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Hydrofoil Design Texts, Software, Sources, and Discussion

Descriptions, Advice, Sources of Information, and Requests For Help

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Fast Ships Paper

[5 Mar 02] Suggested paper for the next AMV CD-ROM: [Hefazi, Hamid](#); Orhan Kural; Hsun Chen; and Tuncer Cebeci, Professors; Eric Besnard, Adeline Schmitz, Kalle Kaups, and George Tzong, Research Associates, "Hydrofoil Design and Optimization for Fast Ships, *Proceedings of the 1998 ASME International Congress and Exhibition Anaheim CA, Nov, 1998*. Abstract: The paper presents a multi-disciplinary design/optimization method for the conceptual design of a hydrofoil based fast ship. The method is used to determine the maximum achievable lift-to-drag ratio (L/D) of an isolated foil-strut arrangement (hopefully greater than 50) at high transit speeds (greater than 75 knots) while lifting masses of 5,000 and 10,000 tons. First, the tools necessary for the study are presented. They comprise a panel method to compute three-dimensional flows around arbitrary configurations with a model for the free surface, a foil cross-section optimization tool, a strut cross-section design tool, and a structural analysis tool. The

computational tools are then integrated into a multi-disciplinary design/optimization approach, which is applied to the design of single foil and biplane configurations. Results show that the goal of $L/D = 50$ is achievable for 75 knots (assuming that techniques can be developed for reducing the skin friction drag to a quarter of its nominal value) and, that for 90 knots, L/D ratios around 45 can be reached. The corresponding break horsepower requirements for 10,000 tons are around 130 khp and less than 200 khp, respectively. Full text posted at: www.csulb.edu/colleges/coe/ae/ae_dept/images/pdf/asmc_paper.pdf. -- Tom Speer (me@tomspeer.com) website: www.tspeer.com

Diesel Engineering Text (1 and 2)

[December 20, 2013] Author: Andrei Makartchouk
Title: Diesel Engine Engineering 2: Thermodynamics, Turbocharging, Dynamics, Design, Control
ISBN: 0984634606
Available on Amazon.com

This book is a revised and extended edition of my previous book below, and provides the foundation for design of diesel engines based on traditional methods in thermodynamics, dynamics, structural analysis, chemistry, heat transfer, applied analysis of system operation, and etc. This edition offers an additional material and examples for calculation of combustion process, thermal efficiency, heat release, NOx emissions, and etc. A diesel turbocharging is included into this edition also.

Providing detailed strategies to analyze, control, and design diesel engines, their systems, and major components, this text can be used as a manual for calculation of diesel engine thermodynamics and dynamics, design of turbocharging, evaluation of structural mechanisms, and modeling of diesel engine systems for optimal performance, efficiency, and maintenance in marine, industrial, automotive and genset applications.

Thank you, Andrei

Speed at Sea

[5 Feb 02, updated 17 Feb 03] Note the webpage URL for *Speed at Sea*, The Journal for Fast Ship Operators: www.rivieramm.com/sas/. -- Robert Gore, Circulation Manager, Speed at Sea & Offshore Support Journal, Riviera Maritime Media; Tel: +44 (0)20 8364 1441 ext6; Fax: +44 (0)20 8364 1331 (E-Mail Address: robert.gore@j-l-a.com).

General Question

[13 Jan 02] Got any blueprints for hydrofoils? (Leprocaun1@aol.com)

Response...

[13 Jan 02] This inquiry is a bit terse, but here goes: We do not offer blueprints of any kind. If you will go to the popular magazines section of the IHS website you will find at least one old magazine that came with blueprints for adding foils to a motor boat. The next month's issue provided plans for building the boat used in the first article. You can get copies of old magazines by watching the eBay auction site or by checking with a local antiques dealer or other seller of old magazines. On a larger scale, you should go to the links page of our website and find the link to Harry Larsen's website on *TALARIA III*. He added a fully submerged foil system with Automatic Control System to a Bayliner cabin cruiser. If it is sailing hydrofoils you are talking about instead of motor boats, you will find quite a bit of correspondence posted from people who have built hydrofoils and who might be willing to help, but no plans are available directly from IHS. If you are talking about model hydrofoils instead of full-size hydrofoils, then there are some possibilities for plans or kits, both for motor and sail powered R/C models or static models... the posted correspondence on the site covers both of these topics. I hope I have answered your question... you gave me no details to work with! -- Barney C. Black (Please use the [BBS](#) to reply)

Source of Marine Documents on Web

[13 Jan 02] There's a fantastic source of books and studies at <http://books.nap.edu/>, many of them available to download and read or print out. There's an extensive collection of marine documents. Hit the "Browse Categories" button to see the range. <http://books.nap.edu/books/NI000359/html/> takes you directly to last year's *Twenty-Third Symposium on Naval Hydrodynamics* (2001), which is what led me to the overall site. -- William Hockberger (w.hockberger@verizon.net)

Analysis Software Release

[11 Nov 01] New Wave Systems, Inc. announces a major new version of ProSurf, its trimmed NURB surface program for the design and analysis of boats and ships. ProSurf 3 is twice as large as ProSurf 2 and costs only \$795, less than half the price of the previous version. In addition, ProSurf 3 contains capabilities not found in any other program at any price. Use ProSurf 3 as your primary hull design and analysis tool or use it as an add-on to your existing suite of CAD programs. See www.newavesys.com for complete details and a limited use, full working demo. Stephen M. Hollister (shollist@home.com)

Need Copy of 1968 Report

[4 Oct 01] I am looking for the following report: "The skin friction of a hydrofoil near a free surface" John C. Gebhardt. October 1968. Do you know anybody who has a copy of this report? -- Günther Migeotte (gunther@cae.co.za) Dept. of Mechanical Engineering, University of Stellenbosch; Banghoek Rd; Stellenbosch 7600; South Africa

NACA Reports of Interest to Hydrofoil Designers

[16 Sep 01] The U.S. National Advisory Committee for Aeronautics (NACA) was chartered in 1915 and operational from 1917-1958. The National Aeronautics and Space Act of 1958 created

the U.S. National Aeronautics and Space Administration (NASA) from NACA. According to the 1999 NASA Technical Manual [NASA/TM-1999-209127](#) *A Digital Library for the National Advisory Committee for Aeronautics* by [Michael L. Nelson](#) of Langley Research Center, Hampton, Virginia, "The main product of NACA's research was its multi-tiered report series. Although the exact number of NACA reports published is unknown, most estimates place this number between 20,000 and 30,000. This collection of work remains in high demand even today, especially in the areas of general aviation and the basic fundamentals of flight. Unfortunately, although significant collections of NACA documents exist at a handful of NASA centers, universities and other government and industrial research laboratories, no single library contains a complete collection. Even what constitutes a complete NACA corpus is subject to debate. Furthermore, because of their age, high circulation, and acid-based paper, many of these reports are in poor condition and will cease being serviceable in the near future. Conversion to digital format [and dissemination over the World Wide Web -- begun in 1995 and ongoing --] is necessary for preservation as well as for wider dissemination." The NACA Technical Report Server (NACATRS), the digital library (DL) that serves the NACA collection can be accessed at <http://naca.larc.nasa.gov/>. NACATRS offers browsing and keyword searching of its holdings. The NACA publications are scanned, but... "Optical Character Recognition (OCR) is not being applied for the NACATRS, primarily because the format of the NACA publications are often pages of equations, tables, charts and figures, none of which are well suited for OCR. Instead, the report is converted into a combination of GIF and PDF files for easier WWW dissemination... The first NACA Reports were issued in 1917, but TNs and TMs did not appear until 1920. The early publications were often either translations from European aeronautics works or authored by universities or other federal or military research laboratories. This is because NACA was initially truly a committee of aeronautically interested organizations rather than a federal agency in present context. As NACA acquired its own staff and developed its own research facilities, the number of publications authored by non-full-time NACA staff decreased. NACA published in a variety of internal report series. Currently [as of April 1999], the NACATRS holds the following NACA publications series:

- *Reports* - NACA reports were considered to be the final and complete documentation on a subject or project and they often superceded one or more other NACA publication types. NACA Reports are sometimes (erroneously) referred to as 'NACA Technical Reports.'
- *Technical Notes (TNs)* - Technical Notes were the basic unit of the research report series. Some early TNs were translations of foreign works.
- *Technical Memorandums (TMs)* - TMs are translations of foreign works. The TM series probably replaced translations in the TN series.
- *'Wartime Reports'* - Reports produced specifically for World War II research, they were declassified after the conflict. Due to their urgent nature, they frequently received little editing when written, and no editing was done after they were declassified. The moniker 'Wartime Reports' was added when they were declassified; previously they were issued as Advance Confidential Reports (ACRs), Advance Restricted Reports (ARRs), Restricted Bulletins (RBs) and Confidential Bulletins (CBs).
- *Research Memorandums (RMs)* - RMs were initially restricted, and represented initial or limited scope results, and thus received less editing and preparation than other report series.

"NACATRS currently does not include:

- *Annual Reports* - Annual Reports were simply the concatenation of a single year's NACA Reports (i.e., excluding TNs, TMs, etc.). Inclusion of the NACA Reports in NACATRS implicitly includes the Annual Reports.
- *Aircraft Circulars* - Reports published in the 1920s-1930s that reviewed the design and performance of contemporary aircraft (one AC per vehicle).
- *Conference or Journal Preprints* - We are unaware of how many items this would include. However, their content would likely be covered in a Report or TN, so this exclusion is probably negligible.
- *Books* - No books by NACA authors are included."

Now, of course, the question is: in all this mass of technical data, which reports are of interest to hydrofoil designers? -- Barney C. Black (Please use the [BBS](#) to reply)

Response...

[16 Sep 01] Besides [Report 1232](#) *A theoretical and experimental investigation of the lift and drag characteristics of hydrofoils at subcritical and supercritical speeds*, and [Report 918](#) *Theoretical Motions of Hydrofoil Systems*, there's [TN 4168](#) *A method for calculation of hydrodynamic lift for submerged and planing rectangular lifting surfaces*, which also deals with hydrofoils. Some of the reports dealing with lift and drag of biplanes can be used, since the linear approximation of the free surface effects gives the same solution for a hydrofoil as the lower wing of a biplane. There are also reports on planing surfaces, which can be useful for hydroskis and for predicting the drag of hulls at takeoff. See [Report 1355](#) *A theoretical and experimental study of planing surfaces including effects of cross section and plan form*, and [TN 4187](#) *High-speed hydrodynamic characteristics of a flat plate and 20 degrees dead-rise surface in unsymmetrical planing conditions*. In general, the NACA reports are a very useful source of information on a lot of topics. -- Tom Speer (me@tspeer.com) website: www.tspeer.com

Russian Hydrofoil Documents in English Translation...

[26 Jun 01] How does one get hold of NAVSEA (Naval Sea Systems Command) translations of Russian papers on hydrofoils etc. I have a number of references. I noticed in some IHS newsletters that Bill Buckley refers to the Naval Surface Warfare Center- Carderock Division Technical information service for such papers. Is this the correct place and do you have a contact address for them? -- Gunther Migeotte (gunther@cae.co.za)

Responses...

[4 Jul 01]The NAVSEA Library is no more. Not sure where these translations may have gone. The Pentagon library is a possibility but I don't know what their policy is for access. -- Mark Bebar (bebar@foils.org)

[4 Jul 01] In connection with the Advanced Ship Data Bank at the David Taylor Naval Research Center, to my knowledge there were never any Russian report translations entered into it, and I am quite familiar with the Data Bank contents. -- John Meyer (president@foils.org)

Wave Theory Sources...

[15 Apr 01] I am trying to see how water waves work, mainly deep water waves. They describe a circular pattern of the water particles, and some sites mention about a slow progression of water particles as the waves pass. The sites have not been detailed enough so I am still searching. -- Gilbert Schmidt. (docscience@hotmail.com)

Response...

[15 Apr 01] There's a comprehensive treatment of ocean waves and the motion of boats in waves in *Principles of Naval Architecture* Vol. III, available from [SNAME](#). Another classic is Theory of Seakeeping by Korvin-Kroukovsky (1961), also from SNAME. If you do a web search on "polyspectra" you will find some modern material on current research. -- Tom Speer (tspeer@tspeer.com); website: <http://www.tspeer.com>; fax: +1 206 878 5269

[15 Apr 01] I would think most good general oceanography texts would provide this. I have one that has what I think is quite a good overview: *Essentials of Oceanography*, 3rd Edition, by Harold V. Thurman, Merrill Publishing Company, 1990. If you find it, "Chapter 9 - Waves" is simple and clear. Other books by Willard Bascom, B. Kinsman, and G.L. Pickard would probably give good treatments. (Bascom had an article in a 1959 issue of *Scientific American* that's good, also.) -- Bill Hockberger (w.hockberger@verizon.net)

[4 Mar 01] The clearest description of deep water waves I've seen is in *Principles of Naval Architecture* (New York: [SNAME](#), 1967, 7th Printing 1986) edited by John P. Comstock. It is in Chapter IX "The Motion of Ships in Waves" by Edward V. Lewis, in particular Section 1 "Ocean Waves." I would guess that this, or a later edition, is still available through [SNAME](#). -- John S. Pattison

[4 Mar 01] Easiest rules of thumb (theory notwithstanding): 1. Wave pitch is 20X wave height. 2. No significant wave action below 2 wave heights. -- Kobitz, Nat (KobitzN@ctc.com)

Foil Design Code...

[4 Jan 01] The XFOIL airfoil design/analysis code has been recently placed in the public domain. It can be downloaded at <http://raphael.mit.edu/xfoil>. I suggest this as a link for your site. -- Mark Drela (drela@mit.edu)

Need Copy of 1994 Shanghai Conference Proceedings...

[17 Feb 01] I am looking for the following conference proceedings: International Conference for New Ship Technology into the 21st Century (NEWS-TEC'94). The conference was held on Shanghai, China in 1994. It has a few papers about the hydrofoil developments in China. The

Office of Naval Research (ONR) had a copy which they tell me they destroyed?! Can you suggest anybody else who would have a copy of this conference proceedings? -- Günther Migeotte (<mailto:gunther@cae.co.za>)

Response...

[18 Feb 01] You may contact The Shanghai Society of Naval Architects & Marine Engineers. Its e-mail address is ssname@uninet.com.cn. Fax: 86-21-64721270. The name of the society's secretary is Mr. Bing-Jin YE. -- Shitang Dong (stdong@online.sh.cn)

Hydrofoil Equations Needed...

[13 Oct 00] Perhaps you could help in suggesting a source for the following. I am interested in obtaining a 'cookbook' type set of 'simple' equations and/or graphs to provide basic engineering guidance for a foil placed in water moving uniformly at about 10 mph and producing a lift of about 150 lbs.. I am not looking for sophisticated mathematics or optimized configuration. It is particularly important that the all the units used be clearly defined. -- David Banks (sagamore@cvinet.com)

Fluid Dynamic Drag and Fluid Dynamic Lift...

[6 Jun 00] I notice that copies of these two out-of-print, self published books, *Fluid Dynamic Drag* by Sighard F. Hoerner (1965) and *Fluid Dynamic Lift* (1975) by Hoerner and editor Henry V. Borst (published posthumously) have gone up for auction on www.ebay.com. These remarkable technical sources cover their respective subjects pretty close to 100%. -- Barney C. Black (Please use the [BBS](#) to reply)

Responses...

[6 Jun 00] I have 1 or 2 copies of the 2nd edition, which I believe this is. I also have a copy of the 1st edition, which I contributed to, when I was at Cornell Lab. -- Nat Kobitz, (KobitzN@ctc.com)

[6 Jun 00] These excellent reference books were frequently used back in the days when we were designing hydrofoil boats. A must for designers. -- Neil Lien (nlien@inwave.com)

Planing Hull Specifications...

[5 May 00] I am a university student studying ocean engineering and I was wondering if you could assist me in gathering some information on planing hull specifications for one of my assignments. -- Daniel Lewis (31322172@students.amc.edu.au)

Response...

[5 May 00] References follow:

- Savitsky, Daniel, "Hydrodynamic Design of Planing Hulls" , Marine Technology, Vol 1, No.1, October, 1964
- DuCane, Peter, "High Speed Small Craft", Temple Press Books, London, 1964, 3rd Edition.
- Blount, D.L., "Small Craft Power Prediction", Volume 13, No.1, SNAME Transactions, 1976.
- Heller, S.R. & H. H. Jasper, "On the Structural Design of Planing Craft", Quarterly Transactions, RINA, July, 1960.
- Allen, R. G. and R.R Jones "A Simplified Method for Determining Structural Design-Limit Pressures on High Performance Marine Vehicles" Paper No. 78-754, AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, CA, April, 1978
- Spencer, J.S., "Structural Design of Aluminum Crew Boats", Marine Technology, Vol. 12, No.3, July 1975
- Silvia, P.A., "Small Craft Design: Structures", paper presented at Small Craft Engineering Symposium, University of Michigan, October 1971

-- Ken Spaulding (secretary@foils.org)

Automated Lift Formula in MS Excel...

[28 Jun 00] I have placed an Excel implementation of Konstantin Matveev's lift formula on [my web page](#). -- Harry Larsen (talaria@foils.org)

Force Model...

[23 Jan 00] I am looking for a theoretical model of the force of bearing on a supercavitating hydrofoil or the name of a French research laboratory that is working on the subject. Do you know whether there are some French ships with supercavitating hydrofoils? -- C. Gouel (cgouel@libertysurf.fr)

Porpoising Question...

[23 Oct 99] I am a Spanish student, and I have read something about porpoising, but I would like to know something more about this effect. Could you give me some information regarding porpoising phenomena? F. Blasco (rbl00003@teleline.es)

Response...

[9 Nov 99] To answer your request on information about porpoising. I assume you are interested in porpoising of planing hulls and the possible effects of hydrofoils. Porpoising of any high speed vessel usually takes place when the trim of the vessel is too high in relation to the amount of lift being generated. There are some papers available which give porpoising limits or planing hulls. A good start would be "Hydrodynamic Design of Planing Hulls" by Daniel Savitsky *Marine Technology*, Oct. 1964. I will have to look through my literature for more references. Hydrofoils can aggravate or improve the porpoising limits of a hull depending mainly on the

position and the amount of lift carried by the foils. A foil carrying a large fraction of the displacement placed quite far forward will likely result in an increase in trim for the vessel and result in earlier porpoising. A foil placed aft will improve the porpoising limits of the hull. There does not seem to be any easy way to determine what the exact effect of specific hydrofoil design will be on porpoising. Model testing remains the best way to find this out. If you can give me more information on the details of your problem, or if you have specific questions, I can be of more help. -- Günther Migeotte (gunther@cae.co.za)

[24 Dec 99] Payne and Martin did reasonably definitive analyses of porpoising in the late 70s and early 80s. Their work was published in the Journal of Ship Research. www.sname.org -- C. D. Barry (cdbarry@hotmail.com)

Calculations For Human Powered Hydrofoil...

[8 Oct 99] I am currently working on my master thesis. The aim is to develop a wing and ground and hydrofoil supported human powered water bike. And here is my question! Do you know how to calculate the spray drag of surface piercing foils and struts? Or where could I find information about these topic. -- Carsten Lehfeld (lehfeld@cadlab.tu-berlin.de)

Response...

[10 Oct 99] There was an excellent report on the subject of Spray Drag of Surface-Piercing Struts. It was written by R. B. Chapman many years ago, but it is a classic paper. -- John Meyer (jmeyer@erols.com)

Flap Design for Hydrofoil-Assisted Catamaran

[8 Aug 99] I am looking for methods or examples of how to design a flap system with the mechanism for adjusting the flap angle being part of the vertical centre strut of the foil. The application would be for hydrofoil assisted catamarans. I am basically looking for conceptual ideas at present so that I have a good idea of what has been done before. The hydrofoil assisted catamarans are quite large and the foils are designed to carry 150t under dynamic load conditions so I need a system that is quite robust, and will not require much maintenance. -- Gunther Migeotte (gunther@cae.co.za) (*editor's note: Congratulations to Günther for winning the FAST'99 competition for the best student paper.*)

Response...

[8 Aug 99] Originally on the *HIGH POINT*, the hydraulic actuators for the flaps were located in the propulsion pods at the strut and foil interface. The actuator moved a crank attached to the fixed pivot shaft for the flaps. This would be a possible system for a catamaran if the foils are spanning across the two hulls. On the *HIGH POINT*, the strut/foil retraction was to lift the assembly straight up. Access to the pod was by drydocking. Thus, during modification, the actuators were relocated to within the strut, with actuator pushing an extension rod to a bell crank and then to the flap. The original concept in design was to design the forces so that the rod was always in tension to avoid bending forces and excessive bearing wear. I know that forces on

the strut measured by strain gages proved that the loads downward were as great as the lifting loads. I do not know how this affected the flap loads. Maybe Bill Buckley can elaborate in this area. As for the follow on ships using the flap system, the modified *HIGH POINT* system provided the flap actuation system. Not knowing your configuration, I shall provide one area of caution. Originally on the *HIGH POINT*, the outboard foil section flaps controlled the roll. The center section controlled lift. In certain conditions like a quartering wave, the flaps were working against each other. The automatic control system algorithms were changed to provide an aileron control. *FLAGSTAFF* and her sister ships and *PLAINVIEW* used incidence controlled foils. The actuators were located in or above the struts with a control rod down to the foil. Again, the design made sure that the attachment point was always forward of the hinge point and the cp was aft of the hinge point of the foil, to avoid rod bending. I do not know any of the details of construction nor the causes and effects on the *USS HAYES*, which is a catamaran hull with a foil across the two hulls. Original trials detected that the ship porpoised under most conditions. The problem was studied about 20 or more years ago by the Navy, and some solution was achieved. Someone might be able to enlighten us as to the cause and cure. -- Sumi Arima (arimas1@juno.com)

Response...

[8 Aug 99] Mr. Arima, Thank you for that information. This is exactly the type of information I am looking for: concepts and what kind of problems I can expect. The idea of placing the hydraulic actuators in the hull with torque rods to the flaps is good, I am going to look into that further. I was thinking along the lines of some mechanism down the vertical strut, but this is more complicated. We usually use an incidence control system on the foils to vary the lift. The foils are connected to the hull via a bearing, and a hydraulic actuator is positioned at the end of the vertical strut, giving a nice lever arm. In this application it is not possible, so a flap system is required. The system is only for lift control and not for ride control at this stage, so a single flap on each side will suffice. Concerning the *USS HAYES*, the porpoising on these type of vessels is a combination of various parameters: foil configuration and positions, foil loading, LCG, and the shape of the hull also influences things quite a bit. We have encountered similar problems in our model tests, but by adjusting foil positions and angles of attack we have always managed to solve the problem for the desired speed range. It is often a trade off between stability of some kind (porpoising, directional stability etc.) and resistance. The best resistance improvements with foils are usually located right at the stability limits of the vessel. So some trade off has to be made. Increased resistance for increased stability. -- Gunther Migeotte (gunther@cae.co.za)

Response...

[8 Aug 99] First of all, flap actuation (i.e. fatigue) loads were a significant consideration in the design of flap actuation systems for Navy hydrofoil ships. This was not fully realized in the beginning and as a result several failures occurred in service. In hindsight there were two factors which lead to fatigue problems. The first was the generally poor high-cycle fatigue properties of the high strength materials involved. The second one, which was the real villain, was the large number of load cycles introduced at individual flap actuators by an autopilot which responded concurrently to a large number of sensors, i.e. height, pitch angle, roll angle, several accelerometers, etc. This was especially true during rough water operation. There were several

unanticipated linkage failures during foilborne operation which got everyone's attention. Of a less critical nature were worn out control bearings that were a maintenance headache especially those on the AGEH-1. These particular bearings were very large and highly loaded because of the foil incidence control system involved. A wear problem occurred over time on other hydrofoil ships at the interface between the fixed and rotating elements of the spherical bearings employed. This was solved by using helicopter type bearings which had a ceramic coating at the interface (i.e. "Kamatics Corp. bearings"). With respect to the magnitude of steady and cyclic loads to be considered in designing a flap actuation system, I have only general suggestions to offer. The steady loads can be estimated (up to the point at which cavitation occurs) by the methodology given in *Theory of Wing Sections* by Abbott and Von Doenhoff, Section 8.8. I believe this old but classic book is still published in paperback form by Dover Publications, Inc. The cyclic loads are an other matter because they are a function of autopilot design, foil and flap configuration, and the characteristics of the rough water environments involved. If your vessel is small enough to employ solid foils and flaps in a material which has relatively good fatigue properties (such as used in marine propellers) you may only need to give special attention to the bearings and rod end fittings if used. -- Bill Buckley (wbuckley@erols.com)

Window Design For Hydrofoil Ships...

[8 Aug 99] I am working as a librarian for the Transportation Safety Board and someone here is looking for an information on hydrofoils. He wants to know if there is a standard for windows (or glass) for hydrofoils. The request is related to an accident that occurred in Lake Superior where one of the glass windows of an hydrofoil was broken by a wave. N.B. In one of your answers (taken from the International Hydrofoil Society web site) you mentioned as reference, the name of Mr. Michael Eames who worked for a Canadian naval project. Would it be possible to provide me a number/info in order to contact him? -- Sylvia Mauro, Librarian, Transportation Safety Board of Canada (Sylvia.Mauro@tsb.gc.ca)

Response...

[8 Aug 99] I have the following comments and one recommendation: I have not made any general survey of existing strength regulations for bridge and other types of windows so I have no comment specific to the inquiry about a standard for window design. I have on the other hand investigated a fair number of ship heavy weather damage incidents and can assure you that wave impact damage is the most common type of structural damage encountered in rough seas. Furthermore, I can state that naval architecture is out of touch with reality in the case of wave impact loadings, and that the design of windows to withstand wave impacts is the area most in need of appropriate design criteria. The reasons for this are not hard to understand. First there is no set of seaway criteria existing that identifies realistic (i.e. actual) seaway conditions that must be withstood. Second, such load criteria as has evolved from service experience is expressed as an "equivalent static load." In real life, the loading is dynamic, and of all components of a vessel which are subject to dynamic wave loads, windows are the most susceptible to failure because they can not absorb dynamic overloads by ductile behavior. The fact that the hydrofoil damage which occurred involved windows cannot be regarded as surprising, nor can the facetious IMO Code requirement be considered surprising either. With regard to obtaining an appropriate basis for window design I would recommend that you contact

a naval architecture firm that designs bridge windows for commercial fishing vessels. I feel sure they will recommend an impact resistant material such as Lexan and a static loading which has withstood severe service. As far as a rational design criteria is concerned only my own First Principles Methodology will suffice, and that is developmental! -- Bill Buckley (wbuckley@erols.com)

Response...

[8 Aug 99] Classification societies also specify design and test requirements for windows and portholes in their rules or guidelines for the construction of ships. Specific rules have been developed by some classification societies for high speed light craft (which cover hydrofoils also). Such rules are produced by Lloyd's Register, Det Norske Veritas (DNV) and the American Bureau of Shipping (ABS) amongst others. The relevant ABS document would be the 'Guide for Building and Classing High-Speed Craft' of which the latest revision I am aware of is February 1997. Part 3, Section 20, Sub-section 8 of the ABS guide refers to window construction and testing requirements. This section gives requirements for the fitting of strong deadlights (covers which can be fitted over the windows in the case of encountering rough weather), window framing, mounting of the glazing in the frame, window thickness requirements and the need for hose (water pressure) testing. It is too difficult to duplicate that section in this email as it contains various equations. A copy of those rules could be obtained from ABS Americas or ABS Corporate HQ at the following addresses: ABS Plaza; 16855 Northchase Drive; Houston, TX 77060 USA; Tel: (281) 877 6000; Fax: (281) 877 6001; Email: abs-amer@eagle.org; or Two World Trade Center, 106th Floor; New York, NY 10048 USA; Tel: (212) 839 5000; Fax: (212) 839 5130; Website: <http://www.eagle.org>

- The classification society rules or guidelines only apply to ships (or hydrofoils) which are built or classed by the society in question. I suspect the hydrofoil involved in the incident on Lake Superior may have been one designed in the former Soviet Union in which case it may not be easy to trace the original design requirement for the windows for that craft.
- Michael Eames died a number of years ago. The Defence Research Establishment Atlantic (DREA) in Dartmouth, Nova Scotia at which he worked is no longer involved in hydrofoil design work.

I will finish with a sobering remark: Several years ago, a pilot boat was hit by a large wave within Port Phillip Bay in Victoria, Australia. These boats are typically of a solid construction with strong bridge windows, but despite this the windows were smashed in by the wave and one of the crew on board the boat was killed as a result. Although not directly related to your inquiry, the details of this incident may still be available through the [Australian Maritime Safety Authority \(AMSA\)](#). -- Martin Grimm (seafite@alphalink.com.au)

Determining Foil Size and Profile...

[21 May 99] Hi, I am a member of the IHS and am interested in building a small, fast hydrofoil sailboat. My question is: What is the average loading per square foot (or square inch) for a

hydrofoil expected to go about 25 kts? Is there a quick formula for determining the size of the hydrofoil based on the weight of the craft and speed? -- Jim Wolbert (wolbert@att.net)

Response...

[22 May 99] I am afraid there is no quick and simple formula to settle questions of hydrofoil size and configuration. There is a great book with many design examples called the *Aero-Hydrodynamics of Sailing*. You can probably find existing boats in the same class as yours in the book and it will give you the good and bad aspects of the existing designs. Hope this helps. -- Marc Schafer (spaceboy@sgi.com)

2nd Response...

[1 Jun 99] There is also good design advice for the construction of hydrofoil sailboats in the book *Hydrofoil Sailing*, the full details of which are listed in the [IHS website bibliography](#). That book covers options for foil configurations, lift and drag estimation, forces acting on the craft while foilborne and aspects of the construction of the foils. A representative value of foil loading can be calculated for the modified Tornado Catamaran *ICARUS* described in the book. This sailboat was fitted with split surface piercing hydrofoils forward and aft. The forward (main) foils carry some 80% of the 600 lb (272kg) total weight over a vertically projected foil area of 8 square feet (0.743 square metres) during takeoff. That corresponds to 60 lbs/sqft (293 kg/m²). This craft lifted out of the water at about 10 knots. For *ICARUS*, as the speed increases the foils will rise further out of the water and the submerged foil area will reduce even though the craft weight remains the same. As such, the foil loading could increase significantly beyond the value calculated above for the takeoff speed. With too great a foil loading, you will run the risk of cavitation or ventilation of the foils. Lift generated by a hydrofoil, like an aerofoil, is dependant on a number of parameters. To accurately predict lift the following parameters should be taken into account (some of these parameters are taken into consideration in formulae provided in *Hydrofoil Sailing*):

1. Lift versus Angle of Attack characteristics of the 2D foil section adopted (such data is available in books providing data on aerofoil sections).
2. The angle of attack of the foil.
3. The submerged foil area.
4. Aspect Ratio of the submerged portion of the foils (i.e. Span divided by Chord Length).
5. The other geometric aspects of the foil including sweep, twist and taper.
6. The dihedral angle of the foil.
7. The speed of the foil.
8. The proximity of the foil to the surface of the water.
9. Downwash effects of one foil on another downstream.

The speed of 25 knots which you are aiming at is fairly high for a sailing craft. Should the drag of the foils at 25 knots be greater than the driving force available from the sails, then the targeted speed will not be achieved. Consequently, the lift generated may be insufficient to fully lift the hull out of the water.

An approach to developing a hydrofoil sailing craft is to first sketch the layout of the craft, including a 'best guess' at the possible foil configuration. The next step is to get good estimates or measurements of weights of items that will make up the craft including the crew load. If you are using an existing sailing craft design as the basis of your hydrofoil, the task of obtaining the weight details may be easier. In that case, you may also be able to establish what speeds are attainable for that type of sailboat without foils fitted. Don't expect the addition of hydrofoils to work wonders for the performance of the craft. Perhaps you could assume 10-20% additional speed beyond the hullborne speed. To get you in the right ballpark for sizing the foils, use the following formula (I have given units in metric):

$$L = 0.5 \times CL \times RHO \times A \times V^2$$

Where:

L = Lift (or the total craft weight supported by the foils) in Newtons

CL = Coefficient of Lift, say between 0.25 and 0.4

RHO = Water Density, 1025 kg/m³ in salt water

A = Total vertically projected area of submerged foils

V = Boat speed in metres per second (i.e.: speed in knots x 0.514)

Assuming that you can achieve 25 knots (V = 12.86 m/s) and you have estimated your craft weight (L) well, the only unknown parameter in the equation is the vertically projected area (A) of all the foils. Choose the foil area such that lift coefficient (CL) is in the suggested range. I hope these suggestions are helpful and don't lead to a complete failure! -- Martin Grimm (seafite@alphalink.com.au)

Foil Design For Twin Keel Sailboat - Guidance Needed...

[20 May 99] I am writing to ask for assistance in locating specific design information on underwater foils. I am doing a concept design of a twin keeled sailboat for which I would like to find lift and drag coefficients for a symmetrical cross section foil. I am a retired Livermoore engineer moderately capable in stress and vibration but weak in hydrodynamics. I am, e.g., ignorant as to how the shape of such symmetrical foils are characterized, i.e., by tabular values, by equation, or even perhaps by a NACA airfoil identification number. Of particular interest is the effect of aspect ratio, i.e., how the lift and drag parameters of a single keel compare to the ones for a double keel of half the chord and proportionally reduced cross section but of the same span or draft. That is, of double keel of the same wetted area as a conventional single one. Regarding the lift and drag coefficients, I have assumed that for the probable small angle of attack of a keel, the lift to drag ratio remains relatively constant for small changes in the angle. Here again however, unlike to angle of attack assumption, my ignorance is large. In thinking about the problem I have wondered if perhaps relevant information on the design parameters of the foils used for lifting high speed power or sailing craft out of the water might apply. Perhaps the such underwater horizontal foils are unsymmetrical as might also be the case for the self

leveling vee type. But maybe their parameters are sufficiently close to those of symmetrical ones that this might be a good place for me to start. In the off chance that there might be a textbook in print on foil design, I would be happy to purchase it if you know of such. Published papers, or perhaps Master or Doctors theses might also be available. Or even Internet items of your Association. Or, as is likely, something that I am unaware of. Thank you in advance for whatever help you can provide without being too much of a demand on your time of patience. If the mathematics of my pipe dream are encouraging, I would be happy to share the idea with you. If at even greater odds there might come to be a prototype, I'd invite you for a sail somewhere in the San Francisco Bay area if it were not for the fact that I am semi-invalided with rheumatoid arthritis and occupy my spare moments now with thinking about sailing rather than actually doing it. -- Jerry B. Cain (jerrybonline@thegrid.net)

Response...

[29 May 99] I can't help at all with the twin keel arrangements, but the single keel will act very much like a wing of twice the aspect ratio. A wing has drag of two types, form drag and induced drag. The form drag comes from the shape of the wing. The induced drag is caused by the energy lost to vortices at the wing tip as the fluid moves from the high pressure area on one face to the low pressure area on the other face. The induced drag increases as the square of the coefficient of lift. The equation is $C_{di} = (1 + \delta) \times C_l^2 / (\pi \times AR)$ Where C_{di} is the induced drag coefficient, C_l is the lift coefficient, and π is 3.1415. AR is the aspect ratio. δ is dependent on the wing shape. An elliptical wing has $\delta = 0$ and will be of the order of 0.1 for a rectangular wing. The actual lift will be $C_l \times \text{area} \times \text{dynamic pressure}$ the actual drag will be $(C_{df} + C_{dl}) \times \text{area} \times \text{dynamic pressure}$ The dynamic pressure is $\text{speed}^2 \times \text{density} \times 0.5$. A symmetrical aerofoil section, with thickness 12% of chord will give a form drag coefficient of 0.007 at zero angle of attack. At 5 degrees the lift coefficient is 0.6 and the form drag is 0.01. I use a program called Panda, from Desktop Aeronautics Inc. to calculate these. -- Malin Dixon (gallery@foils.org)

2nd Response...

[1 Jun 99] First of all, I should warn you that all my hydrofoil experience is limited to what I have read rather than practised! Your concept design for a twin keel sailboat sounds very interesting. I believe the challengers for the most recent Americas Cup yacht race had used twin keels. If I recall correctly, twin in line skegs were fitted to both an Australian and New Zealand bid. In any case, I seem to recollect hearing that it was a little challenging to handle this arrangement. Perhaps you can try to establish the details of those entries?

To answer your questions as best as I can:

2D foil section shapes can be defined by both methods you have anticipated. Applied mathematicians and hydrodynamicists take joy in transforming the equation of a circle into equations for representative airfoil shapes as it is possible to calculate the lift on such 'transformed' 2D sections using purely theoretical methods. Tabular descriptions of foil shapes are however more common. A good review of 2D foil sections and their characteristics is provided in *Theory of Wing Sections* by Abbott and Von Doenhoff. When a foil section is described in a tabular format, the normal convention is to define a baseline through the leading

edge (at the furthest most forward point) and trailing edge of the foil section. At a relatively uniform spacing from the leading edge to the trailing edge, but more finely defined in the first 30% of the chord length, the distance of the upper surface and lower surfaces of the foil section away from the baseline are specified. All data is given as a fraction or percentage of the chord length of the foil so that it can be scaled to any size of foil. In addition to this description, the radius of curvature of the leading edge is also provided as a proportion of the chord length. For the symmetrical section foils as you are interested in, the distance of the upper and lower surface of the foil away from the baseline are equal so only one distance needs to be quoted. A foil section shape commonly used for ship's rudders, fin stabilisers and the like is the NACA 0015. I have used this to demonstrate the tabular definition of a foil section shape:

'x' is the distance from the leading edge of the foil section as a percentage of its chord length. 'y' is the distance from the surface of the foil away from the baseline at the corresponding 'x' position along the chord. Once again, 'y' is given as a percentage of the chord length.

(x , y) -- (0.0, 0.000), (1.25, 2.367), (2.5, 3.268), (5.0, 4.443), (7.5, 5.250), (10, 5.853), (15, 6.682), (20, 7.172), (25, 7.427), (30, 7.502), (40, 7.254), (50, 6.617), (60, 5.704), (70, 4.580), (80, 3.279), (90, 1.810), (95, 1.008), (100, 0.158)

For this section, the leading edge radius is 2.48% of the chord length. The designation given to NACA foil sections has a pattern, but the full details are best obtained from reading books such as *Theory of Wing Sections*. A simple subset to illustrate the sequence is those with a number starting with '00'. These are symmetrical sections where only the thickness to chord ratio (t/c) has been varied. In that series, the final two digits represent the thickness to chord ratio as a percentage, so for the NACA 0015 section, the thickness is 15% of the chord. The thickness is the widest point on the foil section. From the table above, it can be seen that the maximum thickness on the section occurs at 30% of the chord length behind the leading edge. At that point the distance of one surface away from the baseline (or in this case also the centreline) is 7.502% of chord length. The total thickness is double this amount, ie about 15%. A typical sailing boat keel section would probably have a thinner foil section unless it is also used for ballast purposes.

All the above points concerned the 2D section profile of a foil when end on. When you make reference to the Aspect Ratio of the foil, you are moving onto 3D aspects of hydrofoils or aerofoils (wings). As you are apparently aware, the Aspect Ratio is one element of describing the planform of a hydrofoil, ie its shape when viewed from above. The aspect ratio of a foil is defined as its span divided by its average chord. A word of caution here: most equations for lift and drag refer to the effective aspect ratio which is based on the effective span of the foil. If you have a foil attached to a wall, like say a rudder or keel below the hull of a yacht but in close contact with it, then its effective span is twice the geometric or physical span of the foil. The wall, or hull of the yacht in this example, acts like an image plane. Due to the presence of the hull, water flows over the real keel or rudder as if it was attached to a mirror image of itself. This is because no water can flow through the hull surface unlike at the tip of the keel where a tip vortex is created.

All other parameters remaining the same, a high aspect ratio is good for achieving a high lift to drag ratio. The best illustrations of this are the long narrow wings which are fitted to modern

gliders. The aspect ratio of the wings of such gliders are in the range of 30 to 40 for high performance types and their shallow glide slope is a direct indication of their lift to drag ratio. Compare that to the inefficient stumpy wings of a fighter aircraft, good for their intended purpose, but lousy if you want efficiency!

Extending this to your sailboat, a single keel of say 1.0 metre geometric span and 1.0 metre chord (aspect ratio of 2 if the underside of the hull can be considered as a continuous wall) would have a lower lift to drag ratio than two keels each with a 1.0 metre geometric span and 0.5 metre chord (each having an aspect ratio of 4), even though the planform area is the same.

There is a down side... Regardless of whether you place the keels side by side or in line with one another, the combined lift to drag ratio will be degraded somewhat compared to that of two keel considered in isolation. This is because the keels will cause a downwash on one another. The degradation in lift to drag ratio will depend on the separation you are able to achieve between the keels. As an example, the lift and drag ratio on biplanes is still affected by the interaction between the upper and lower wings despite their spacing. I think that side by side keels may be preferable from a point of view of giving more predictable handling characteristics for the boat.

Regarding the lift to drag ratio, this does not remain very constant, even at small angles. For symmetric foils of high aspect ratio, the lift varies fairly linearly with increasing angle of attack starting at zero lift for zero angle of attack. The drag on the other hand is already non zero at zero angle of attack due to skin friction and profile drag and then increases roughly in proportion to the square of the angle of attack. Consequently, the lift to drag ratio is zero at zero angle of attack then rapidly climbs to its maximum value at angles of attack of as little as 3-4 degrees before falling again as the drag rapidly increases with further increases in angle of attack.

So, you can see that you need to achieve a fine balance if you want to develop an efficient sailboat!

Most text books on aeronautical engineering will give you the information you need to help with most aspects of the keel design for your concept (except perhaps the interaction between both keels as the angle of attack changes). If both keels are side by side, the text books should even provide you with a method of allowing for the so called 'biplane effect' described previously. All you need to do is exchange the density of air (about 1.223 kg per cubic metre) with the density of water (about 1025 kg per cubic metre in salt water) in the formulae that are provided. Another relevant source of information would be a naval architecture textbook, say *Principles of Naval Architecture* published by the Society of Naval Architects and Marine Engineers. This provides good guidance on the lift and drag to be expected from relatively low aspect ratio rudders. The equations in that text book can be converted to spreadsheet format without undue difficulty and this makes the calculation process quicker and easier. -- Martin Grimm (seaflyte@alphalink.com.au)

Follow-up Questions...

[7 Jun 99] Does the profile drag coefficient term remain substantially at .007 over the likely ranges of angle of attack and boat velocity? Secondly, does the apparent double aspect ratio of

the keel due to the wall effect still obtain if the keel is at an angle to the hull rather than being perpendicular? -- Jerry B. Cain (jerrybonline@thegrid.net)

The Race...

[27 Apr 99] We are currently designing three 9' horizontal foils for my 60' long and 59' wide 15.000# trimaran with 3,000 sq. ft. of sail. (ex Ker Kadelac) They are being designed to swing aft and up in case of collision. Would appreciate info from anyone experienced with this type of application. Also, interviewing ambitious students willing to get their hands dirty. -- Peter Murray tel.1.561.708.7008; fax..219.2270; (therace2000@hotmail.com)

Student Wants Info...

[3 Apr 99] I'm a French mechanical engineering student and I'm searching for some information about hydrofoil design (theory and design). Can you give some more information about the subject ? (web site, books, etc.) -- Cédric Kuchler (Cedric.Kuchler@ismcm-cesti.fr)

A Good Book...

[31 Dec 98] As a much younger armchair participant, fueled by my dad's experiments in submerged hulls, 'bulbous bows' (way before they showed up on Japanese tankers !), and solid airfoil/wingfoil sails, I read a great book *Sailing Hydrofoils* by James Grogono and two of his associates. David's experiments and accomplishments were mentioned several times - he DID it, not just wrote about it. Thanks for the vicarious moments, David! - Eric Wuolle (eric.wuolle@home.com)

Response...

[6 Jan 99] For those who are interested in sailing hydrofoils, and who want some good design guidance and a review of some of the craft that had been built by the early 1970s, the full details of the book to which Eric referred are: *Hydrofoil Sailing*; Alan J. Alexander, James L. Grogono and Donald J. Nigg; published in Great Britain in 1972 by Juanita Kalerghi ISBN 0 903238 00 4. The book covers the full range of design considerations for hydrofoil sailboats in an easy to read format. -- Martin Grimm (seafite@alphalink.com.au)

Micro-hydraulics...

[31 Aug 98] I Am VERY interested in micro-hydraulics. Do you know who has info? -- Nat Kobitz (Hynat@aol.com)

Seaplane Applications...

[20 Jun 98] I am looking for a simple equation to estimate lift and drag for a submerged hydrofoil and possibly one to determine lift and drag as the foil lifts out of, and finally off, the water. This is for a seaplane application. For example: Coefficients of lift and draft as a function

of aspect ratio, angle of attack, and velocity. I would be very pleased to get some links or other references to tests or research related to this application. -- Tom Croswell

Response...

[8 Jan 99] There is some good guidance on estimating lift and drag of hydrofoils for preliminary design purposes in the following reference: [Eames, M.C.](#), "Principles of Hydrofoils" in the book *HIGH-SPEED SMALL CRAFT* by Peter Du Cane, David and Charles (Holdings) Limited, Devon, 1974, Fourth Edition, Chapter 3, pp 12-54. This chapter of the book was written by a man who really understood hydrofoil design as he was deeply involved in the Canadian naval hydrofoil project which led to the construction of [FHE-400 BRAS d'OR](#). [Michael Eames](#) has presented his notes in a way that can be digested with relative ease. With the exception of the influence of the water surface and of cavitation, the lift and drag of a hydrofoil can essentially be determined using the same principles as applied for aircraft wings. There are many aeronautical engineering texts which provide such information. -- Martin Grimm (seafite@alphalink.com.au)

Read a Good Book Lately?

[16 Jul 97] I'm becoming very interested in boat foils as in my previous interests, gliding and building of composite structures, there seems an obvious similarity to boat foils. Also I'm fed up going everywhere at 8 knots in the Sigma 33 I presently crew on. Can you recommend any good semi technical books on the subject to familiarize myself better with the problems of foils. It would seem to me that aircraft technologies should be pretty similar but we perhaps don't need such big surface areas. -- Wayne Richards (e.w@virgin.net).

Response...

[5 Nov 97] According to veteran IHS member Sumi Arima (arimas1@juno.com): In answer to your question on text books, there is no one good book on foils. Most of the hydro types use Horner's books *Fluid Dynamic Lift* and *Fluid Dynamic Drag*. When we bought a set, the only source was from Horner's widow. College libraries generally have it, but local libraries do not." There is also *Principles of Naval Architecture*, which is a two volume set published by the Society of Naval Architects and Marine Engineers ([SNAME](#)). IHS maintains [a list of hydrofoil-related articles and papers](#), but most are hard to find. Another suggestion, the [Amateur Yacht Research Society](#) publishes quite a few technical papers, and there is an index of titles on their site... you may see something that addresses your specific need and can contact them for a back issue of the journal containing articles in which you have interest. You should also explore the extensive technical links at the [Links for Yacht Designers](#) web site. Finally, if you have specific questions, I can try to forward them to technically oriented members that can discuss them with you. Also I can post questions on the IHS website and solicit responses from all who visit the site. -- Barney C. Black (Please use the [BBS](#) to reply)

Hull Resistance Calculator...

[25 Jul 97, updated 27 Dec 00] I have been experimenting with a hull resistance calculator, based on Joe Norwood's book (chapter 3). A draft version of this is available online at

<http://www.users.globalnet.co.uk/~fsinc/yachts/spreads/fred.htm>. I would like some feed-back from potential users, particularly from those who complained that they could not understand the book. Please send any suggestions for improvement. Does anyone have any ideas about anything else that they would like to have an on-line calculator for? -- Fiona Sinclair

(fsinc@globalnet.co.uk). Yacht Research website:

<http://www.users.globalnet.co.uk/~fsinc/yachts/>

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