International Symposium on Marine Propulsion
smp'09, Trondheim, Norway, June 2009

50 Years Rational Theory of Propulsion

Recent Results and Perspectives

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"Immediate plausibility and the agreement with the usual jargon indicate - far from being philosophical virtues - that not much progress has been achieved or will be achieved."

Paul Feyerabend: Against method. 1965.

ABSTRACT

Design, testing and evaluation of vehicles propelled in fluids, ship hull-propeller configurations in particular, are traditionally based on the naïve conception of propulsors producing thrust to overcome the resistance of the bodies to be propelled. While for more or less slender hulls this conception has been more or less sufficient for more than a century this conception is no longer adequate for more or less advanced hull adapted or even hull integrated propulsor configurations.

In view of the well known deficiencies of the traditional approach even in case of traditional hull propeller configurations the author has developed a rational theory of propulsion, essentially coherent, axiomatic systems of conventions for the rational resolution of conflicts, typically between ship owners and ship yards.

These abstract theories, clearly (to be) distinguished from their operational interpretations in terms of experimental, physical or numerical, and theoretical hydromechanics, have permitted to solve a number of fundamental problems of propulsion theory, which could not possibly have been solved following the traditional approach.

During the past fifty years of development the rational approach has paradigmatically been demonstrated in a number of different problems to offer dramatic conceptual and commercial advantages. A prominent example is the identification of scale effects in wake and thrust deduction fractions at the METEOR under service conditions from quasi-steady tests even in heavy weather taking only 30 minutes.

The latest, simplest by-product of these solutions is the evaluation of traditional speed trials without reference to any hydrodynamic and/or ship theory, to any model test results and any other prior information, as it should be in view of the transparency urgently requested by ship owners, but not satisfied by the recently adopted standard ISO 15016: 2002-06.

Keywords

Rational theory of propulsion, evaluation of steady speed trials, theory of hull-propeller interactions, evaluation of quasi-steady trials, METEOR: full-scale tests and scale effects, monitoring of powering performance in waves and ice, design and evaluation of ducted propulsors as pumps.

1 INTRODUCTION

1.1 Motivation

Based on investigations of 'unconventional' propulsors since 1959 and on results of systematic model tests with ducted propellers for seagoing vessels in 1961 the author has soon been convinced, that the deficiencies of the traditional approach could no longer be overcome in the context of the traditional framework, or as Einstein said more generally and concisely, 'that problems can never be solved by the methods which have caused them'.

Consequently the author has reconstructed the theory of ship propulsion starting from first principles, conceiving a rational theory of propulsion since 1968, explicitly since 1980, and until now has paradigmatically developed some fundamental applications to certain states of maturity over the past nearly thirty years. Though looking back at that meanwhile 'historical' development the topic of this paper is not the past, but the future.

As neither 'standard' propeller design nor 'standard' power prediction belonged to the duties of the author at VWS, the Berlin Model Basin, the development of the rational theory 'took place beside' the traditional mainstream, thus permitting to shed light on that stream and on future developments.

1.2 Meta-model

Very early the author noticed that the basic problems to be solved are not physical, not hydrodynamical problems, but conceptual problems arising in the rational resolution of conflicts between the parties concerned, typically ship owners and ship yards.

The essential result of conflict theory (e. g. Vayrynen 1991) is that conflicts can be resolved rationally only by

setting up coherent, i. e. axiomatic systems of conventions to be agreed upon by the parties, the players taking part in the game.

Coherent systems of conventions consist of basic concepts implicitly, coherently 'defined' by basic sentences, the axioms, and rules formally to define further concepts and to deduce further sentences, the 'theorems', the consequences, which 'have to be' accepted by each of the parties having agreed upon the basics and the rules of the game. This is not the place to discuss the fact, that human beings are not rational beings and are not necessarily 'honest', but try to change the rules during the game and to evade unfavorable consequences of the conventions they agreed to at the beginning.

Since Hilbert's fundamental work independent interpretations of concepts, e. g., of hull resistance and propeller advance speed, are no longer considered to be acceptable, to meet current standards of rationality. To repeat: concepts are only meaningful and to be interpreted in the context of the conventions adopted. The standard example is Euclid's definition of a point 'having no extension'. This definition is not 'meaningful' if standing alone, it requires the concept of extension, i. e. the 'whole' of geometry. The frequently heard question, not only posed by naval architects 'how do you define and/or measure this concept' indicates that the usage of axiomatic systems have not been understood.

1.3 Applications

Accordingly the abstract models, adequate for the purposes at hand, have been constructed as axiomatic systems in order to arrive efficiently at generally acceptable standards. Such abstract models are essentially standardized, hopefully adequate representation spaces for the systems under investigation permitting to identify their individual 'coordinates', their 'parameters', their properties in these spaces.

Consequently the values of the parameters are in general different in different representation spaces, by definition, and the usual simple minded requests for comparative evaluations, e.g., of trials data, are not addressing the 'real' problems under discussion. Except in trivial cases the parameters cannot be compared in a meaningful way. The same holds in case of simple minded requests for comparative designs, e. g., of ducted propulsors.

Systems of the type outlined have been set up among others for hull-propeller interactions in 1980, permitting their identification of on model and full scale, and, based on that work, more recently for the evaluation of traditional steady speed trials 1998 without reference to model test results and any other prior information, as it must be.

Such systems are not results of ad hoc 'magic' tricks or more or less 'professional fumbling but are 'model based'. Three lines of work followed by the author are clearly to be distinguished:

traditional hull-propeller configurations undergoing traditional steady trials, not requiring any reference to hydrodynamic and ship theory, but only to the principle of objectivity, Buckingham's Π-theorem;

traditional hull-propeller configurations, where hull and propeller can no longer be separated physically, but only conceptually, requiring a 'momentum based' abstract theory of hull-propeller interactions;

advanced hull-integrated propulsor configurations, where even the conceptual separation of hull and propulsor is not possible and thus the concept of interaction is no longer meaningful, requiring an 'energy based' abstract theory treating interactions implicitly.

In general propulsor hydrodynamics is embedded into hydromechanical systems theory, a subset of classical mechanics. Accordingly the aggregate balances of classical mechanics are adopted, the momentum balance and the energy balance. Additional axioms are required to 'constitute' the different special cases mentioned.

1.4 Interpretations

Concepts introduced are clearly to be distinguished from their interpretations in terms of results of hydrodynamical experiments, physical and/or numerical in accordance with the underlying models!

In all cases the work of the author has been limited to the core problems. Neither test conditions and performance nor the 'use' of the results have (yet) been subject of his scrutiny. Admittedly the use of the result is the main concern of users. But what is the use of 'useless' data, unreliable, doubtful data suffering from severe systematic errors much more disturbing than the random errors currently being 'cultivated'.

Typical 'uses' are the power predictions based on model test results (Bose, 2008) and the 'corrections' of trial results for conditions differing from those at the speed trials (Hollenbach, 2008), the 'corrections' applied following more or less crude, rather standard rules, often (still) relying on model test results etc.

Despite numerous publications of the author on innovative solutions of problems, which could not have been solved without the explicit powerful tools indicated, only few naval architects have immediately understood the simple principles and taken advantage of their potential for dramatic rationalisation of scientific and industrial research.

Even for the uninitiated this short introductory exposition leaves no doubt that the essential parts of professional solutions are the conceptual frameworks to be set up. Contrary to the opinion repeatedly expressed by colleagues systems identification is not the essential constituent of the approach. The methods of systems identification based on physical or numerical experiments are 'only' tools to be professionally applied.

1.5 Craftsmanship

Once and again the author has 'found out', not being told so, but by 'accident' or by 'inquisition', that colleagues have tried to apply the approaches proposed and claimed that these 'did not work'. And further investigations, some-

times taking years due to the 'secrecy' of the 'research', revealed the reasons, often just lack of phantasy and/or lack of professional craftsmanship.

To be specific, the craftsmanship required includes the capabilities to solve ill-conditioned systems of linear equations by singular value decomposition, to estimate spectra from truncated records using auto-regressive models, to identify systems in noisy feed-back loops using correlation with signals independent of the noise and, last but not least, to use the axiomatic approach. All of these techniques mandatory for successful applications are described in great detail in papers and lectures to be found on the website of the author.

More fundamental and serious than the lack of craftsmanship has been lack of understanding the problems to be solved and the solutions developed, not in the traditional contexts 'which have caused the problems', but by imbedding the problems into more general contexts. In any 'individual' case of 'doubt' the author has carefully and patiently answered the questions of his colleagues and explained every single step in detail. Only very small parts of the resulting vast correspondence are (yet) to be found on the website of the author.

Despite this considerable effort the traditional training of naval architects is still widely considered as perfect qualification to 'judge' the rational approaches and solutions, the latter not only proposed, but paradigmatically demonstrated in every detail to be operational in practical applications, even full scale, 'inaccessible' to the traditional approach.

1.6 Prior discussions

In order to get away from accidental information and to provide for a wide coverage of past and future developments of the rational approach the author has asked colleagues at various institutes, known to work on related problems and procedures, for short contributions concerning their experiences, positive and/or negative, using the approaches proposed and their plans along these lines (2008).

Surprisingly, hardly any formal responses, the executive summaries expected, have been received, maybe due to the 'secrecy' of the pertinent projects. A rare exception has been the response of Iannone working at INSEAN on further developments of model scale performance evaluation and full scale powering predictions for various propulsor configurations.

Very exceptional has been the invitation of the author by the Trials and Monitoring Group of MARIN at Wageningen under van den Boom for a workshop, held January 15, on the monitoring joint industry project (SPA-JIP), following up the trials joint industry project (SAT-JIP). On occasion of that workshop all questions of the author concerning applications of his rational approach at MARIN have been addressed and answered.

Though many institutes are working on related problems they are reluctant to communicate and join forces. In the 25th ITTC Propulsion Report Kerwin is quoted: 'Progress in research might well benefit from greater interaction between developers of different approaches.'

1.7 Limitations

The problem of this paper is to introduce within the limits of eight pages to be presented in twenty minutes the results and further perspectives of fifty years of advanced research into various aspects and problems of ship propulsion in the spirit of the motto by Feyerabend. In view of the limitations the initial idea to provide a short tutorial of all the various applications so far had to be abandoned. Even exceeding the limits the basic ideas can only be crudely sketched, adequately and efficiently only in a language by necessity differing from the traditional jargon. The underlying hierarchy of meta-theories can neither be assumed to be known nor be referred to in further detail.

The way chosen to solve this problem is to limit the exposition to the fundamental ideas and to recent work, projects and discussions and to refer to papers, presentations, numerical studies in the Mathcad environment as well as formal discussions and informal correspondence published elsewhere and since 1990 available on the website of the author via hyperlinks. Hopefully in the near future all papers of the author will be readily accessible that way.

1.8 References

Further, as a matter of efficiency, the paper and its presentation, are conceived to complement each other. The handouts of the latter, twenty-four slides on four pages will be published together with the paper on the website of the author, which provides among others complete references to work of the author not only concerning problems of propulsion and will be archived permanently at the Deutsche Nationalbibliothek at Leipzig in accordance with the DNB Law of July 22, 2006.

The website covers 'General subjects', 'Mechanics in general', 'Motions of vehicles', 'Propulsion in general', 'Ducted propulsors' and 'Various materials' in sections 'Recent additions', 'Papers annotated' and 'Bibliographies', and further 'Terms of usage', 'Letters (yet) unanswered', 'Fields of research', 'Biography of the author' and 'Useful links'.

Only very few items of the material can be referred to in detail and can be listed in the REFERENCES, among them some recent survey papers (2003, 2005, 2006) and discussions (2007, 2009). The chapter 'Propulsion mechanics' in 'Classical mechanics reconstructed', the opus magnum of the author to be published early in 2009, provides a detailed survey of the essentials in the context of mechanics in general and is also to be found on his website.

Often the only reference to the work of the author is that to the meanwhile 'historical' Proceedings of the 2nd INTERACTION Berlin '91 without recognition of the conceptual and practical solutions achieved already at that time (Muntean, 2008; Bose, 2008). Further fundamental results of work during the following twenty years, prerequisite for successful future applications, are rarely re-

ferred to, among them the calibration of propellers in the behind condition and the robust identification of wake and thrust deduction fractions, where applicable.

2 STEADY TRADITIONAL SPEED TRIALS

2.1 Some 'history'

The present paper does not follow the history of the development but starts with the most recent developments of the 'simplest' problem tackled, the evaluation of traditional steady speed trials. Only after the 'adoption' of the ISO Standard 15016: 2002-06 the problem is attracting due interest and accordingly there are more activities to be reported than in the more demanding research fields.

The whole work of the author on the rational evaluation of traditional speed trials, triggered by the Japanese ISO/CD, from April 1998 until September 2003 including the pertinent correspondence is documented in the first section under 'Papers on propulsion' on his website.

All the essentials of the solution in the spirit of the metamodel have already been outlined in the draft of 'Guidelines for the assessment of ship speed and power performance by means of speed trials' and in the cover letter to Prof. Ikehata, the convener of the ISO/TC8/SC9/ WG2 (1998). Both documents have been filed on 1998-06-23 by ISO/TC8/SC9/WG2/N28 under the title 'Prof. Schmiechen's comments to ISO/TC8/SC9/WG2/N20, Informative'. The author as a single person was not eligible to contribute a minority vote comparable to that of the Korean Standards Group.

Based on a half-sentence in his METEOR reports of 1990/91 the author has demonstrated that the Japanese ISO CD, later DIS 15016 was not only error prone, but was lacking the transparency urgently requested by ship owners, navies in particular, and lacking the precision necessary for the validation of computational 'codes'. Although he informed all bodies 'concerned' accordingly in time (1998) and told them how to circumvent the problems nobody felt 'concerned'.

Despite severe reservations of many yards ISO 15016: 2002-06, standardizing the unsatisfactory practice of our grandfathers, has been adopted after consent of most national Standards Groups. Only the Korean Group opposed the new standard, but for the wrong reason. They wanted to introduce more hydrodynamics, an even more fancy sea-keeping theory than the Japanese 'based' on shaky grounds, the crude estimates of the sea state.

A misprint in the ISO example has been clarified in a long correspondence documented on the website of the author. But only recently, during the workshop at Wageningen on January 15, 2009, he has been told that another, more important sign error has been detected and corrected in the standard. Although 'everybody' knows about the interest of the author in the 'criminal case' he has not been informed and not been asked to change the exposition of his previous findings accordingly. The case will now be followed up in due course.

2.2 Rational solution

The basic problem, the identification of the unknown current flow velocity, can in fact be solved without any reference to hydrodynamic or ship theory and to model test results, propeller open water characteristic in particular, and to other prior information, as it must be, solely by reference to Buckingham's Π-theorem, in engineering jargon referred to as principle of dimensional analysis (2006).

The problem of identifying the performance at no wind and waves from traditional steady trials can be solved in two steps, by solving two sets of linear equations:

> The propeller performance in the behind condition, i. e. in the full scale wake (!), and the current velocity can be identified simultaneously by solving one set of linear equations. After the 'calibration' the propeller power characteristic in the behind condition can be used for monitoring purposes, e. g. to determine the value of current velocity from measured values of the rate of revolution and the torque.
>
> Further the power required due to the resistance in water, in wind and in waves can be identified simultaneously by solving another set of linear equations. Identifying parameters of models from observed data, even visually observed wave data, has the advantage that systematic errors in the observations are to a great extent automatically accounted for.

This very simple, but fundamental example clearly shows that the present, very involved practice according to established and standardised procedures requiring a large number of doubtful conventions, mostly tacitly implied according to the state of the art in naval architecture, is largely based on superfluous assumptions. But who likes to be told that his deeply rooted beliefs are plain 'superstition'?

2.3 Traditional approach

According to the meta-theory explained the reasons for the deficiencies of the standardised traditional approach are that the procedure is ill defined, i. e. is lacking a coherent model, and that it is lacking advanced methods of systems identification, mandatory in case of the ill conditioned problems at hand.

The analysis can be greatly improved if it is not based on obscure averages, but on the quasi-instantaneous values preferably of quasi-steady tests as described in the following, providing for variability and not suppressing all relevant information as is done in traditional steady speed tests.

As a consequence the traditional approach is error prone, leading to erroneous results even in the example provided with the ISO standard and in a test case of the German navy. The failure of the traditional method confirms a basic rule in hydromechanical experiments: If the speed through the water has not been determined correctly everything else can safely be forgotten.

Ship owners in particular have always felt the results of the traditional evaluation of speed trials to be not particu-

larly reliable and trustworthy. And this situation has not only been unsatisfactory, but found to be unacceptable as on the basis of the results contractual disputes are to be settled. Accordingly the author has timely and strongly urged on a serious discussion not only of the details, but of the fundamentals in the first place.

But only after the acceptance of ISO 15016: 2002-06 owners, yards and model basins realised that they had for incredibly long time completely neglected the evaluation of the performance of ships under service conditions. Practitioners have been left pretty much alone with the most fundamental problem of ship theory, while chairs of ship theory and recently ITTC Committees are busy with fashionable CFD codes, forgetting about the fundamental conceptual problems.

2.4 Further work necessary

Naval architects need to take the discomfort of the industry they are serving very serious and come up themselves with adequate solutions before outsiders or industry tell them what they better should do or should do better. An example is the development at Wärtsilä (Muntean, 2008).

Based on experience gained during the evaluation of further test cases, the results of which may not be published (yet) for proprietary reasons, further steps towards a rational standard have been summarized in a Memorandum published in HANSA (2006). In view of the forthcoming update of ISO 15016: 2002-06 the author strongly recommends and promotes the timely discussion. A project to that effect is presently underway at the Technical University Berlin under the guidance of Prof. Holbach.

The last data the author successfully evaluated were those of a ship with CP propeller built at a Turkish yard, the trials conducted in the Sea of Marmora. Quasi-steady propulsion tests planned and scheduled to be performed with a sister ship have been cancelled after Prof. Bavin returned from Paris to St. Petersburg.

2.5 Related developments

Finally ISO 15016: 2002-06 has been felt so unsatisfactory that MARIN at Wageningen was successful in gathering a considerable consortium of owners and yards prepared to spend money on the 'Speed Trials Analysis Joint Industry Project' (STA-JIP); MARIN report, Sept. 2005, no. 86, 16. The report published is concerned only with the 'Recommended Practice for Speed Trials', but not with the analysis of the data (Verkuyl, 2006).

"This document is made public by the group. The Recommended Analysis and the QSTAP software are for STA members only. The STA-Group consists at the moment of 26 ship owners and yards." On occasion of the workshop at Wageningen on the subsequent SPA-JIP mentioned it was only released that the 'secret' analysis method is based on rational approach of the author since his demonstration of its superiority.

Already since 1999 the rational procedure of trials evaluation has been further developed and used at HSVA by Schenzle, who has been witnessing its evolution since the early discussions at the German Standards Group NSMT 1998, immediately understood its principle and potential.

Though in the recent presentation and paper of Hollenbach (2008) the essential arguments in favour of the 'HSVA method' are in every detail, even in wording exactly the same as in the 'ISO Draft '98' of the present author (1998) Hollenbach in a letter to Wagner, in copy to the author, 'argued' that an appropriate acknowledgement of the pioneering work of the author was felt to shy away the clients addressed! The logic of this argument is felt to be far beyond the horizon of rationality the author is trying to promote.

Especially in view of the fact that for years HSVA had already been relying on the rational approach the statement of the ITTC Committee on Trials and Monitoring in the Report to the 24th ITTC concerning these matters is particularly ridiculous. The report of the Specialist Committee on Speed and Powering Trials provides a comparison of all trials codes currently in use (2006). The method proposed has been considered as 'a category by itself. It does not really follow the same format as all the other methods and hence was not used in the comparison of factors reviewed in each method.'

The Committee missed to note that the work of the author purposely does not follow the same format! According to his experience and to the ISO example the problem is not so much to analyse random errors of the traditional approach, but the dominant problem is still to avoid its conceptual and systematic errors not mentioned by the Committee.

In the recent Report to the 25th ITTC (2008) the conceptual problems of trials evaluation are no longer dealt with although many establishments are working on the problems, some 'secretly' as has been mentioned. Instead, one finds a large number of studies concerned with the application of CFD methods.

2.6 Other procedures, tests

Shortly after the author retired from VWS a research project has been carried out at VWS by his former colleagues Nicolaysen and Stitterich, both without experience in speed trials. Contrary to Schenzle at HSVA, in a number of personal discussions they 'refused' to follow the rational procedure, subject of the author's successful research proposal.

In accordance with their traditional training and with all pertinent 'Codes' they decided to 'rationalise' the traditional approach based on model propeller open water and interaction data. According to their report the method has not been tested under service conditions, and needs further research (Kracht, 1998). In a conversation Kracht mentioned that he has not been involved in the 'research', but has only presented the paper at Stralsund (1998).

Driven by Kappel's interest to demonstrate the merits of his propeller design comparative tests have been carried out and evaluated by Andersen (2005). In view of the in-

tricacy of such comparisons the procedures are felt not meet the required standards of objectivity.

In the recent book of Bose dedicated to powering prediction the fundamental problem of speed trials, the proof of the pudding, is mentioned neither in the table of contents nor in the subject index. While earlier there has been a strong feed back between trials and predictions at present the latter appear to be more or less 'self-contained'.

3 HULL-PROPELER INTERACTIONS

3.1 Abstract theory

Not all problems are as simple as that of trials analysis, but they rather need some sufficiently rich ship theory. Thus, e. g., the axiomatic theory of hull-propeller interactions is based on the model of ideal propulsors in ideal displacement and energy wakes.

In traditional teaching and arguing this model and its consequences are being referred to only more or less implicitly, rather cursory, while the author is using the model explicitly, e. g., deriving the thrust deduction theorem after introducing the powerful concept of the equivalent propeller outside the displacement wake due to Fresenius.

The abstract theory formalises Froude's conceptual framework for 'open' propellers behind 'slender' hulls. The axiomatic system of conventions defines a representation space adequate for the purpose at hand even if the physical separation of hulls and propellers is no longer meaningful, as in case of hull integrated propulsors, or is practically not possible, as on full scale.

Coherently defining the concepts of hull resistance and propulsor advance speed behind the hulls at the condition of self-propulsion in the context of an axiomatic system of conventions provides the only rational way to solve the basic problems at hand: to replace propeller open water and hull towing tests by conventions applicable on model and full scale in the same way. As has been explained Froude's procedure of separate tests with model (!) hulls and propellers is not meeting the current standards of rationality.

3.2 Operational interpretation

Further, performed at flow conditions very different from those at self-propulsion these tests do not only provide incoherent, 'useless' data for the detailed analysis of the powering performance, but, even worse, they cannot be performed with hull integrated, wake adapted propulsors and, worst of all, they cannot be performed at full scale under service conditions.

The crucial constituents of the rational interpretation of resistance and propeller advance speed are sufficiently robust axiomatic thrust deduction and wake conventions replacing hull towing and propeller open water tests, respectively.

Following some intermediate stages thrust deduction and wake fractions are finally simply postulated to be proportional to the jet efficiency, the constants representing the nominal thrust deduction and wake fractions, respectively. In case of the wake fraction the additional axiom required concerns the hydraulic efficiency, postulated to be maximal in the range of interest.

While the thrust deduction axiom has explicitly been demonstrated to be plausible on theoretical grounds, closely resembling the global approximation of the thrust deduction theorem, the plausibility of the wake axiom has not yet been demonstrated in comparable theoretical depth.

3.3 Merits of different propulsors

Triggered by his paper on the rational evaluation of ducted propulsors in open water (2007/2009) and by the consideration of Sistemar's CLT Propellers according to the design of Gomez (Gennaro, 2008) the author, during the preparation of this manuscript, felt the necessity to revise his 'instinctive beliefs' concerning the objective comparison of the merits of different propulsor configurations.

In case of propulsors in open water the ratio of the actual propulsive efficiency and of the ideal or jet efficiency, the hydraulic or pump efficiency, has been proposed as objective measure of merit. But the author has 'never' appropriately questioned and scrutinized the definition of the jet efficiency fundamental for the determination of thrust deduction and wake fractions.

In case of 'open' propellers the jet efficiency has naively been based on the thrust loading of the propeller in the same way as in case of the ideal propulsors producing ideal jets. As long as only open propellers are compared, this procedure is adequate in view of the axial vorticity in the jet, but *in general* it is felt to be inadequate.

In terms of pump theory only propellers with the same flow rate and the same power can be compared. The same condition has been observed earlier to define equivalent propulsors in the theory of hull-propeller interactions and to arrive, among others, at the thrust deduction theorem.

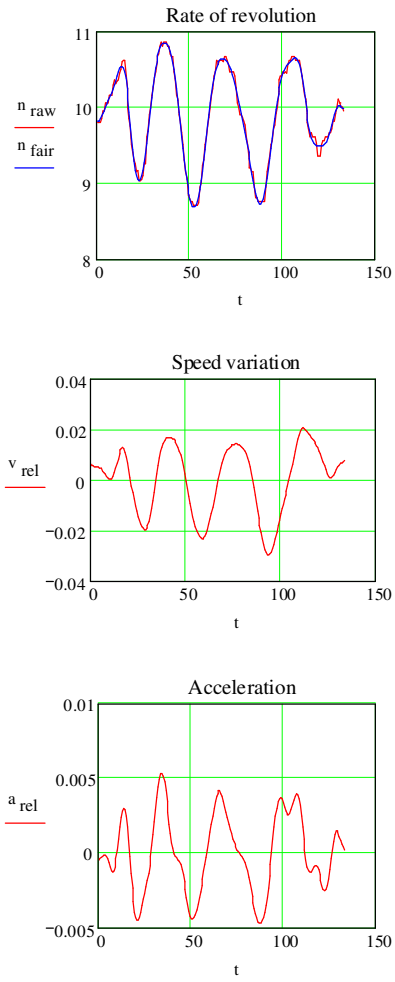
Accordingly a procedure based on power or energy flow permitting an objective evaluation of the merits of propulsor configurations with stators has been conceived and tested numerically (2009). In general only the area, the rate of revolution and the thrust of the 'rotor' are available as data and accordingly the rotor has to be 'calibrated' as flow-meter. This can be achieved ideally by assuming constant axial velocity before and behind the rotor and by assuming a potential vortex leaving the rotor and hence the corresponding tangential velocities behind the rotor.

4 QUASI-STEADY TRIALS: MODEL SCALE

4.1 The 'model' test

Model testing is primarily performed for the purposes of full scale powering prediction. This is the reason, that the identification of the model performance and the scaling problem are not always cleanly separated. Else the announcement of the book by Bose could not possibly have started with the sentence: "The ship resistance problem is approached from the point of view of powering prediction." (2009).

The widely felt deficiencies of Froude's method of separate hull towing and propeller open water tests have lead to an increased interest in the evaluation of load varying and quasi-steady self-propulsion tests alone. The latter tests have been promoted by the author since his first paper of 1980. They culminated in the METEOR tests in the Arctic Sea (1988) and in the 'final' evaluation (2008) of a 'model' test of 1987, preceding the METEOR tests, in order to demonstrate the feasibility of the latter.



The coherent model and the coherent set of data recorded during the quasisteady 'model' test of only two minutes duration permitted to identify coherent interaction data in a wide range of propeller advance ratios.

The rate of revolution of about 10 Hz had been changed randomly in the range of about 10 % at the carriage speed of 1.34 m/s resulting in changes of speed and acceleration in the ranges of only about 0.02 m/s and 0.005 m/s^2, respectively, 'derived' from the surge measured relative to the accompanying towing carriage. Due to resulting changes in model trim accelerometers cannot be used without due corrections, hardly to be determined with the precision necessary.

The evaluation of the quasi-steady 'model' test has been rigorously scrutinized by Wagner and again been updated by the author in 2007 and 2008, all the details of the analysis to be found on the website of the author. The last detailed studies revealed that the former evaluations happened to be correct 'only by accident'. In general the axiom of maximum hydraulic efficiency in the range of operation considered, essentially a 'hypothesis' adopted to arrive at a simple and robust procedure, is not 'automatically' met, but the condition has to be provided for by appropriate selection of the speed range evaluated.

The results have been compared with those of the traditional evaluation based on hull towing and propeller open water tests. In case of the rather slender hull form tested the agreement of the results is very close. Although in principle this agreement is not to be expected and not necessary, as mentioned in the introduction, the close agreement is definitely a very 'practical' requirement in view of the vast experience accumulated with the traditional method.

The technological and commercial advantages of the procedure, not even requiring a towing carriage but just radio controlled models, are evident provided one is not totally blind on both eyes. Extended experimental studies necessary for the validation of flow codes and/or optimizations can thus be performed very quickly, very cheaply and, last but not least, most reliably over wide ranges of operational parameters.

The important point here is that the quasi-steady propulsion tests cannot only be performed on model scale but on full scale as well, thus permitting to identify scale effects experimentally. Such tests have been performed with METEOR and her model results to be shown in the next chapter.

4.2 Related developments

As has been mentioned the author himself has not been concerned with powering prediction, but the work of his former colleague Kracht at VWS (1998/99) as well as the work of Iannone at INSEAN (2003) are closely related to his ideas and to the work of Jan Holtrop at MARIN and of Bose now at the Australian Maritime Hydrodynamics Research Centre at the University of Tasmania.

The method of quasi-steady overload testing developed by Holtrop and his colleagues at MARIN is not yet fully operational. In a former discussion the author has been wondering how the inertial effects were treated and suggested his method of quasi-steady propulsion testing. Only at the recent workshop at Wageningen he was informed that a captive test technique is under development. Contrary to tests with freely moving models captive testing suffers from severe noise problems, and, worst of all, it is not applicable full scale.

To the 'knowledge' of the author his method of quasi-steady model self-propulsion tests is currently being studied for application at the SVA Potsdam. On repeated requests neither a confirmation of this 'rumour' has been obtained nor any information on the state and results of the project so far.

In the present context the book on 'Marine Powering Prediction And Propulsors' by Bose is of interest, recently

published by SNAME (2008). In the announcement it is noted (2009): "The ship resistance problem is approached from the point of view of powering prediction. Model testing, including resistance, propulsor open water and *self propulsion load varying tests,* are described together with model to ship extrapolation methods. *Methods of ship powering extrapolation using data from self propulsion load-varying tests only are described*."

On inspection of the text the coverage of the latter subject is felt not to be up to date. Quasi-steady testing on model and full scale has reached a state of maturity since 1990 as documented in numerous publications. The latest scrutiny and revision of the model procedure has taken place in mid 2008 as mentioned before.

Based on his work on systems identification at MIT (1968/9) the author has developed quasi-steady testing in manoeuvring and propulsion at VWS, the Berlin Model Basin, not only to reduce testing time, but to increase the precision of the data necessary for the reliable determination of differences in performance due to small differences in geometry, load conditions and/or operational conditions of models and ships investigated.

Remarkable tests of this type have been performed in the towing tank of VWS to establish the dynamic stability of high speed craft (1982, 1984) and in the large free surface cavitation tunnel UT2 to establish the forward foil performance of the Boeing Jet Foil (1980) and the performance of two series of sail boat designs (1993).

5 QUASI-STEADY TRIALS: FULL SCALE

5.1 METEOR project

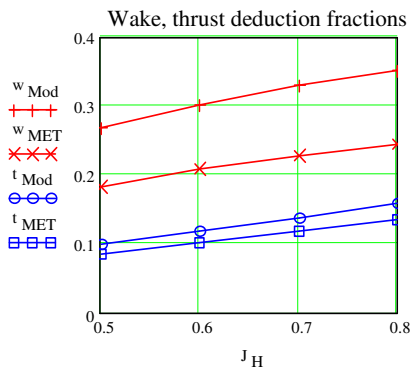
In order to demonstrate the applicability of the technique full scale, even in 'adverse' weather conditions, in heavy seas, quasi-steady propulsion tests have been performed with the German research vessel METEOR in the Arctic Sea between Spitzbergen and Greenland already in November 1988.

Thus, world wide for the first time ever, scale effects in wake and thrust deduction fractions have been determined experimentally by comparing model and full scale results obtained according to the same experimental and analysis methods. Neither theoretical considerations nor the experimental results support the traditional 'axiom' that 'there is practically no scale effect in the thrust deduction fraction'.

The methods and the results have been discussed at the 2nd Interaction Berlin '91 with the ITTC Powering Performance Committee attending. The complete Proceedings are to be found on the website of the author.

The METEOR tests, re-evaluated 2002, are the spectacular triumph of Horn's vision of propulsion tests evaluated without reference to model hull towing and model propeller open water tests. Horn's early attempts in 1935 (ITTC 1937) to overcome the deficiencies of Froude's method, though only concerning the wake on model scale, suffered from conceptual limitations and inadequate measuring and computing techniques in those days.

They were finally disrupted by the war and started anew with fundamental work on performance criteria (1968/70) and the axiomatic theory (1980) of the author.



From there on it took another twenty-five years of hard work to reach the present state of maturity. Although the need for full scale tests is ritually repeated so far nobody appears to have undertaken tests similar to the METEOR tests.

5.2 Thrust measurements

The complete analysis of hull-propeller interactions on full scale depends crucially not only an adequate conceptual framework but on precise measurements of torque and, additionally, of thrust, necessary for the identification of the additional parameters introduced.

To the knowledge of the author all the 'smart' proposals and expensive developments of thrust meters so far have turned out to be not routinely applicable, and worse, not sufficiently precise, lacking adequate calibrations under service loads including calibration of the cross talk of torque on the thrust signal.

In Germany a Laser based system has been developed (Krohn, 2003) and a similar system has been developed in the Netherlands by VAF for Wärtsilä (Muntean, 2008). Requests for more detailed information on routine applications have not been 'successful'. The system developed in Germany for measurements at trials has occasionally been used by FSG Flensburg; it is no longer available, 'the project being finished' (private communication).

In the METEOR project a 'shaft dynamometer' has been used, a hollow section replacing an original section of the shaft, instrumented and calibrated as a six component balance in the range of service loads. For 'routine' applications on given ships short, carefully calibrated two component shaft dynamometers should be sufficient and not expensive, if designed and ordered together with the shaft.

Another requirement instrumental for the success is to prevent systematic errors due to feed back of noise by correlating with signals in the loop independent of the noise. In the METEOR project the rate of shaft revolutions has been linearly lowered about 10 % and raised again during measurements of about 30 minutes, the amount of change randomly chosen as in the 'model' test, the long duration of a test chosen to avoid hysteresis, in hindsight too cautiously.

As has been discussed at the workshop at Wageningen there is no need for special test signals, but any change in the rate of revolution occurring during 'normal' operation will serve the purposes noise suppression during monitoring. In the project SPA-JIP of MARIN, gathering an impressive consortium interested in the problem of monitoring, not only owners and yards, but many classification societies, this technique is presently under investigation.

5.3 Related work

In a SNAME paper Abkowitz has described the use of extreme engine manoeuvres (1988). But these manoeuvres resulting in flow conditions different from those prevailing 'around' the operational conditions provide data 'by definition' not suitable for the identification of the powering performance of interest.

And these manoeuvres are certainly not practical at all. Chief Engineers will not perform such manoeuvres again and again to monitor the powering performance and Captains will not permit to perform such manoeuvres under service conditions, definitely not in 'adverse' weather.

By contrast the axiomatic model of the author published in 1980 and for the first time put into operation in 1988 to identify the powering performance of the German research vessel METEOR, requires only very moderate engine manoeuvres, which can be executed once in a while, even in severe weather, and will hardly ever be noticed by Chief Engineers.

A paper proposed on experience gained in the METEOR project for presentation at the SNAME Annual Meeting 1991 was turned down by Abkowitz not understanding what had been achieved in following Horns ideas. Admittedly, at that time the conceptual solution of the wake problem was still lacking the ultimate maturity and robustness required.

And recently a paper proposed on the 'Rational theory ... ' to be presented at the SNAME Annual Meeting 2008, was turned down with the 'argument': "that the material may not be appropriate for this forum." The question concerning another, appropriate forum was not even answered. These responses are mentioned here not to contribute to the history of science, but in view of the future. When will naval architects wake up? Hopefully before other people tell them how to solve their problems professionally!

An example is the monitoring project of Wärtsilä Netherlands (Muntean, 2008). All offers of the author to support that project since January 2007 and requests concerning information about progress of the project remained unanswered. A recent attempt to the same effect failed again, maybe because of the safety cordon of Wärtsilä.

6 WAKE ADAPTED DUCTED PROPULSORS

6.1 Propulsors are pumps

The solutions so far have been based on the naive conception of propulsors as thrusters overcoming the resistance of hulls to be propelled. In advanced hull-propulsor configurations, maybe pump jets, 'starting' with ducted propulsors, this point of view is no longer adequate.

For these configurations thrust is no longer a meaningful measure of performance and no longer a meaningful goal of design. Consequently, in this context at least, the concept of thrust has to be and can, in fact with great advantage, be ‘deleted from our intellectual inventory’ and our design procedures.

An alternative much more adequate and efficient conception is to consider propulsors as pumps feeding energy into the fluid and establishing the conditions of self-propulsion, vanishing net momentum flows into the hull-propulsor systems. And the simplest of such pumps are ducted propulsors.

Most design methods are still concerned with ducted propulsors in open water. And methods to deal with hull-propeller interactions are often very crude, to say it politely. In view of the fact, that interactions mostly take place between hulls and ducts, these methods are neither realistic nor acceptable.

6.2 Open water condition

In order to understand the operation of propulsors rational models of ideal propulsors have been outlined (1978). The latter are conceived as extended potential force fields generating vorticity only at their boundaries. If properly designed this vorticity leaves the fields as cylindrical vortex tubes.

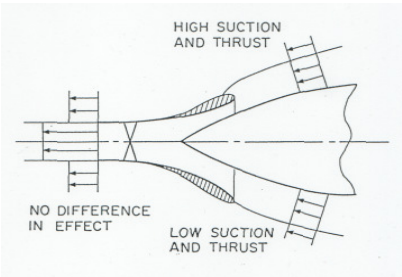
This model provides a much more 'realistic' model of a propulsor than a 'singular' actuator disc, as it does not suffer from the edge singularity studied by Sparenberg and his students. This model shows that momentum theory and vortex theory are the two sides of the same medal and that the purpose of ducts is not to provide thrust, but to avoid edge singularities and thus approach ideal propeller performance.

An absolutely fundamental result of momentum theory is that the thrust of a duct depends solely on the ratio of the appropriately defined actuator area to the fully developed jet area and not on the shape of the duct, flow separation 'of course' being avoided. Thus the higher the thrust of the

duct the higher the frictional losses at the duct and the danger of cavitation at the actuator.

6.3 Behind hull condition

Basic for the rational approach has been the fundamental observation that most interactions take place between hulls and ducts (1961). According to Bernoulli's law the additional (!) thrust at the ducts and the suction at the hulls constitute energetically neutral hydrodynamical short circuits as in case of interaction of hulls and open propellers. Thus the higher the thrust of a duct the higher the suction at the hull and the higher the frictional losses at duct and hull.



The experimental results of the author on hull-duct interaction contradicted the deeply rooted instinctive beliefs of his director and his supervisor so much that the report was not registered as VWS Report proper and banished into the basement. Although dismantled as plain superstition the deeply rooted beliefs mentioned are still popular among 'experts'.

In view of the large variety of configurations it is felt that the current academic and industrial activities to optimize ducted propulsors in open water using CFD methods are not yet facing and addressing the real problems. There is no way to proceed along the traditional approach to account efficiently for hull-propulsor interactions.

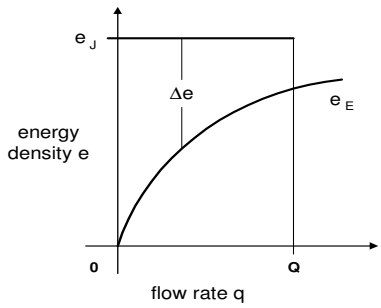
But in the Propulsion Report to the 24th ITTC 2005 it is stated: "Estimating wake and thrust deduction and understanding the influence of scale effect is also being improved by more realistic information on the flow field in and around the hull-waterjet system, …" (2005). Similar research projects are mentioned at the 25th ITTC (2008).A unified CFD-approach towards that goal has been proposed by Kerwin et al. (ITTC, 2008/85).

6.4 Design goal

Based on 'A Speculative Reconstruction' (1983) a corresponding method for the design of wake adapted ducted propellers has been proposed and tested. The method, starting from the condition of self-propulsion, of overall zero momentum flow into the system, essentially from the effective resistance and the corresponding effective thrust and net power to be fed into the flow, arrives at an invariant design goal, the required energy density, alias 'head', 'over' the flow rate.

Accordingly a wake adapted propulsor has been designed and tested as a pump including all interactions implicitly (1992). As in pump design thrust is no longer considered as measure of performance and as design goal. The method does not require any clumsy search for an optimum, but is concentrating on the essentials, design and evaluation of an optimum pump meeting the design goal implying optimum propulsion. As in pump design everything else is being dealt with in terms of energy flows and the thrust and all interactions are being treated implicitly observing the condition optimum propulsion from the beginning!

As in pump design the thrust comes in only at the end, as a 'nasty' by-product. All pumps develop thrust, although pump designers do not want to produce thrust. But they cannot avoid it and they 'finally' have to know its magnitude for the appropriate design of the bearings necessary.



At NSTL Visakhapatnam a propulsor has been successfully designed and tested according to the procedures outlined (personal communication, 2006). But research on the hull-propeller-duct interaction at the same institute has been felt not to be up to date as discussed during lectures at NSTL (2003). All attempts to stay in contact and further to cooperate with the colleagues failed because of the safety cordon around the Navy Establishment.

6.5 Prospects

In formal and informal discussions with Abdel-Maksoud and Kuiper the author has repeatedly pointed out that the problem is not to apply the tools available in the traditional context, but to understand the hydromechanical principles and take advantage of the potential the rational approach of pump design is offering. This is not 'just another' way of looking at the problem, but reducing it to the core problem.

Again all details, including two recent contributions to papers presented at annual meetings of STG (2005, 2006) and the accompanying detailed theoretical and numerical evaluation of a ducted propulsor in open water (2006/7), are to be found on the website of the author since March 2007 and are finally due to be published, hopefully in a March edition of HANSA 147 (2009).

7 CONCLUSIONS

7.1 Review

Since fifty years now the author has promoted not 'the', but only 'his' rational theory of ship propulsion, the abstract theories, representations spaces constructed for the purposes at hand, clearly distinguished from their operational interpretations. In a large number of studies and papers he has shown that the axiomatic models and the corresponding rigorous systems identification procedures

permit solutions of fundamental problems unsolved before, in fact impossible to be solved using the traditional approach.

But in order to put things into perspective, it is noted expressis verbis that the rational approach is strictly conventional as is the traditional approach, there is no other way. As has been pointed out over and over again the core problems to be solved are rational resolutions of conflicts and the appropriate tools to solve them are coherent, i. e. axiomatic systems of conventions appropriate for the problems at hand. Some of the models and rules may look pretty far fetched for naval architects but if they are duly observed a lot of unnecessary 'research' can be avoided.

In the meantime the methods developed are being promoted by Wagner in courses on propulsion held at model basins and propulsor suppliers (2006/08).

7.2 Lack of cooperation

Though the problems identified and the solutions proposed are now beginning to be acknowledged the tendency to cooperate and to arrive jointly at sound solutions, meeting generally acceptable standards, is felt to be rather low.

One reason may be the principle 'Not invented here!', still widely adhered to. The other reason is the competitive situation among the model basins and others. As methods cannot be patented advanced methods can be sold with profit only if treated 'confidentially'. A typical example is MARIN's method of trials evaluation in the SAT-Joint Industry Project.

This recent development is quite different from the early days when Tank Superintendents 'founded' ITTC to arrive jointly at solutions of the conceptual and procedural problems faced by the community in serving industry. Consequently some of the older gentlemen on the Executive Committee, whom the author has served as Secretary 1969/72, were strictly opposed to 'experts' and 'professors' dominating ITTC, the former concerned with 'details only', the latter, not serving clients, having 'no responsibility'.

7.3 Lack of innovation

The author is particularly impressed with the 'creative' and 'innovative' attitudes expressed by repeated questions of the type: 'Has somebody else done this before? Before I try to understand the simple ideas and take advantage of them?'

The only 'real' question is: 'If the author could solve all the fundamental problems mentioned, what can I do now and what needs to be done next?' And the simple answer is: 'Understand the simple principles and take competitive advantage of the concepts and power tools provided for the solution of other problems at hand.'

On the meta-level the pressing problems are design and evaluation of research strategies and of corresponding test techniques and construction of adequate performance criteria. In view of the models outlined even the uninitiated, or only those?, will feel that some of the current research projects may be mere waste of money.

The situation is similar to that earlier met in boundary layer research, when Hermann Schlichting decided to write his famous 'Boundary Layer Theory' with the goal to stop the waste by rationalising the 'research' on boundary layers at his time.

7.4 Acknowledgement

The author is greatly indebted to Dr.-Ing. habil. Klaus Wagner of Rostock, formerly at the VEB Dieselmotorenwerk, DDR Kombinat Schiffbau, for his unending patience in scrutinizing arguments and numerical procedures exchanged in an intense correspondence since they first met in the re-united Berlin at the author's 2nd INTERACTION Berlin '91 and particularly during the preparation of the present paper.

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State: March 08, 2009.