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School's in!

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Abstract

In courses of ship design and engineering the particulars of the profession are well-taught. However, driven by software and computer advancement, in the industry over the past decades new tools have emerged, such as optimization, geometric modelling, CFD, big data and machine learning. These tools have been considered too complex for an undergraduate program. Yet, some knowledge of this trade is essential on every professional level, and our proposition is that if the material is offered in a first-principle fashion, in combination with practical exercises and oral discussion, the heart of the matter can very well be educated to an undergraduate. Recently, a 30 EC minor was given in this fashion.

1. The tale of two misunderstandings

For the COMPIT audience we don't have to argue that the ICT revolution of the past decades has brought our profession much. Also in the society in general, the awareness and expectations in this respect are high, fed by the maturing of the global connectivity, and the expectations of Artificial Intelligence (AI). Expectations may even rise to unrealistic levels, an example being the "misconception regarding the electronic availability". This is the idea that if data is available in digital form – somewhere, somehow – then this is effortlessly consumable and usable in each and every computer program. A striking example of this misconception was shown when a client of one of the authors (a manufacturer of loading and stability software, www.sarc.nl) asked whether it would be possible to extend a loading program of another brand with scans of their ship-specific IMDG manual.

A second misconception is observed in *Koelman (2019)*, where the urgency of deeper education in advanced technologies is motivated by "Personally, I believe that there is a bit of an emergency; the older generation has the idea that young people are so skilled with computers because they grew up with them and are surrounded by them – the digital natives – but that knowledge is usually superficial. It is therefore necessary to offer training in digital engineering skills to those who are interested".

The first misunderstanding relies on the second, so to combat both, increasing the level of knowledge is sufficient. To this end, we recently rolled out a dedicated minor course. This is presented in this paper, not only with the objective to inform the Compit community, but also to identify opportunities for collaboration.

2. Place and content of the minor AETS

"Maritiem Instituut Willem Barentsz" is the maritime institute of NHL Stenden University of Applied Sciences, with four-year BSc courses in Ship Design, Master Mariner and Ocean Technology, as well as an MSc course in Marine Shipping Innovation, www.nhlstenden.com/en/miwb. The first semester of the fourth BSc year is allocated for a 30 EC (at 28 hours/EC, corresponding to 840 hours) minor. The advantages of using a minor for our ambition are a) its relatively long time span, b) its position later in the course, which makes that students have already a bit of a substantial body of skills and knowledge and c) the fact that minors are elective, so that only students with genuine interest will attend.

The minor was baptized "Advanced Engineering Tools for ShipX", where X is a placeholder for design, operation or management. Its content consists of seven courses on:

- Workable knowledge with Python, 4 EC.
- Numerical methods in engineering, 3 EC, in particular maritime applications of numerical differential equations and statistics.
- Linear programming and non-linear optimization, 3 EC.
- Data and shape modelling, 5 EC, in particular conventional regression (linear and polynomial) and ship shape modelling. As well as their interrelations.
- Hands-on experiments with computations on stationary fluid flow (with a commercial CFD package), 4 EC.
- Classification of data, and a too brief introduction into AI. Including an outlook into the normative aspects of these technologies, 5 EC.
- A research assignment of 6 EC, where the students are invited to apply the learned techniques on a maritime subject of their own liking.

The courses are taught with introductory lectures, references to relevant literature, and assignments, many assignments, which are performed in alternating groups of two or three persons. Deliverables consist of reports, working computer programs, presentations and an occasional podcast.

The governing learning strategy is where possible to minimize the use of too complicated mathematics, and to rely on elementary physical or mathematical mechanisms instead. For example, a planar moment of inertia (I) is usually educated using Steiner's theorem, which in its turn is derived by analytical integration. Our proposition is that by this detour of integration + theorem the insight into the heart of the matter is obfuscated. While the essence of I is simply the summation of every tiny piece of area multiplied by the square of its distance from centroid. Cumbersome to compute in this fashion for a human, but for a computer only a trifle. Such a ‘first principle’ approach illuminates the essence, while the use of previously derived “theorems” only obscures it.

In this sense there is an analogy with “object lessons” (Dutch “aanschouwelijk onderwijs”, German “Anschauungsunterricht”), a concept attributed to Comenius (1592-1670). Its original implementation was that in addition to language (Latin, in those days), objects or visuals may serve better for students to receive or discover ideas. The correspondence is that also in our view the language of higher mathematics is not always the best instrument to transfer knowledge. For our audience.

3. Highlights of some of the courses

Ideally, we would like to recite the minor in its entirety, but lack of space and your patience won't allow it. So, we will elucidate a few noteworthy things.

3.1 Programming, numerical methods and optimization

The aim of the Python course was to provide the students with a practically useful tool. In this respect Python is superb; it is generic, elegant, supported by a vast amount of resources (forums, books, a nice learning app; Sololearn) and a plethora of libraries with all kinds of tools and functions for mathematics, numerical analysis, text processing, file management, data analytics, AI etcetera. A funny aspect of Python is its dynamic typing, which initially hides the importance of typing. Attractive for beginners, although in somewhat more mature applications type incompatibilities and related confusions still will pop up. An illustrative example popped up with an exercise with Holtrop’s method for resistance prediction. Due to an input error one of the parameters was way out of range, and inserted into the Holtrop equations it led to a negative number being raised to a real power. Upon the resulting Python error message, the student found an alternative mathematical library, which did not tag the equation as erroneous, and gave a nice number as result. Actually two numbers, because the solution of this equation lies in the complex plane, so the ship’s resistance consisted of two components, one real and one imaginary. Would Python not be that forgiving with types, quite some confusion would have been avoided. Anyway, this is just anecdotic and a minor detail, Python is the best language for our goals.

It may be obvious that just four EC is insufficient to educate seasoned Python programmers. But that has never been the goal of this minor. Programming skills up to the level of numerical operations, functions, file I/O, simple graphs and the usage of external libraries are sufficient, for now.

Another illustration of our aim to leave out maths wherever possible is the exercise of the heave motion of a vertical cylinder. The standard textbook solution requires some mathematical skills, resulting in the well-known logarithmic decrement. However, with Newton's second law and numerical integration in small time steps the solution is also found. And not with less understanding, because that is not in the mathematical analysis, it is in internalizing F=m·a, and its power in practice. After this exercise, the student is gently reminded that the analytical solution is only valid for linear cases, while the numerical one is universal.

Another example is the way non-linear optimizations are taught. We are not talking about gradient and Hessian matrices (well, we show one slide with partial derivatives for a few seconds to illustrate there is more background than we elaborate), but try to make the algorithms palpable with the analogy of looking for the top of a mountain while standing on its flank in the fog. To paint a picture of the form of student assignments, two examples of optimization problems are presented in the appendix.

3.2 Data and shape modelling, and CFD

The data modelling part contains exercises with linear least squares regression, applied on 2D and 3D linear as well as 2D polynomial functions. A non-programming exercise was the modification of a vessel's bulb shape, with a dedicated hull shape modelling program, Fig.1. This ship was the same as subsequently used for CFD, and as an intermediate step a physical model was prepared for 3D printing, Fig 2.

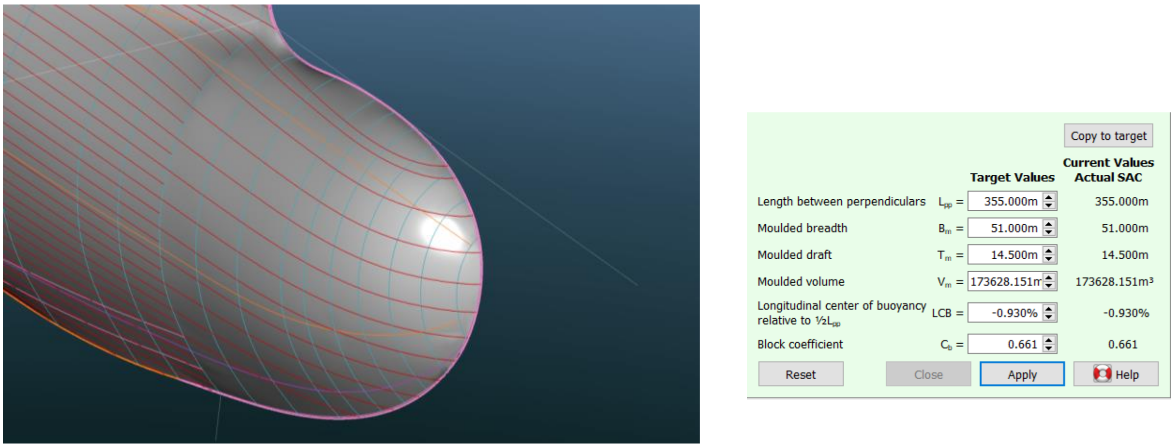

Fig.1: Bulb shape modification exercise


Fig.2: A subgroup of students proudly showing their 3D print

This CFD course gave us a bit more than three weeks to teach the very first principles of stationary flow around the hull, and the related resistance. To students with basic knowledge of fluid flow around the hull, resistance components, shallow water effects and empirical estimation methods for resistance. But without prior exposure to potential flow or Navier-Stokes. In order to teach the students a practical application, a full-blown commercial CFD program was chosen for these exercises. In this case STAR-CCM+, by Siemens. One of the reasons for this choice was the associated extensive helpdesk support as kindly offered by Femto, www.femto.eu.

With the assistance of an external tutor, www.sastech.nl, an achievable goal was formulated; that at the end of the course the student is capable, in her or his role as ship designer, to order a CFD calculation with an external specialist, and to be able to understand the reported results and conclusions in a responsible manner. Thanks to hard work of the students, in this short time span they independently managed to produce reliable results, Fig.3.

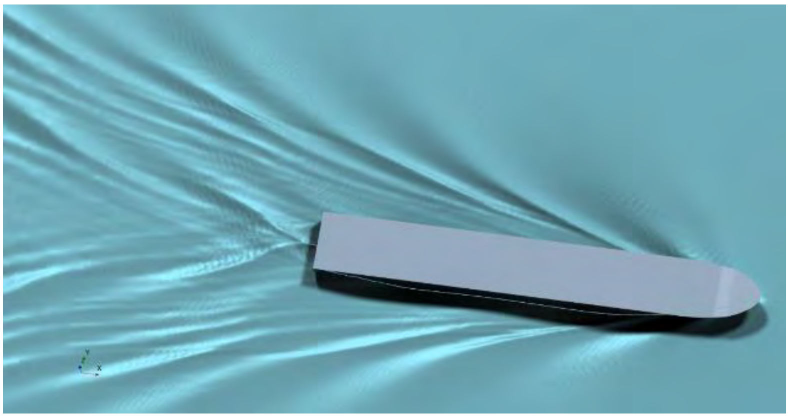

Fig.3: An example of a student's result after two weeks of CFD training and exercises.

3.3 Data science and the research assignment

The data science course changed the mood a bit. Until now the emphasis was on algorithms and programming, but here a number of speakers from the industry were invited to present their vision, developments and achievements. With the idea to build a bridge between theory and practice. Yet, this course also contains a programming assignment, or actually a match, where a (moderately polluted) database with all kinds of general particulars of 13,000 ships was supplied. The task was to learn an algorithm to derive the ship type from its particulars. The winner is the group with the highest score on a separate test set.

A single EC from the data science course has been dedicated to normative aspects of algorithms and AI. Here some papers and podcasts have been supplied, with the student's task to reflect and report, also in a Podcast, on two of the supplied propositions, from which examples are:

- There is a positive relationship between the amount of data available and the quality of the product designed with it.
- One day an autonomous sailing boat in the Rainbow class (https://regenboogclub.nl/de-regenboog/) will win a major sailing contest.
- Offensive autonomous naval vessels should be banned.
- Only when autonomous (sea, road or air) vehicle control is guaranteed to be safe it should be allowed in public.

For the research assignment each student chose an individual subject:

- Optimization of frame spacing for minimum weight.
- Machine learning system for determining causes of Engine Room alarms.

- Determining deck construction using a variable frame spacing.
- Application of Neural Networks in Ships' Autopilot settings.
- Track optimization in an Yngling sailing race.
- Optimization of ship routes in extreme waves.
- Optimization of ferry service across Amsterdam IJ.
- Application of water bags to improve stability during lifting operations.
- Analysis of trends in larger container ships.

This course was closed with a short paper and a mini-symposium.

4. Results, appreciation and the lessons learned

Looking back, we can conclude that quite some exercises have been made with reasonable success, for example:

- Heave motion in time domain.
- Cross-flooding time in case of damage (first-principle).
- Double pendulum (note www.myphysicslab.com/pendulum/double-pendulum-en.html contains a nice illustration of the phenomenon).
- Weather routing (a specimen of nonlinear optimization).
- Regression and correlation.
- Spline curves and surfaces.
- Hull shape design.
- Machine learning: ship type classification.
- The research assignment results in four of the mini papers to be published in a Dutch professional journal.

Subjects where students unintendedly spend a bit too much of their time looking for clues have been:

- In optimization, the difference between optimization goal and boundary conditions.
- A bit of installation hassle with CFD. Fortunately, with the tremendous support of the supplier and the NHL Stenden staff this was quickly resolved.
- Occasionally with the wave spectrum (which, by the way, has been taught in other courses in lecture form before).
- With the manoeuvring exercise. In hindsight the problem could be traced back to incomplete formulation of the exercise (where a rocket was intended to be at rest in vacuum in space, which was not clearly mentioned, so the students envisioned the rocket to be launched from earth under the influence of gravity, a somewhat more complicated situation).

We started the CFD course fully concentrating on the installation and operation of the CFD software package, based on the idea that basic concepts of flow and resistance have already been addressed in courses on hydrodynamics. That was a step too far, to which should be added that the Master Mariner students did not have this background anyway. So, next year's CFD course will start with some introduction on flow phenomena, consisting of e.g.:

- A lecture, presenting these subjects in a visual way ("object lessons"). Supported by some of the tons of available Youtube videos.
- An exercise with a fluid flow training tool. To this aim we will actively experiment with the program Lily Pad, as presented in *Weymouth (2015)*.
- Material from other sources or institutes. E.g. *Vaidya (2020)* provides a nice literature overview (although most of it does not relate to moving objects at the interface between two mediums).
- A Python programming assignment with 2D potential flow with a few sources and sinks, leading to (variants of) the Rankine oval. Such a task a) forms the glue between the preceding

programming exercises and CFD, while b) this is CFD in its most elementary form and thus hopefully provides some insight into its principles.

Finally, we do not want to leave unmentioned a few remarkable quotes from the student survey:

- Hold on and be patient, it's all going to be fine.
- Tip for students next year: immerse yourself in the assignments and take some time to play around with them a bit. Eventually you will come to a solution.
- The guidance and tips in the past year have been very useful, it really is a top minor. The assignments last year were sometimes unclear, but I expect that that will be adjusted. I really liked the idea of working in as many different teams as possible and I would recommend it for next year.

5. Conclusion and appeal for additional exercises

The minor AETS was recently given for the first time and was quite successful. Next year the intake restriction will be removed, and the minor will also be open to students from outside NHL Stenden. We are considering offering it as a post graduate course as well.

Finally, we would like to make an appeal to the reader. The COMPIT audience is known for its significant share of professors and lecturers, some of whom might have been involved with a similar endeavour. If you happen to have useful material – exercises, data sets, research topics, video clips etcetera – and are willing to share it, please contact the authors.

Acknowledgement

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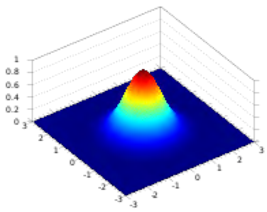
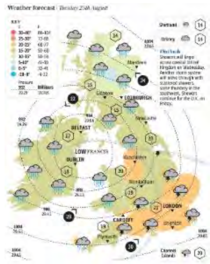
Appendix with two examples of optimization assignments

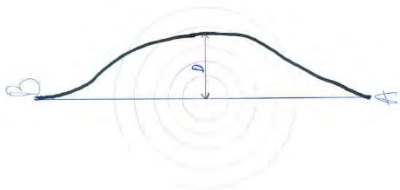
Weather routing



A ship is sailing from A to B, a distance of 3000 nm. Right in between, summer storm Francis is developing, with wind gusts to 70 mph. Wind and waves in this storm lead to speed reduction, which is modelled by a symmetrical two-dimensional Gaussian function, see https://en.wikipedia.org/wiki/Gaussian_function#Two-dimensional_Gaussian_function, as depicted at the left, with standard deviation $\sigma_x = \sigma_y = 1000$nm. The ship has a design speed of 16 knots, while the maximum speed reduction in the middle of the storm, parameter A of the Gaussian function, is 10 knots.



1. The master of the ship is inclined to smooth manoeuvering, so she chooses a cosine-like (in the interval 0 to 2π) trajectory shape, with a maximum distance D from the undisturbed trajectory. According to the sketch right. Please determine D which leads to the quickest passage through the storm.
2. This computational model is rather simplified. Please reconsider the whole aspect of ship routing, and conceptualize a more realistic model.



Fleet optimization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Optimal vessel speed and fleet size for industrial shipping services under the emission control area regulation

Dian Sheng[a,b,*], Qiang Meng[b], Zhi-Chun Li[a]

Please scan supplied paper *Optimal vessel speed and fleet size.pdf*, which contains a useful method to optimize a fleet for ECA areas. As side product this paper contains a concise formula to determine the optimal size and speed of a fleet of (equal) ships, see eqs. 1a, 1b and 1c. Regrettably, in these equations the effect of higher speed on engine wear and lubrication oil consumption is not included. In order to compensate for this effect, the last factor of eq. 1a (+ γN) is multiplied by an 'engineering coefficient' of $(0.9 + 0.1 \times v^2 / v^2_{design})$.

If this equation is applied on a fleet of ships with these consumption rates

Fuel consumption ton/day	33
Fuel consumption ton/hour	1.375
Design speed knots	18.2

and these financial data (with notations according to table 1 of the paper):

K	1000
S	6000
Ic	2
L	1200
gamma	1500000
eta2	600
D	200000
Tp	48

then determine the combination of v (sailing speed) and N (number of ships in the fleet) which minimizes AFC (Annual Fleet Costs).