basic design, improved the lift-drag ratio achieved by incomplete ventilation (for full submergence) by approximately 30 percent. The highly swept supercavitating wing was originally designed without twisting the wing to account for the induced effects of sweep. When the wing was twisted to account for sweep-induced effects, the optimum lift-drag ratio was increased by approximately 40 percent!" *[quoted from: Johnson, Virgil E., and Scherer, J. Otto, "Some New Results of Research on High Speed Hydrofoils," Hydrofoil Symposium Held at the 1965 SNAME Spring Meeting, Seattle Washington.]*

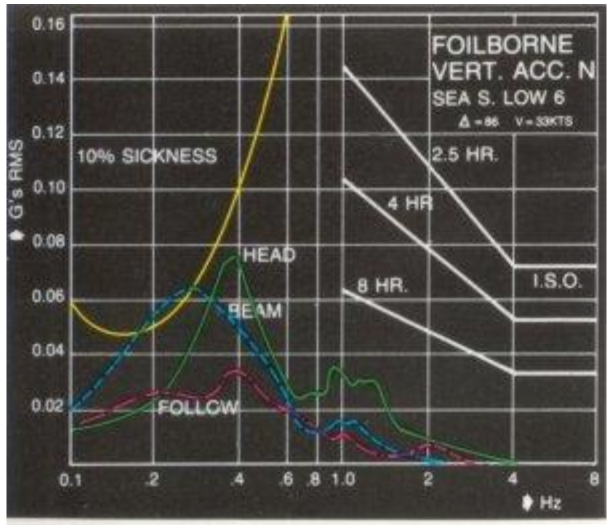
The same paper has a chart showing a supercavitating foil stalling at 80% of cruise speed when maintaining lift through incidence control, flying down to 57% of cruise speed when fixed but extended with a 60% chord trailing edge flap, and operating down to 50% of cruise speed with both the flap and incidence control. Drag at that condition was about 5X that at cruise. This might give some guidance as to what's reasonable in the way of takeoff speed with supercavitating foils and variable geometry. -- Tom Speer (tspeer@tspeer.com) website: www.tspeer.com fax: +1 206 878 5269

Follow Up...

[21 Apr 01] My specific interest is not so much for vehicle support, but wind propulsion. So, the foils are indeed turned up spanwise vertical to generate principally lateral lift (like sails and centerboards). One of the proposals I'm trying to assess is a supercavitating paravane. It's basically a centerboard detached from the boat, and flown like a kite underwater (but sideways, like a skier outside the wake). In the abstract, it has some striking similarities to Tom's minesweeping sled. So, the datums he provides for supercavitating L/D between 5 and 9 are quite helpful. Moreover, those insights let me know that yes, it is *theoretically* possible for high-speed sailcraft to attain both high speed and high wind factor (4 to 8) with supercavitating centerboards. The lateral lift application doesn't have an actual take-off problem to deal with. But, my engineering skepticism still remains, centered around cavitation transition and ventilation issues. While I slowly admit that some of these high-speed sailing schemes are possible, their success seems to require some pretty spectacular engineering. -- Phil Morris (phil.morris@alum.mit.edu)

Seakeeping / Motion Sickness Graphs

[30 Mar 01] The seakeeping performance of fast ferries is often illustrated by way of graphs of RMS vertical acceleration levels (typically expressed in g's) versus motion frequency for particular sea conditions. To illustrate this I am including such a plot as obtained from a Rodriquez brochure for the RHS 160F series of surface piercing hydrofoils. As can be seen from the graph, the acceleration levels of the hydrofoil (presumably at its CG location) are indicated for a range of relative headings to the waves for a frequency range from 0.1 Hz to 8 Hz. On top of this are indicated the limits for 10% motion sickness (ie the MSI level, although exposure period is not indicated on the graph) and also ISO limits for human exposure to vibration at higher frequencies. I would like to ask how these graphs are generated as it is not clear to me exactly what they are illustrating.



RHS 160F rough sea behaviour

Real ships operate in irregular waves where there is not a constant encounter frequency or wave height with every successive wave which is encountered by the ship. Only in model tests can regular waves with a single height and period be generated to establish the performance of model boats or ships in under idealized regular conditions. The Rodriquez graph suggests the data is for Low Sea State 6 seas (Significant Wave Height of 4m or more but well less than 6m). As this is an irregular seaway, I am not clear of the meaning of the unbroken plots of RMS vertical acceleration over the large range of frequencies from 0.1 Hz to 4 Hz (corresponding to encounter periods from 10 seconds down to 0.25 seconds) that are given for the craft at various different relative headings to the wave direction. It seems to me that it may be some sort of de-composition of the irregular motion data from sea trials back into a response for a series of theoretical regular wave conditions? If that is the case, then what is the meaning of comparing these ship response curves with the various Motion Sickness Index (MSI) or ISO vibration limits?

What I would have expected is that each run from sea trials in a particular seaway would generate a single data point only on the graph of RMS acceleration versus modal encounter frequency. Runs into head seas in a given seaway would have a higher modal encounter frequency than beam seas which in turn would be higher than the encounter frequency for runs in following seas where the ship and waves are traveling in the same direction.

I have only used the Rodriquez graph as an example to illustrate my uncertainty. Various designers and builders of fast catamaran and monohull ferries have used a plot format almost identical to that of Rodriquez for their hydrofoils, hence there must be a logical explanation of the interpretation of such graphs. I would welcome a reply which helps to explain it. My understanding is that the original tests on volunteers in a test rig to establish trends in the occurrence of motion sickness were performed at various regular frequencies of vertical motions. I have never properly understood how the jump has been made from this data to the case of irregular vertical motion exposure although I am familiar with the formula that should be used to calculate MSI levels for irregular vertical motions such as in a real seaway. Can anyone give suggested references which will also help to clarify this for me? -- Martin Grimm (seaflite@alphalink.com.au)

Responses...

[1 Apr 01]Here's my take, based on reading Vol. III of "Principles of Naval Architecture" - maybe some of the NAs out there can fill in or correct this:

- The graphs you're looking at are wave response spectra, not the response to the boat to a particular set of waves. These are really averages over all random seas. Note that the units are RMS g's - the average of the acceleration squared - which is much like a standard deviation.
- There are idealized wave height spectra which are based on oceanographic research. Typically these show the wave height-squared vs. frequency for different sea states or wind conditions (assuming the wind has been blowing for a long time over a wide area). There are even specialized wave height spectra for different parts of the world, such as the North Sea. These spectra are for regular waves, in which all the waves are marching in the same direction.
- In addition to the wave height spectra, there are also wave direction spectra which account for the fact that the waves in a random seaway can be coming from a variety of directions, but there will still be a direction from which most of the waves are coming. So when you multiply the wave height spectrum by the wave

direction spectrum, you end up with a composite spectrum for a random seaway as a function of both wave length (or frequency) and direction.

- I would guess the plot you've shown is probably based on a wave height spectrum for an open ocean seaway with a significant wave height of 4 m (the average of the highest 1/3 of the waves) - the plot is labeled "Sea S. Low 6", and a sea state 6 would have a range of 4 - 6 m with an average of 5 m. It could also be from a random seaway with the wave directions distributed in, say, a cosine-squared fashion about the dominant direction. This defines the operating environment.
- For a given boat, one can calculate the dynamic response to a given wave of a given size from a given direction. If the boat is subjected to the same wave for a long time, the boat response will settle down to being a sine wave of the same frequency but possibly a different amplitude and shifted in phase (the peaks of the boat response won't occur at the same time as the peaks in the wave). Above a certain frequency, the boat will be increasingly unresponsive to the wave because it is too massive to follow it. At very low frequencies, the boat will follow the wave almost perfectly and the boat response will be the same as the wave. In between, there may be a resonant frequency at which the boat's response will actually amplify the wave. This response of the boat to waves of a given frequency is given in terms of response amplitude operators, or RAO's, which are the ratio of the size of vertical response of the boat to the size of the wave. There's a different RAO for every point on the boat - for example, the bow RAO is greater than the one at the center of gravity because the bow moves up and down as the boat pitches. The total response of the boat comes from summing the individual responses of the boat to the individual waves.
- So when you multiply the wave spectrum times the RAO as a function of frequency, what you get is another spectrum which represents the statistics of the boat's motion to a random seaway. This is what you're looking at in the plot. One could also generate the same results by running a simulation of the boat in a seaway and repeating the simulation many times (hundreds or thousands) with random variations in the sea and averaging the results (a Monte Carlo analysis).

I have a question of my own regarding the graph: I have seen the same boundaries for acceleration used in other reports, and I believe they are described in an ISO standard. However I've not been able to find it. Can anyone provide me with the standard? -- Tom Speer (tspeer@tspeer.com) website: www.tspeer.com fax: +1 206 878 5269

[3 Apr 01] I was able to put my hands on relevant documents fairly quickly. In the Rodriquez graph, the motion sickness limit curve on the left and vibration limit curves on the right come from ISO 2631-1978 (E) "Guide for the evaluation of human exposure to whole-body vibration," Second edition 1978-01-15, and a later amendment and a later addendum. As close as I can determine quickly, the motion sickness curve is for 10% of the crew sick in a 4-Hour exposure. The curves were derived from human performance experiments in ship motion simulators to be compared with a 1/3-octave analysis of ship motion spectra - in this case, the vertical acceleration at some specified location on the ship. In the case of fast ferries, ride comfort is a primary concern. And this type of a plot shows the frequencies at which the human body is most susceptible to motion sickness and most sensitive to structure-borne vibration (from machinery and hull pounding in heavy seas, for instance). To derive a single-value criterion for design studies, we analyzed the ship motion spectra of frigates and destroyers in heavy seas. In cases where the peak in the motion spectra reached the sickness limit curve, we integrated the motion spectra and found limit values clustered around a root-mean square (RMS) average of 0.2 G vertical acceleration. The analysis of high-speed craft would likely yield a different single value. Now to the documents, the base ISO 2631-1978 (E) and Amendment 1 of 1982-04-01explain the "Fatigue decreased proficiency" end of the spectrum - 1.0 Hz and above. Addendum 2 "Evaluation of exposure to whole-body z-axis vertical vibration in the frequency range 0.1 to 0.63 Hz," of 1982-05-01, explains the motion sickness range - though the limit curves are shown as linear "buckets." The smooth curves, from which Rodriquez picked one, were shown in the human performance analysis reported by O'Hanlon, J.F. and McCauley, M.E., "Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion," Aerospace Medicine, April 1974. -- John H. Pattison

Follow up...

[3 Apr 01] To Tom Speer: I believe I have a copy of the standard you are seeking details for, but can't trace it at the moment. Here are a pair of references to that standard from another document I have. I don't know if it has been updated since:

ISO 2631/1-1985(E), "Evaluation of Human Exposure to Whole-Body Vibration - Part 1: General Requirements", 1985, International Organization for Standardisation.

ISO 2631/3-1985(E), "Evaluation of Human Exposure to Whole-Body Vibration - Part 3: Evaluation of Human Exposure to Whole-Body Z-Axis Vertical Vibration in the Frequency range 0.1 to 0.63 Hz", 1985, International Organization for Standardisation.

It seems part 1 deals in part with the range of frequencies above 0.63 Hz but I can't be sure. My feeling is that this is more associated with vibration due to propulsion machinery on larger merchant ships than with wave induced whole ship motions. The standard was drafted in around 1972 and first released, already as ISO 2631, in 1974 with the title "Guide for the Evaluation of Human Exposure to Whole-Body Vibration". Although I have never come to terms with the various models of the effect of ship motions on humans, I found that the approach proposed by the late Peter R. Payne seemed to have an elegant unified approach across the whole frequency range. He also came from a background of planing craft and hydrofoil design so would have had high speed craft motions in mind. For details, see:

Payne, Peter R., *On Quantizing Ride Comfort and Allowable Accelerations*, paper 76-873, AIAA / SNAME Advanced Marine Vehicles Conference, Arlington, Virginia, 20-22 September 1976.

Back to my seakeeping / motion sickness question: If you indeed believe the Rodriquez data I used as an example is a motion response spectrum where the actual measured irregular time trace of acceleration has been de-composed into its frequency components, then that is also the way I viewed it except that I didn't say so as clearly in my original question. Going on from this common interpretation we have made, I feel that doing this spreads the total 'energy' associated with the acceleration time trace across a large frequency range and thus makes the resulting plot appear as having a far lower magnitude of acceleration than if a single equivalent RMS acceleration based on the complete irregular acceleration time series had been plotted at a single frequency corresponding to, say, the average frequency of the acceleration peaks in that irregular signal. The current approach for assessing Motion Sickness Index for an irregular vertical motion on a ship is to treat the irregular oscillation as if it was the same as a sinusoidal motion having the same RMS acceleration and a frequency corresponding to the average period of the acceleration peaks of the irregular motion, or more commonly the average period of the displacement peaks is used. This is fairly well described in the following text book:

- Lloyd, A.R.J.M., "Seakeeping - Ship Behaviour in Rough Weather", Ellis Horwood Series in Marine Technology, Ellis Horwood Ltd, 1989.

That book appears to have an error in the equation for calculating MSI but that may have been corrected in the more recent and revised issue of this excellent reference book on the subject. -- Martin Grimm (seaflite@alphalink.com.au)

Drag Reduction via Magnetic Fields?

[16 Mar 01] Concerning the practical application of using elecro-magnetics in drag reduction... How can I try this out on a home built catamaran? It seems to me that the amount of drag reduction could be extreme, and the speed increase would also be equally radical. I am in the most early stages of planning to build a multi-hull yacht and I want extreme speed with extreme luxury (don't we all?). Electromagnetic hull drag reduction might allow enough of an increase in speed to make hydrofoils a real world option. In this case I see it as transitional. A help to obtain the required speed for a cruising cat to get to hydrofoil speeds. Even if 100% lift is not induced, increased lift is a form of anti-gravity and reduced wetted area, so speed is increased. Certainly, however if this will work with only permanent magnets to some degree then so much the better. I also have other drag reducing ideas for the hull as well but obviously electromagnetics should work with any shape. So how can I practically do this? Implant wires, magnets and whatnots into the gel coat? I'd really like to know. If you have anything for me I would appreciate it and who knows maybe I will be able to make use of it. -- Steve Van Brown (lordvalraven@hotmail.com)

Responses...

[23 Mar 01] What can you have read to lead you to think you could do this?! The concepts for electromagnetic turbulence control for drag reduction remain quite immature and still lacking any definitive demonstrations of success at meaningful Reynolds numbers. I wouldn't encourage you to continue his thinking in this direction. Let me know if you have any questions about where things stand. -- Stan Siegel (Stansiegel@aol.com)

[23 Mar 01] Electromagnetics for drag reduction falls into the same category as magneto-hydrodynamic propulsion; that is, fun but no payoff. A Japanese gambling magnate spent about $20M to produce a great looking ship that went---you ready?---5 knots. The U.S. Navy topped this by giving Textron $25M to reduce drag and make a propulsor for subs. Result: 00000000. If you want to reduce drag for about 100x the potential payoff, put the power into a two-phase (non-Newtonian) flow system like Prairie Masker. That system introduced air bubbles at the bow to ventilate the surface. It may not work well with hydrofoils but it would make an interesting experiment and a real contribution if you could pull it off. -- Nat Kobitz (KobitzN@ctc.com)

[23 Mar 01] I am very much interested in this subject also. If you haven't logged onto the German website (http://www.fz-rossendorf.de/FWS/FWSH/EBLC/separation-control/), you should because it has some interesting info. -- John Meyer (jmeyer@erols.com)

Side Force Over-Predicted Due to Ventilation...

[2 Mar 01] Surface piercing struts at a slight angle to the flow (e.g. in a steady turn) experience a side force that is over-predicted by normal hydrofoil theory. This is due to the suction side being ventilated to atmospheric pressure. Ventilation could extend all the way to the foil. Do you know of any literature concerning this subject, and how one predicts the side forces accurately? -- Günther Migeotte (gunther@cae.co.za)

Responses...

[5 Mar 01]The Hydronautics handbook that I sent you has a chapter on ventilation. The gist of the chapter is that there are 4 necessary conditions for ventilation to occur: 1) the local pressure must be less than atmospheric, 2) there must be a path for air to be conducted to the low pressure area, 3) there must be separated flow, and 4) the cavity formed must be stable. The key condition is #3, separation. If you have fully attached flow, any air introduced will simply stream off in a row of bubbles and not ventilate the flow. So the key would seem to be to design so as to maintain a margin against separation, either due to boundary layer separation or cavitation, and then analyze the strut in the conventional way. This being the case, one would be advised to avoid sharp-edged sections that will promote leading edge separation bubbles. It's interesting to note that successful hydrofoil sailboats, such as the *RAVE*, have struts that are constantly loaded sideways and use conventional section shapes. -- Tom Speer (tspeer@tspeer.com); website: www.tspeer.com; fax: +1 206 878 5269

[5 Mar 01] If a hydrofoil does not have any wings that pierce the surface, only struts, it will be unstable in roll so it will usually be banked into any turn, so there will be no steady side forces on a strut. However the side forces depend on the control philosophy of the roll control system. It is possible to corner a hydrofoil unbanked, but the cornering will be limited by the roll control flap limit. Also the angle the boat takes up when it is loaded off-centre depends on the control system. The obvious philosophies are to keep the boat flat or to centralise the average flap position. If the boat is kept level, there will be no side force on the struts, but if the flap position is centralised the boat will lean to keep the center of gravity above the center of the wing. If the main foil is tilted, the lift it produces is not vertical, so the sideways force is: w * tan(theta), where w is the boat weight and theta is the angle of tilt. Side wind forces have to be taken on the strut. I haven't got a clue how to calculate it. When the flow over the strut is calculated, the angle of attack will have to be adjusted until the lift (sideways) equals the sideways forces. The flow over a strut causes areas of increase and reduced pressure. I haven't done the calculations, but I think that the angles of attack will be so small, less than 2°, that the changes in pressure increase or decrease will be minimal. It is the pressure decreases that encourage ventilation, and if it is a problem, the struts thickness will have to be reduced. In which case, the strut will have to be longer in chord to be strong enough, so the angle of attack will be smaller, also reducing the ventilation problems caused by turning. From my experience on a Trampofoil, the main wing would ventilate quite badly if it hit the surface. I even videoed this happening from underwater in a swimming pool. However, the struts would not ventilate under any conditions. This included when the Trampofoil was ridden with the main wing at about 10° to the horizontal, and when it was steered violently, there was no problem with the front strut (which was the rudder) ventilating. I don't think that you need to worry about ventilation caused by side forces. Ventilation may be a problem, but side forces will not add to it significantly. The structural effects of side forces need to be considered. -- Malin Dixon (gallery@foils.org) Holly Cottage, 9 Barton Road; Carlton, Nuneaton CV13 0DB England; phone: +44 1455 292763; Mobile +44 7798 645574; Work +44 24 7664 2024; Fax +44 24 7664 2073

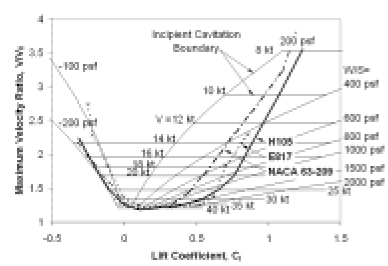
[6 Mar 01] Put a fence around the strut about 1 foot below the flight waterline, and another about a foot below that. The first one should be about 6 inches high, the second about 4. This should handle the problem of increased side force due to ventilation. Incidentally, it also works for struts for fully submerged foils. -- Nat Kobitz (KobitzN@ctc.com)

Cavitation Bucket Diagrams

[2 Mar 01] We are French students working on foils and the problem of cavitation. In the FAQ of your web site, we have read a message of Mr Martin Grimm who speaks about cavitation bucket diagrams. We would like to find an example of these diagrams to illustrate a tutorial project. Could you help us by sending us a diagram or any valuable information? -- Mathilde Pascal (Mathilde.Pascal@etu.enseeiht.fr) and Ludovic Léglise (hya54@etu.enseeiht.fr)

Responses...

[2 Mar 01] I've attached an excerpt from the paper I just gave to the Chesapeake Sailing Yacht Symposium. It shows such a diagram and discusses its relevance to the hydrofoil design. I've also included an enlarged version of the diagram. I've chosen a somewhat idiosyncratic way of plotting this diagram. The X axis is often angle of attack, but I've chosen to use lift coefficient because different sections have different zero-lift angles of attack and lift coefficient is what really counts to the designer. But the biggest difference is that I have plotted velocity ratio on the Y axis instead of pressure coefficient or cavitation number. I did this because pressure coefficient is proportional to velocity squared, so it emphasizes areas of high velocity which are not of real interest. By plotting vs. velocity ratio I have expanded the bottom of the chart which is where the section will be operating when cavitation is a concern. The other thing you will find on this chart that I've never seen on any other diagram is an overlay of freestream velocities and foil loading corresponding to incipient cavitation. I found this

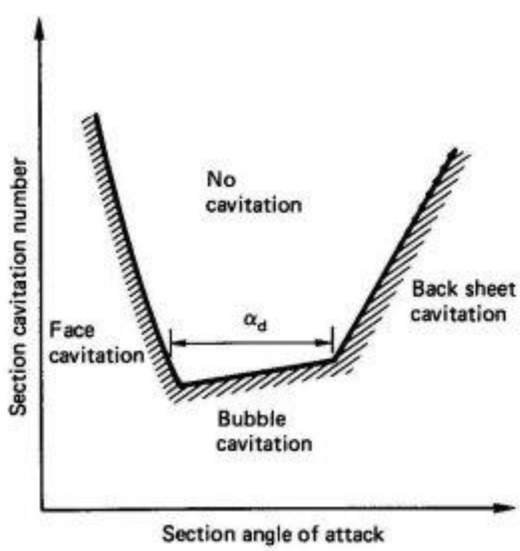


Click on Image For Larger Version

really helped me to understand the section curves in the context of the boat's design. I haven't actually plotted it out yet, but I suspect that had I used pressure coefficient for the Y axis, the lines of constant foil loading would have been straight lines. Finally, my apologies for using English units. I'll leave conversion to metric as an exercise for you students!
-- Tom Speer (tspeer@tspeer.com) website: www.tspeer.com; fax: +1 206 878 5269

[6 Mar 01] Tom Speer has already given you a good reply following your request for examples of 'cavitation bucket diagrams'. I will however provide you one more example which is presented in the more usual manner with section cavitation number on one axis and foil angle of attack on the other. The attached diagram has been adapted from one of the figures in a very well presented and comprehensive book on the subject of marine propellers, namely: *Marine Propellers and Propulsion*, by J.S. Carlton (Senior Principal Surveyor, Technical Investigation, Propulsion and Environmental Engineering Department, Lloyd's Register) Butterworth-Heinemann Ltd, Linacre House, Jordan Hill, Oxford OX2 8DP First published 1994. ISBN 0 7506 1143 X.

There are no scales on the axes of the diagram as it is illustrative only. You can see from the shape of the curve where the 'cavitation bucket' term came from. Even though you may already be familiar with the terminology on the diagram, I will run though it for completeness:



The section cavitation number is defined as:

Sigma o = (po - pv)/(0.5 rho V^2)

where:

po = Free stream pressure in absolute terms, i.e. not relative to atmospheric pressure (SI units would be Pa).

pv = Vapour pressure of the water in absolute terms (SI units of Pa).

rho = Water density (SI units would be kg/m^3)

V = Free stream velocity, i.e. well upstream of the foil (SI units would be m/s)

(I have avoided using subscripts or the usual Greek symbols so that I can send you this message in plain text)

For a foil traveling say 1 metre below the water surface in salt water, po can be calculated as:

po = patm + rho.g.h

where:

patm = Atmospheric pressure, say 101300 Pa

g = Acceleration due to gravity, say 9.81 m/s^2

h = submergence of the foil (in metres if using SI units consistently)

hence:

po = 101300 + (1025 x 9.81 x 1.00) = 111355 Pa

In salt water you can take the vapour pressure to be say: pv = 17000 Pa to be on the conservative side. The vapour pressure of distilled fresh water can be as low as 1700 Pa.

You can see from the diagram that at high angles of attack, cavitation will occur on the top side of the hydrofoil (called the 'back' in propeller terminology). At low or negative angles of attack, the low pressure moves to the bottom of the hydrofoil (this being called the 'face' on propellers). If the water flow past the foil is fast enough and the foil is not deeply submerged, then cavitation can even occur when the foil is at the zero lift angle of attack. This form of cavitation is referred to as bubble cavitation because of its appearance. This cavitation occurs simply a result of the thickness of the foil which causes the water velocity to increase slightly as it passes the sides of the foil and in turn the local pressure of the water drops below the vapour pressure.

These days, there are techniques available to design foils which are fairly tolerant of variations in their angle of attack and so can avoid the onset of cavitation. Such foil sections have a fairly wide cavitation bucket (defined by the parameter "alpha d" on the figure), though the limit at which bubble cavitation occurs may then shift to higher cavitation numbers so the bucket is no longer as deep. -- Martin Grimm (seaflite@alphalink.com.au)

Follow Up...

[10 Mar 01]We have built a model of a foil with a NACA 0015 profile. Where could we find the cavitation bucket diagram corresponding to this kind of foil? Mathilde Pascal (Mathilde.Pascal@etu.enseeiht.fr) and Ludovic Léglise (hya54@etu.enseeiht.fr)

Follow Up Response...

[11 Mar 01] Here is how you build a cavitation diagram:

Go to http://raphael.mit.edu/xfoil/ and download XFOIL. This is the most powerful airfoil section design tool available. Do not think of using anything else you can download from the Web -they are all inferior to this program.

Put in the coordinates for your foil.

Analyze the section for a number of angles of attack, covering the intended range of operation. Examine the pressure distributions for each angle of attack.

For each angle of attack, record the minimum pressure coefficient that occurs anywhere on the section. The cavitation number, sigma, is simply the negative of the minimum pressure coefficient, Cp. (sigmai = -Cpmin where sigmai is the cavitation number for incipient cavitation and Cpmin is the minimum pressure coefficient)

Plot the minimum pressure coefficient vs angle of attack or lift coefficient, according to which you prefer.

Repeat steps 2 through 5 for each section you wish to consider.

I recommend you plot sigmai vs CL for the following reasons. If you disregard the vapor pressure of water, which is small, the critical speed for incipient cavitation at the surface is approximately

Vcrit = 14/sqrt(sigmai) m/sec

sigmai = $(14/\text{Vcrit})^2$

Vcrit is the freestream velocity above which cavitation may occur. Note that this is a horizontal line when superimposed on a cavitation diagram. If you know the freestream velocity (boat speed) and you know the lift coefficient, then you know how much load each square meter of the foil is carrying:

L = CL * 1/2 * rho * V^2 * S

[L/S]crit = CL * 1/2 * rho * $(\text{Vcrit})^2$

[L/S]crit = CL * 1/2 * rho * 14^2/sigmai

sigmai = {1/2 * rho * 14^2 / [L/S]crit} * CL

Note that for any given foil loading (L/S), the quantity inside the braces {} is a constant so this is a diagonal line extending from the origin of a sigmai vs CL plot.

Finally, to put together the whole cavitation picture, do the following:

Lay out axes of sigmai vs CL

Plot horizontal lines corresponding to the critical cavitation boat speeds.

Plot diagonal lines corresponding to the foil loading for incipient cavitation. Note that this forms a grid which is independent of the choice of foil section.

Plot sigmai vs. CL for the hydrofoil section.

Now, not only do you have the cavitation diagram for the section, you can relate it to key design aspects of the boat as a whole. You can see immediately how heavily the foil can be loaded and how fast the boat can go before encountering cavitation. Since the grid is universal, it can be used to define the requirements for designing a hydrofoil section, which you can do with XFOIL as well.

There is an excellent paper on the cavitation of hydrofoils in the latest issue of the Society of Naval Architects and Marine Engineers' Journal of Ship Research, written by researchers at the Institut de Recherche de l'Ecole Navale, 29240 Brest-Naval, France: J.-A Astolfi, J.-B. Leroux, P. Dorange, J.-Y Billard, F. Deniset, and S. de la Fuente, "An Experimental Investigation of Cavitation Inception and Development on a Two-Dimensional Hydrofoil," Journal of Ship Research, Vol. 44, No. 4, Dec. 2000, pp. 259-269. It shows more cavitation diagrams and also the degree to which experimental cavitation occurs at Cpmin. The agreement is excellent at the bottom of the bucket and Cpmin is a conservative estimate for the sides of the bucket. They also discuss the interaction of cavitation and laminar flow, which will be important for your low Reynolds number experiments. -- Tom Speer (tspeer@tspeer.com) website: www.tspeer.com; fax: +1 206 878 5269

Manual Control of Sailing Hydrofoils

[28 Feb 01] Has there been any recent input on manual foiler control (say, of the *RAVE*) or does anyone have any thoughts on the subject? -- Doug Lord (lorsail@webtv.net)

Responses...

[28 Feb 01] I have my doubts if manual ride level controls are useful at all, if you actually mean "real time" adjustment not preset positions:

As a dinghy sailor, you have enough to do with steering, sheeting, weight trim, sail adjustment etc., so almost no time for more to worry about.

Light, smallish craft do react very quickly on even the slightest foil adjustments, even larger units as high speed ferries use auto controls, either with mechanical or electronical input, self-driven with pushed or trailed surface level arms or combinations of servo power from electric-hydraulic-air or such.

I just wanted to express that for looong extended cruises full and only manual control could be exhaustive and boring. IF humans can act as quick or better than automatics, okay !

-- Claus-C. Plaass - Pickert 10 - 24143 Kiel - Germany - email (plaass@foni.net), ph +49-431-36 800

[4 Mar 01, updated 3 Nov 02] I designed several manual controlled foil stabilized outriggers. From the first one it was plain to see that manual controlled full foilers was the way to go to generate performance all around the course. Sailing is just too dynamic not to have manual controls. I invited Greg Ketterman to sail my boat proposing to change his tri-foil to manual control but he explained that for he was working on larger designs where this might not be possible. I think it is inevitable. Let me know if you are interested in more details as to how we controlled them. I have several designs and several published articles about these boats. Last article was in *Multihulls* March/April issue. A Yahoo search for John Slattebo will reveal two more. -- John Slattebo (raptor16@sbcglobal.net) website: (http://hydrovisions.com/)

Reynolds Number Scaling Effects

[20 Feb 01] Do you know of any references or anybody who has investigated Reynolds number scaling effects of hydrofoils under the free surface. What I am primarily interested in the loss in lift of model foils due to their lower operating Reynolds numbers. So far the only info I have on the subject is Dr. Frans van Walree's Ph.D. thesis. My own calculations show this loss of lift depends on the Reynolds number as well as the submergence of the hydrofoil and can be as high as 30%. -- Günther Migeotte (gunther@cae.co.za); Dept. of Mechanical Engineering, University of Stellenbosch; Banghoek Rd; Stellenbosch,7600

Responses...

[21 Feb 01] I've not been able to find any information on Reynolds number effects on hydrofoils, either. It's not clear to me just what the mechanism would be for Reynolds number-dependent free surface effects on a fully submerged foil, except indirectly through modification of the pressure distribution and thereby the boundary layer. For surface piercing foils and struts, I could see how viscous effects would affect the spray drag etc. All the investigators I know have assumed that the foils would be operating at fairly hi Re and would be pretty much fully turbulent. For what it's worth, I've designed some hydrofoil sections which should tolerate a much wider Reynolds number range, suitable for models operating down to 300,000 - 400,000. Possibly less with BL trip. Xfoil results are at http://www.nasg.com/afdb/show-airfoil-e.phtml?id=1187. I'd like to know more about what you've found and how you do your calculations. I don't have any free-surface capability other than the infinite-Froude number linear approximation. Two big issues I wonder about are spray drag of struts and surface piercing hydrofoils producing lift, and prediction of ventilation. -- Tom Speer (tspeer@tspeer.com) www.tspeer.com fax: +1 206 878 5269

[21 Feb 01] One good reference for these effects is the Ph.D. thesis of Dr. Frans van Walree at MARIN. If you check out the IHS website, somewhere you will find a link on how to obtain a copy of his thesis. He found that there is a viscous reduction in lift curve slope for all Reynolds numbers, but for Rn>1e6 the effect is small. If one is using thin wing theory, the extra lift caused by the thickness of the foil is cancelled by the viscous effect giving a lift curve slope close to 2pi. As the Reynolds number gets lower one is forced to introduce viscous corrections and account for the thickness of the foil. I have followed a similar line to van Walree in trying to calculate viscous effects. I have compared experimental results for hydrofoils with numerical results of the vortex lattice method of AUTOWING (http://www.cl.spb.ru/taranov/Index.htm). Autowing has been well validated for hydrofoils. Comparing the exp. and calc. lift curve slope, I found that for the 3D hydrofoils I examined, the viscous effect on lift disappears as the foil approaches the free surface. For h/c<0.25 it is practically negligible. After thinking about this, I think it makes good sense. Viscosity affects mainly the suction side of a foil, as it has adverse pressure gradients. Using Xfoil one can clearly see that the boundary layer reduces the suction pressure (compared with potential flow) and hardly affects the pressure side as it has favorable pressure gradients. I have not heard of anybody else mention this. Close to the free surface the suction side of the foil contributes very little lift, so the effect of the boundary layer is small. Xfoil predicts the viscous loss in lift quite well if Rn>5e5 with leading edge turbulence stimulation for deep submergences. For free transition, Xfoil under predicts the viscous loss in lift. If you come up with any other info please let me know. What is needed now is a version of Xfoil with a free surface model to investigate this further.... -- Günther Migeotte (gunther@cae.co.za)

[21 Feb 01] I can suggest one fairly old reference on model testing of hydrofoils compiled for the International Towing Tank Conference (ITTC) which may be of help: DTNSRDC-81/26 (or 81/026 ??) 'Status of Hydrodynamic Technology as Related to Model Tests of High-Speed Marine Vehicles', July 1981. Unclassified, Approved for Public Release, Distribution Unlimited. David W. Taylor Naval Ship Research and Development Center. Author of Hydrofoil section: B. Müller-Graf (who is still an IHS member) Abstract reads: The High Speed Marine Vehicle Panel of the 16th International Towing Tank Conference prepared hydrodynamic technology status reports related to model tank tests of SWATH, semidisplacement round bilge hulls, planing hulls, semisubmerged hydrofoils, surface effect ships, and air cushion vehicles. Each status report, plus the results of an initial survey of worldwide towing tanks conducting model experiments of high speed vessels, are contained herein. Hydrodynamic problems related to model testing and the full-scale extrapolation of the data for these vehicle types are also presented. -- Martin Grimm (seaflite@alphalink.com.au)

Section and Materials For Supercavitation Foils

[23 Nov 00] This concerns foils for a 22ft racing catamaran powerboat a friend of mine is currently constructing. The HYSUCAT concept consists of a main foil supported on the lowest point of the hull and spans horizontally across the tunnel between the two hulls just in front of the center of gravity. There are also two smaller aft foils close to the stern that does not span the whole distance across the tunnel. On this particular boat the chord length is 160 mm and the span approximately 950mm. As this boat is powered by two 150Hp outboards, the maximum speed would be around 70 Mph. The main purpose of the fwd foil is to reduce the slamming of the hulls and also to bring it onto a plane much quicker. The foil section currently used on a slower boat is an arc of circle foil manufactured from stainless steel. This foil section was probably used for ease of manufacturing. I have recently manufactured a couple of carbon/kevlar foils for my Trampofoil with great success and would thus like to manufacture another foil for the racing boat using a more optimum foil section and composite materials. The section I have picked was the E817 but I am wary that this foil section might cavitate at these high speeds. My knowledge on super cavitating foils is very limited but I have seen some sections with the sharp entry and flat rear end witch looks promising. What section would you propose to use in such an application and where can I get hold of some data and information regarding these high speed foils? What would the implications be in using a composite material and corrosion due to cavitation? -- Ben Lochner, Cape Town, South Africa (benl@kingsley.co.za)

More on Retractable T-Foils

[20 Oct 00] In the current (Autumn 2000) newsletter, there's an article about MDI's retractable T-foil for Incat, with most of the historical information coming from Fast Ferry International, and some information from John Adams here at MDI. I would like to add a few statements on a more personal plane. The original 74m wave piercer ride control system was basically as stated in the newsletter (as an excerpt from Fast Ferry International) except- the first 4 square meter pivoting T-foils with flaps (1 per hull) were designed at that time as well. (not the center mounted retractable) I know because I did the 3D CAD integration of the concept, and came up with some interesting features of the 4 sq M foil actuation mechanisms myself. Most of these features are still in use today, some were a learning curve. The previous pioneering ROCS for a non-SES vessel was a smaller foil stabilized catamaran *CONSOR 9*, which had hull mounted fins. The T-Foil idea was originally pushed very hard by a 'staunch' engineer (who would NOT let go of it...) from the UK- Lionel Frampton of Marine and General Engineering, Ltd. UK. Without Lionel's persistence, the foils may have taken a much different tack indeed, and I feel he should receive some acknowledgement for the prevalence of the T-foil today. I also worked on the Corsaire 11000, 12000, and 13000 designs, actually building 2 model scale T-foils and integrating them in the tank model at DTRC, in what I believe was the first tank testing of an active ride control system of this type. It was, in fact, the 1/14th scale model referenced in the article (paper given by Christian Gaudin of ALN and Raymond Dussert-Vidalet of SNCM at the 16th Fast Ferry International conference). I also designed the integration of the trim tabs and roll fins for these model tests. The model T-foils are still being used for various tests. It was pretty exciting to see them in the IHS newsletter! -- Rick Loheed (rloheed@islandengineering.com)

Reynold's Number Calculation

[7 Oct 00] I would really appreciate answers to two quick questions: 1)How can I calculate the Reynold's Number of a hydrofoil? 2)Are there any good sources of hydrofoil coordinates or data on the internet? -- David Shelton (DBshelton2@aol.com)

Responses...

[7 Oct 00] The Reynolds Number (Rn) = vL/(nu). Where: v = velocity, L = length, nu = kinematic velocity. It is important that the units be consistent. For example, v in feet/sec, L in feet, nu in sq feet/sec. L is a characteristic length, typically the foil's chord. Nu varies with temperature and fluid (in fresh water at 59F nu is 1.22603 X 10^{-5}). The Reynolds Number for each foil and strut must be calculated separately. -- King James H CRBE (KingJH@nswccd.navy.mil)

[7 Oct 00, updated 17 Feb 03] There is an airfoil database at http://www.nasg.com/afdb/index-e.phtml. There is a freeware NACA foil generator program available at http://ourworld.compuserve.com/homepages/Harold_Ginsberg/boatship.htm. Also, see the links page on the IHS site for additional sources of design info. -- Barney C. Black (Please reply via the BBS)

[9 Oct 00] The Reynolds Number is the non-dimensional ratio of the inertial forces to the viscous forces pertinent to a body moving in a fluid. It is given by the following equation; R= velocity times a length parameter divided by the kinematic viscosity of the fluid. You can see that it doesn't make any sense to ask-- what is the Reynolds Number of a hydrofoil?-- without specifying *what* Reynolds Number, e.g.., a foil, a strut, the hull, etc. If you mean a foil, the length parameter is generally the chord. If it's the hull, the length parameter is generally the length of the hull. The larger the Reynolds Number, the less important are the viscous forces, conversely, the smaller the Reynolds Number, the more important are the viscous forces. A Reynolds Number approaching zero corresponds to flow in which inertial effects are negligible by comparison to viscous effects such as a steel ball dropping in a tube of honey. In the case of "hydrofoils," the question is -- for what length parameter and for what flow velocity? After all this explanation, the bottom line is that I don't believe that the Reynolds Number is of particular concern for "hydrofoils." What is important is the Froude Number, which is the ratio of inertial forces to gravity forces, the inception of cavitation on the foils, and foil or strut ventilation. -- Bill Ellsworth

[9 Oct 00] Reynolds Number is defined as: Rn = V * L / NU Where: V = Velocity (of the hydrofoil) through the water in metres per second (m/s); L = A reference length in metres (m). In the case of hydrofoils the chord length is used as the reference length to calculate Reynolds Number. NU = Kinematic Viscosity of the water in metres squared per second (m^2/s). Any other consistent set of units can be used, as Reynolds number is a dimensionless quantity. For fresh water at 15 degrees Celsius: NU = $1.13902*10^{-6}$ m^2/s. For salt water with salinity of 3.5% at 15 degrees Celsius: NU = $1.18831*10^{-6}$ m^2/s. For any reasonable range of water temperatures, the Kinematic Viscosity can be calculated approximately with the following equations (giving results in units of m^2/s again): For fresh water: NU = $(6.8309*10^{-4}*TEMP^2 - 5.227728*10^{-2}*TEMP + 1.76836591)*10^{-6}$. For salt water with salinity of 3.5%: NU = $(6.6375*10^{-4}*TEMP^2 - 5.145326*10^{-2}*TEMP + 1.80950523)*10^{-6}$ Where: TEMP = Water temperature in degrees Celsius.

Which Foil Section is Best

[29 Aug 00] I wish to construct a few recreational dynamically supported pleasure craft. I have been conversing with Mr. Larsen (an IHS member) and Mr. Mateev (Cal Tech and IHS Member). They have been most helpful in helping me to assess the basic design constraints required. Based on their correspondence, I would first like to pursue the construction of a hydraulically retractable surface piercing (shallow draft) hydrofoil. The prototype craft is to be in the 20 foot (6 meter) range with a displacement of 2500 to 3000 lbs. (1150 kilograms to 1350 kilograms). I believe this to be the standard displacement for this size of craft. Target speed to be 50 knots. Power to come from an I/O arrangement with a standard V-8 gasoline motor generating approximately 300 hp (223.8 kW). Engine may be further modified to increase output. Leg to be a modified unit with a "Vari-Prop" pitch adjustable prop. Ride height is as of yet undetermined. I have not purchased the boat yet. I am hoping to construct a two piece interlocking foil arrangement that could hydraulically split for the purpose of retraction. Time line is (10) months to construction. Among these design criterion is foil selection. I was referred to you by Professor Kinnas (University of Texas at Austin, Department of Civil Engineering, Ocean Engineering Studies). I presently have little knowledge of the physics involved in foil selection. Any assistance would be gratefully accepted. -- Wayne Gillespie (wayneg99@telus.net)

Response...

[29 Aug 00] Regarding hydrofoil sections, I like the NACA 16-series hydrofoils because they provide good cavitation resistance, which you will need at 50 knots. As design speed increases, the hydrofoil thickness/chord ratio and lift coefficient must reduce to prevent cavitation. I used a NACA 16-510 hydrofoil section for surface piercing hydrofoils developed in the 1950's, which had a max speed of 46 mph with the 65 hp outboard I was using at the time. You might want to read my article on hydrofoil boats in the pioneer section of the International Hydrofoil Society Web Pages. An excellent source for other hydrofoil cross sections is in the book "Airfoil Design and Data" by Richard Eppler, published by Springer-Verlag, 1990. -- Tom Lang (tglang@adelphia.net)

Follow Up...

[8 Sep 00] Thank you very much for the input. I suppose that I will have to find a supplier / method of production for the foil(s). How are the actual; dimensions obtained? Are there on line resources available to this end? Distance between supports will have to be determined as well. I have visited the University of Texas at Austin pages and found an interactive applet design page that models relative lift and drag ratios of given foil dimensions. Most interesting. I however presently lack the understanding of the data to interpolate. Do you know the approximate cost of dies for aluminium extrusion? Are there any points of interest in the production end of foil extrusion that you have learned through your experience? I will endeavour to obtain the referenced book. You mentioned that a 1.5 deg twist in the foil of your kit allowed the craft to lean into the turn by allowing the inner foil (on the turn) to ventilate first. Can you elaborate on the process involved that cause this to happen? Conversely, it there is information within existing reference texts, I would be most grateful if you might simply direct me in the appropriate direction. -- Wayne Gillespie (wayneg99@telus.net)

Response...

[8 Sep 00] You might want to consider making composite hydrofoils; however, extrusions are easier to work with. The foil cross sectional dimensions are available from the Eppler book, or in the case of NACA sections from the Dover book by Abbott et al, "Theory of Wing Sections". The Marks Handbook on Mechanical Engineering is one of many references on beams and structural strength. You might re-contact IHS to see if he has a list of references on hydrofoil design, and if they know of any sources of extrusions. Also, you could contact Alcoa for their list of existing dies and the cost of new dies. I think that there are many hydrofoil enthusiasts who would like to buy extrusions. You might ask IHS about references concerning ventilation. Also, it would be helpful to join the IHS; the special student cost is very low. My experience showed that ventilation occurred when angle of attack increased around two-to-three degrees above the design angle at a 30 deg dihedral, more with a higher dihedral, and less with a lower dihedral. Much depends on the accuracy of the hydrofoil nose region. Ventilation occurs when the hydrofoil boundary layer separates near the nose on the upper side, and air fills the separated region, generally superventilating the entire foil section downward for several inches; the result is the sudden loss of all lift in the supervented region. Sharp nose sections ventilate sooner than airfoil noses. Fences can be used to stop ventilation at intervals, but add some drag. -- Tom Lang (tglang@adelphia.net)

Sailing Hydrofoil Design Data

[19 Feb 00] FYI, Here's a new link for your "Websites of IHS Members" section. I've put up some information on hydrofoil sections that might be of interest. -- Tom Speer (tspeer@tspeer.com)

Fences

[5 Jan 00] I am about to start my hydrofoil setup for my solo sailing 18 Square, but I have some questions about certain aspects of design. The main question is what are fences on hydrofoils for? What do they do and how should the be arranged on a foil shape? I want to make foils like those from *ICARUS* and I know they used fences. Are they a way to keep water down? Visual marker for the skipper? Another question is what is the chord size for *ICARUS* ? It looks like 4"-5" because it is larger than the crossbeam on a Tornado beach catamaran. What size do you think would suit a 360 pound catamaran sailing at or above 25 knots with 200-400 pounds of crew weight? This assumes I do use the *ICARUS* foil setup. I may use the *ICARUS II* setup and use a smaller chord, this is pretty much just a doubled up bottom lifter foil. This setup was used when they had the double rig. I noticed you didn't have any photos of this great boat either, I have found two of them on this page: http://home.worldonline.nl/~hbsmits/hydrofoi.htm -- Michael Coleman (MECcoleman@aol.com) -- Mike's NACRA Page -- Mike's 18 Square Page

Response...

[5 Jan 00] Fences reduce spanwise flow. Since the pressure under the foil is greater than that on top, the water wants up any way it can. Going around the tip reduces the lift ;therefore, fences or tiplets or tiprings. If you are making an exact copy of *ICARUS* foils use the same fences. If not, the best is to do some simple tank tests (try the Naval Academy). If you want to risk a little loss in efficiency scale the *ICARUS* foils and fences. ALSO, do *not* change the aspect ratio of the foils without testing. Reducing it will change flight characteristics. Increasing it will change structural loads. SUPPLEMENT: Strut fences are good for reducing downflow on the strut, both water, which reduces lift and air, which ventilates the foil and screws everything up. GOOD LUCK!!! -- Nat Kobitz (kobitzn@ctc.com)

2nd Response...

[5 Jan 00] I do not know of any hydrofoil ship with fences on the foil itself. Fences were put on the struts to interrupt ventilation. Ventilation is when the air flows from the water surface creating a cavity between the strut surface and the water. Due to the difference in density of air and water, ventilation could cause loss of lift and/or control. The fences are essentially flat plates attached to the strut perpendicular to the strut surface and in line with the water flow. Generally they were contoured in simular shape as the strut. A good example is the cavitation plate on an outboard motor or the I/O drive. Fences were not used on any of the Navy hydrofoils. As far as the remainder of your questions, I plead ignorance. -- Sumi Arima (arimas1@juno.com)

3rd Response...

[4 Jun 00] The following is quoted from the 1967 book *Hydrofoils* by Christopher Hook and A. C. Kermode: "One serious problem with both these systems [ladder foils and V-foils] is air entry, for by the very nature of the design, some parts of the foil, or some of the foils, are always at or near the surface; they are in fact surface-piercing foils. This means that it is all too easy for air to get in and spoil the lift. The danger of air entry can be reduced to some extent by fitting fences, baffle plates, or screens on top of the foils; as their names imply, they act as barriers to the air, and may temporarily prevent it from getting further down the foil, but like most fences they can be jumped, and as one fence emerges, the air jumps to the next fence down."

Experimenter Needs Advice on Foil Sections

[7 Feb 99] As a new IHS'er, I recently purchased Dave Keiper's notes and 3" foil & strut stock. After reading his notes, however, I feel I need to get started in this fascinating world of hydrofoils at a little more basic level, and tackle my 1982 Nacra 5.2 hydrofoil project a little later... after I successfully build a more basic hydrofoil project (I'm a marketing type, not an engineer)! I wish to construct a stable towed hydrofoil platform, utilizing 4 ea. 6" surface piercing foils in a split-tandem configuration. I'm guessing that each foil would be angled out 55 deg. from the vertical strut. I would like to carry a loaded vessel weight of 800-900 lbs., at speeds up to est. 45 mph. What foil section would be best suited for this application, and who can I purchase 6" foil and strut stock from? I recall reading that Alcoa offered foils, but don't know what to ask for ! Do you have any suppliers you could recommend that make such foil stock? Any suggestions / recommendations for this towed contraption? -- Brian Ballou

Response...

[8 Feb 99] Recently I attended the Düsseldorf Boat show - known as the World's largest. I remember having seen symmetrical foils of a very high surface quality, weldable and with two internal struts for stiffening. Chord length was about 6-8", thickness was about 1 inch, wall thickness was some 1/6 inch. Comes in lengths of 6 m (20') If this is of any interest to you, please let me know with details, such as required section, total length and max length for shipping. I already discussed the matter with the manufacturer, so sending you an offer shouldn't take very long. My offer for the 3" chord length NACA 16-008 and Clark-y remain valid. -- Claus-Chris Plaass (plaass@foni.net) phone: +49-431-36 800

[11 Nov 01] Foil Stock, carbon fiber NACA 63-412, 120mm chord: http://imca-wa.freeyellow.com/Resources.html. -- Tom Speer (me@tspeer.com) website: www.tspeer.com

The Right Section?

[updated 18 Aug 98] I need to find the proper foil section to use for a strut section . . . my experience is all with Aerodynamics, not Hydrodynamics, so am out of my comfort zone (Reynolds number wise). Issues: (1) Maintenance of fully attached flow throughout range of 10-60 MPH; (2) Essentially zero degrees angle of attack (strut); (3) Very small chord (in the range of 1/4 to 1/2 inch) -- Scott Kelley (scottk@iccom.com)

Response...

[7 Oct 98] Sorry it has taken so long to get back to you, but I had to get hold of Abbott and Von Doenhoff's book on "Theory of Wing Sections". I recommend a very simple section; namely NACA 0012. A thicker section would normally lead to cavitation at a given high speed, so it is a tradeoff between cavitation and structural adequacy. As in most things it's a compromise! -- John Meyer, President IHS (president@foils.org)

Response...

[18 Aug 98] I believe the question of what section to use involves more issues than Scott Kelley is aware of. In any event I can recommend that he contact David Taylor Research Center (now Naval Surface Warfare Center - Carderock Division) to obtain a copy of the following report: Rothblum, R. S., D. A. Meyer and G. M. Wilburn, "Ventilation, Cavitation and Other Characteristics of High Speed Surface-Piercing Struts", Report NSRDC 3023, July 1969. This is the most comprehensive test report on strut hydrodynamics which I encountered in my previous work on hydrofoil loads criteria. I must say the strut dimensions which he cites seem bit unusual. For a chord of 0.25 in. and a representative 10% thickness this would result in a maximum thickness of 0.025 in. -- Bill Buckley (wbuckley@erols.com)

Response...

[18 Aug 98] The old Hydrofoil Design Data Log (DDL) had foil section shapes for all of the Navy's hydrofoils. It should be in the Advanced Ship Data Bank at CDNSWC, and I don't think that kind of data is classified. -- Mark Bebar (Bebar_Mark@hq.navsea.navy.mil)

Response...

[18 Aug 98] The main considerations for using a small chord (~1/2 inch) strut at high speed (60 knots) are endurance and providing smooth flow around it. These tasks are opposite in some sense. The thicker the strut, the more durable it is, but it gives results in diminishing the speed at which cavitation begins. I think it is necessary first to calculate the thickness at which endurance will be guaranteed, then choose the profile for the smoothest flow.

Endurance. In your design, you should consider the strut as a rafter with one attached end or both attached ends or as a frame with certain shape. The maximum value of forces acting on the strut must be taken when calculating the bending moments. The calculation is made by standard methods of elasticity theory or some empirical expressions. The thickness of strut paneling is determined from condition of providing the endurance at the maximum bending moment. The maximum contracting stress cannot be more than Eulerian stress with endurance reserve 2.5. (The thickness of the strut cannot be less than the thickness of strut paneling.) If flow is non stationary (for example wave impacts take place), then it is necessary to check the dynamical endurance of the strut by means of experiment or complicated calculations.

Choice of the Profile. If the smoothest flow is needed, you can try a profile with circled bow edge and sharp stern edge something like NACA-0009 (it is sometimes used as a rudder), it must work until high speed without cavitation. You can estimate the speed at cavitation will start using expressions given on my web page. But usually in hydrofoil systems other strut profiles are applied. The bow edge is circled or sharp, the stern edge is obtuse (like a wedge). It enables to diminish the resistance at some speed range (so-called effect of resistance crisis), in spite of flow estrangement.

-- Konstantin Matveev (matveev@cco.caltech.edu) website: www.hydrofoils.org

Design Studies For Hydrofoils and Struts...

[25 Oct 97] As part of DARPA's assessment of the potentials for high speed ships, we have two groups doing some top level design studies for hydrofoils and struts. Is there a stress limit you would recommend using to account for a readily available high strength steel that would account for future detailed fatigue analyses? I don't know if there's any useful data from the prior hydrofoil programs that would shed some light on this. -- Stan Siegel (stansiegel@aol.com)

Response...

[2 Nov 97] I'm glad to hear there is still some interest in hydrofoils if only in regard to concept studies. Regarding the question of a stress limit for future detailed fatigue analyses, I can not suggest "a value" because of the many serious issues involved in such a selection. The most practical suggestion I can offer is for the parties involved to obtain the static strength, fatigue and flaw growth properties of the 17-4 ph material employed in the design of the PHM-3 series foil system. The cyclic loads which would be needed could be ratioed up or down from the Boeing load criteria as a starting point. Obviously they would need to retrieve and review the stack of Boeing reports involved- no small task in itself. As far as selecting a readily available high strength steel is concerned, such a step is a potential minefield as I think you know. I'm not a fan of 17-4 ph, but it was used with fair success in the PHM-3 series ships after a complete redesign of PHM-1 foil system. HY-130 was used successfully in elements of the PCH-1 Mod 1 foil system, but it (and the required coatings) were never subjected to the extended service experience of the PHMs. It may be the better material but we have no proof. Perhaps I'm being a bit too realistic for concept studies which sometimes are not very realistic in the first place. In any case, if I can be of further help to you don't hesitate to contact me. -- Bill Buckley (wbuckley@erols.com)

This Page Prepared and Maintained By...

International Hydrofoil Society

PO BOX 51 - CABIN JOHN MD 20818 - USA

webmaster@foils.org

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