Geosci. Model Dev. Discuss., 8, C4033–C4046, 2016
www.geosci-model-dev-discuss.net/8/C4033/2016/

Geoscientific Model Development Discussions Open Access EGU

Interactive comment on "VISIR-I: small vessels, least-time nautical routes using wave forecasts" *by* G. Mannarini et al.

G. Mannarini et al.

gianandrea.mannarini@cmcc.it

Received and published: 18 February 2016

General comments

The paper targets an approach to optimal routing in rough seas, considering various constraints with regard to feasibility and safety. The work seems well organized and the authors have done a good job in identifying the major issues involved as well as presented an algorithm for the solution. However, being a naval architect myself, I render the hydrodynamic ship model as presented here suitable for a 'proof of concept' study only. The assumptions considered in simplification will necessarily lead to huge deviations for real ships and thus lead to wrong results.

–Authors' response:
We thank the Referee for his/her comments, giving us the opportunity to improve the manuscript and stimulating VISIR's further development. Being open source and modular in structure, VISIR easily allows for refinements of individual model components, such as the vessel hydrodynamics. In our specific comments below, we provide an example of such customizations.
(In the following "GMDD" stands for Mannarini et al. (2015). When not specified, all other references to equations, figures, and tables are relative to the present document.)

Specific comments

A - *P7926, eq 16: The common convention in fluid dynamics is that a resistance is always a component opposite of the motion, therefore multiplication of R_{aw} with $\cos\alpha$ is not reasonable. However, R_{aw} depends on the encounter frequency, wave height, wave encounter angle (and more). The multiplication with $\cos\alpha$ would imply a "thrust force" for $\alpha = 180^o$ which is not reasonable.*

–Authors' response:
In GMDD, we used a definition of wave added resistance somewhat different from the usual one. We defined the resistance as a vector force *applied to* the vessel (P7925, row 23). The component opposite the motion mentioned by the Referee is then $R_{\text{aw}}\cos\alpha$, stemming from the dot product of ship velocity and resistance vectors (Eq.14 of GMDD). Such a quantity is not necessarily negative at $|\alpha| > 90^o$, since the $\varphi(\lambda/L, \alpha)$ factor in R_{aw} (cp. Eq.19 of GMDD) can change its sign, balancing the $\cos\alpha$ factor. (We note that, besides depending on wave encounter angle, the φ factor also

contains the dependance on wavenumber. Instead, the wave height dependence is included in the factor carrying the dimensions of a resistance in Eq. 19 of GMDD.)

However, we realize that the approach chosen for GMDD has the shortcoming of forcing $R_{\mathsf{aw}} \cos\alpha = 0$ for beam seas, corresponding indeed to the output of a few numerical models, see e.g. Grigoropoulos et al. (2000), but not always to measurements (such as those for a frigate: McTaggart (1997) and for a S175 ship: Liu and Papanikolaou (2013)), especially for short incoming waves.

For this reason, and for compliance with the convention on R_{aw} suggested by the Referee, we are going to change this part of the formalism of GMDD, as reported below in the "Authors' changes to manuscript" paragraph.

However, we point out that the numerical results of GMDD are not affected by the beam seas issue, since we neglected both the α dependence in R_{aw} (upon setting $\varphi = 1/2$, see P7928 row 3 and P7959) and its projection $R_{\mathsf{aw}} \cos\alpha$ against the direction of advance of the vessel ($\alpha = 0$ always, see P7928 row 7).

–Authors' changes to manuscript:
A1, A2, A3, A4.

A1) On P7925, row 22-25, to replace:
That is, given the brake power P, the total propulsive efficiency η and the total resistance R_{T} *applied to* the vessel, it is required that

$$\eta P = v \cdot R_{\mathsf{T}}(\vec{v}; \vec{p}_{\mathsf{s}}, \vec{p}_{\mathsf{e}}) \tag{1}$$

where v is the ship velocity in steady conditions, $\vec{p}_{\mathsf{s}}$ is a set of ship parameters, and $\vec{p}_{\mathsf{e}}$ is a set of relevant environmental field values as in Tab.6.

A2) On P7926, row 11-18, to replace:
A possible decomposition of the resulting force is to distinguish calm water resistance

R_{c} from resistance R_{aw} due to only sea waves,

$$R_{\mathsf{T}} = R_{\mathsf{c}} + R_{aw} \tag{2}$$

Each of the addends is meant as the force component opposite the motion of the vessel.

A3) On P7928, row 1, to insert:
where α is the angle between wave direction and vessel direction of advance (as seen in Fig.3, $\alpha = 0$ in case of head waves).

A4) On P7962, to replace:

Table 1. Ship and environmental parameters employed in the power balance equation Eq.4 of GMDD and in the inequalities for the safety constraints Eq. 5 of GMDD. Derived parameters such as T_{E}, $\widetilde{\sigma_{aw}}$ and $\widetilde{Fr}$ are omitted. For an explanation of symbols, see Table 8 of GMDD.

	Name of the condition		$\vec{p}_{\mathsf{s}}$						$\vec{p}_{\mathsf{e}}$				
$F_{eq}(\vec{v}; \vec{p}_{\mathsf{s}}, \vec{p}_{\mathsf{e}}) = 0$	Power balance equation		L	B	T		P_{max}	c	λ	H_{s}			α
		Parametric roll	L			T_{R}			λ	H_{s}	T_{w}		
$F_{ineq}(\vec{v}; \vec{p}_{\mathsf{s}}, \vec{p}_{\mathsf{e}}) \leq 0$	Safety constraints	Pure loss of stability	L						λ	H_{s}	T_{w}	θ_{w}	
		Surfriding/Broaching-to	L						λ	H_{s}		θ_{w}	

B - *P7927, eq 18: Taking C_T as constant is a very crude approximation as this will neglect all effects of wave making (C_R) which especially for smaller sized vessels (as proposed here) has a significant value and changes the resistance curve to be more like a polynomial of the order of 3 or 4 rather than 2 as proposed here. There are various simplified calculation methods available that (even though not being exact) at least consider the general trend of the resistance more appropriately. Please check for Holtrop & von Mennen for a "standard procedure" which perhaps would be better* *suited for a proof of concept study.*

–Authors' response:
We agree with the Referee that a hydrodynamic drag coefficient C_T, including (at least) the residual resistance and the friction coefficient, is not a constant with respect to ship speed. We were aware of this effect at the time we wrote GMDD, citing the Froude decomposition (P7927, rows 1-5) and qualitatively estimating the impact of taking C_T as a constant (P7927, rows 11-12). However, the reason we went into such an approximation is twofold:

i) we wanted VISIR to be run without specifying too many parameters, which may be unknown even to the vessel operator. For instance, the proposed statistical method by Holtrop (1984) (suggesting an exponential dependance of the wave making resistance on the Froude number) involves 12 geometrical parameters of the hull (draught T, forward draught T_F, beam B, waterline length L, longitudinal centre buoyancy lcb, length of the run L_R, displacement ∇, midship coefficient C_M, prismatic coefficient C_P, waterplane area coefficient C_{WP}, transverse area above the keel line A_{BT}, position of the centre of transverse area h_{BT}). In contrast, VISIR-I just employs 3 structural parameters (waterline length L, beam B, draught T).

ii) we too think that specifying a parametrization of C_T out of a statistical reanalysis of measured data may still imply significant inaccuracies, as stated by the Referee. Indeed, as optimization studies demonstrate (Peri et al., 2001), substantial improvements in vessel performances can be achieved through some minor changes to the hull shape, while keeping constant the principal hull parameters. Hence, it is believed that the most reliable way to account for all the aspects of calm water resistance (both frictional and residual) and added resistance in waves would be to use towing tank data *for the specific hull geometry*, properly transformed to account for scaling effects. This was also suggested in the conclusions of GMDD (P7947, rows 14-16).

We also point out that a constant C_T, identified in the top speed regime, does not imply neglecting all effects of wave making, but rather overestimating them (GMDD, P7927, row 12).

However, in order to numerically evaluate the impact of the assumption of a constant C_T done in Sect.2.3.2, following the comments by the Referee we have performed an extensive sensitivity test, reported in the "Authors' changes to manuscript" section below. The main conclusion of that study is that, while a polynomial behaviour of C_T will shorten the duration of the routes by a few percent - and could be considered for the next version of VISIR - the initial approximation of a constant C_T does not lead to dramatically different results.

–Authors' changes to manuscript:
B1, B2.

B1) On P7927, row 4, to add:
"It is our aim that VISIR-I runs without specifying too many vessels parameters. For instance, the statistical method by Holtrop (1984) involves 12 geometrical parameters of the hull. This approach may still imply significant inaccuracies. Indeed, as optimization studies demonstrate (Peri et al., 2001), substantial improvements in vessel performances can be achieved through some minor changes to the hull shape, while keeping constant the principal hull parameters. Hence, it is believed that the most reliable way to account for all the aspects of calm water resistance (both frictional and residual) and added resistance in waves would be to use towing tank data *for the specific hull geometry*, properly transformed to account for scaling effects."

B2) In Appendix, to add a new Section "Beyond a constant drag coefficient C_T":
"In order to numerically evaluate the impact of the constant C_T assumption done in Sect.2.3.2, VISIR-I routine `ship_resistance.m` can be used to solve Eq.16 of GMDD in presence of *any* polynomial form of $C_T = C_T(v)$. In particular, we have

tested

$$C_T(v) = \gamma_n v^n \tag{3}$$

for various values of n. If the value of γ_n is identified at the top powering conditions and $H_s = 0$, (cp. Eq.18 of GMDD), it reads:

$$\gamma_n = \frac{\eta k_3}{\frac{1}{2}\rho S} c^{-n} \tag{4}$$

where k_3 is given by Eq.23 of GMDD and c is the vessel's top speed. The ρS dependence is canceled in the resistance R_c:

$$R_c = C_T \frac{1}{2}\rho S v^2 = \eta k_3 v^{2+n} c^{-n} \tag{5}$$

generalizing Eq.25 of GMDD.

The case $n = 0$ corresponds to the results shown in Sect.2.3.2, while $n = 1, 2$ leads to a polynomial of degree 3 or 4 respectively for the residual resistance (we are still neglecting the v dependence of the frictional component in R_c). In the following, we augment the results already provided for $n = 0$ in Sect.2.3.2 of GMDD, and report a comparison of the $n = 1, 2$ cases in Fig.1.

First of all, we note that, at maximum engine throttle, the speed curve as a function of H_s (Fig.1a,b) is scarcely affected by the value of n. This is due to the fact that, for $H_s = 0$ and maximum throttle, the speed is constrained to be always c per construction and, for large H_s, the wave added resistance dominates the calm water resistance (cp. Fig.6 of GMDD) and consequently the residual resistance. The effect of varying the value of n is also displayed by the plots of engine throttle needed for sustaining a given Fr (Fig.1c,d). For calm sea, the minimum sustained speed increases with n, as expected (P7927, rows 11-12), since a lower C_T -keeping all other parameters fixed-means a higher vessel speed.

Finally, we can visualize the effect of n on the route kinematics for the case study #3 of Sect.3 from panels Fig.1e,f. Such a case study is chosen for display since the changes to route geometry due to $n \neq 0$ are most noticeable. However the other cases were also addressed by the sensitivity test and the results are summarized in Tab.2[1]. There is an effect on the length of the diversion of the optimal with respect to the geodetic route. The overall kinematics of the route is also affected, as the same sea state is experienced at (slightly) different times during navigation. From Tab.2 it is seen that the total navigation time is reduced for larger n, as expected. Maximum time-savings sum up (for $n = 2$) to about 7% of the duration of the $n = 0$ route (case study #1). Thus, we can conclude that - though a polynomial behaviour of C_T will shorten the duration of the routes and could be considered for the next version of VISIR - the initial approximation of a constant C_T does not lead to dramatically different results."

C - *The criteria for stability, parametric rolling etc, are of course important to consider, however, as these all depend to a large extent on the specific hull shape and weight distribution the derived approximations seem to be to crude for providing relevant results for technical application.*

–Authors' response:
Following the above discussion (item **B**), we cannot but agree with the Referee that the stability constraints proposed for VISIR-I should be carefully considered. Actually, we even anticipated this in GMDD (P7931, rows 10-19). Nonetheless, we deemed that it is meaningful for a ship routing code to embed the possibility to set such constraints. We would like to observe that they are responsible e.g. for the fact that a (safe) least-time route can still be longer than the corresponding geodetic route (see e.g. case study #3

[1] The values of case study #2 ($n = 0$) were updated, since what was published in GMDD suffers from a versioning issue.

Table 2. Summary metrics for the routes of all case studies of Sect.3 and different values of n parameter in Eq.3. Voluntary speed reduction is allowed. For both the geodetic and the optimal route, $\Delta = J(n)/J(0) - 1$ is the relative difference in navigation time with respect to the case of constant C_T (i.e., $n = 0$).

case study	Quantity	units	Geodetic route				Optimal route			
			$n=0$	$n=1$	$n=2$	$n=3$	$n=0$	$n=1$	$n=2$	$n=3$
3*# 1	Length	NM	127.5	127.5	127.5	127.5	131.6	131.4	131.4	131.6
	J	hh:mm	14:02	13:29	13:10	12:57	13:39	13:03	12:41	12:26
	Δ	%	-	-3.9	-6.2	-7.7	-	-4.4	-7.1	-8.9
3*# 2	Length	NM	138.2	138.2	138.2	138.2	139.7	139.7	139.9	139.7
	J	hh:mm	15:21	14:57	14:40	14:28	15:23	15:00	14:45	14:33
	Δ	%	-	-2.6	-4.5	-5.8	-	-2.5	-4.1	-5.4
3*# 3	Length	NM	270.4	270.4	270.4	270.4	277.4	277.3	278.0	277.9
	J	hh:mm	27:00	26:34	26:18	26:08	27:47	27:32	27:22	27:14
	Δ	%	-	-1.6	-2.6	-3.2	-	-.9	-1.5	-2.0

in GMDD, P7945, rows 13-17). While their actual functional form may be different from what has been implemented in VISIR-I, in the routine `edge_delays.m` we addressed the problem of implementing multiple constraints in a numerically efficient way. The VISIR user is allowed to individually switch off such stability constraints by changing the corresponding flags in the namelist file `safety_pars.txt`.

–Authors' changes to manuscript:
C1) On P7931, row 19 to insert:
"While the actual functional form of the safety constraints may be different from what has been implemented, the VISIR-I code addresses the problem of implementing multiple constraints in a numerically efficient way. The VISIR user is in a position to individually switch off such stability constraints by changing the corresponding flags in the namelist file."

D - *It shall be noted, that this topic is not so new and has been approached before, see e.g. http://www.researchgate.net/publication/237717485_Pareto_Optimal_Routing_of_Ships*

–Authors' response:
The work cited (Harries et al., 2003) is an interesting one, we will quote it. It offers an example of two of the reasons why we developed VISIR. First of all, we aimed to have a self-contained, fully open source code. This would ease further developments, as we have just done in **B**. Secondly, having the Mediterranean Sea as a target region for VISIR-I, we designed a routing system able to cope with complex coastlines and archipelagic subregions (such as the Aegean Sea), whereas several of the routing systems described in the literature (see also Sect. 1.1 of GMDD) fail to avoid the landmass.

–Authors' changes to manuscript:
D1) On P7916, row 11 to insert:
"Harries et. al. (2003) propose a hybrid method making use also of third-party optimization software. They employ swell forecasts by ECMWF for the Atlantic Ocean and represent the ship route in terms of parametric curves (B-splines), that are perturbed with respect to the calm sea route. They rely on modeFRONTIER package for multi-objective (least time and fuel consumption) optimization. Also, the vessel hydrodynamics are not solved internally, but via the SEAWAY package. Route optimization is claimed just for the open-sea part of the route, and one of their results even shows that the route does not always avoid landmass[2]."

E - *There are also several commercial providers of such service available, in fact almost all weather data providers e.g. AWT, which are used in ocean shipping on a regular basis. However, these services typically also include crude models of the hydrodynamics, only, since details of the specific ship are not available so there are still improvements possible. I would encourage the authors to point out how the described procedure improves the algorithms used in commercial shipping.*

–Authors' response:
We thank the Referee for this observation. In fact, the construction of VISIR model aims to offer to the scientific and technical communities an open platform, whereby various ideas and methods for ship route optimization can be shared, tested, and compared to each other. In this respect, the fact that in VISIR - through this paper and related source code - the various system components (vessel model, shortest path algorithm, and processing of the environmental fields) are openly documented and made publicly available should enable unprecedented developments. In particular, improve-

[2]See passage in the region of New Brunswick (Canada) - Maine (USA) in Fig.3b of Harries et. al. (2003).

ments with respect to commercial softwares are possible thanks to the modularity of the source code, and the fact that it does not rely on any external package, allowing for customizations of each VISIR subsystem. Answer to item **B** of this review provides an example for that.

–Authors' changes to manuscript:
E1) On P7948, row 5, to add:
"In conclusion, we would like to stress the potentiality of VISIR to offer to the scientific and technical communities an open platform, whereby various ideas and methods for ship route optimization can be shared, tested, and compared to each other. In this respect, the fact that in VISIR-I - through this paper and related source code - the various system components (vessel model, shortest path algorithm, and processing of the environmental fields) are openly documented and made publicly available should enable unprecedented developments for the efficiency and safety of navigation."

References

Grigoropoulos, G., Loukakis, T., and Perakis, A. N.: Seakeeping standard series for oblique seas (a synopsis), Ocean engineering, 27, 111–126, 2000.

Harries, S., Heinmann, J., and Hinnenthal, J.: Pareto-Optimal Routing of Ships, in: International Conference on Ship and Shipping Research, 2003.

Holtrop, J.: A statistical re-analysis of resistance and propulsion data, International Shipbuilding Progress, 31, 272–276, 1984.

Liu, S. and Papanikolaou, A.: Added Resistance of Ships in Quartering Seas, in: V International Conference on Computational Methods for Coupled Problems in Science and Engineering, COUPLED PROBLEMS, 2013.

Mannarini, G., Pinardi, N., Coppini, G., Oddo, P., and Iafrati, A.: VISIR-I: small vessels, least-time nautical routes using wave forecasts, Geoscientific Model Development Discussions, 8, 7911–7981, doi:10.5194/gmdd-8-7911-2015, http://www.geosci-model-dev-discuss.net/8/7911/2015/, 2015.

McTaggart, K. A.: Added Resistance Prediction in SHIPMO7 Using a Near-Field Method., Tech. rep., DTIC Document, 1997.

Peri, D., Rossetti, M., and Campana, E. F.: Design optimization of ship hulls via CFD techniques, Journal of Ship Research, 45, 140–149, 2001.

Interactive comment on Geosci. Model Dev. Discuss., 8, 7911, 2015.

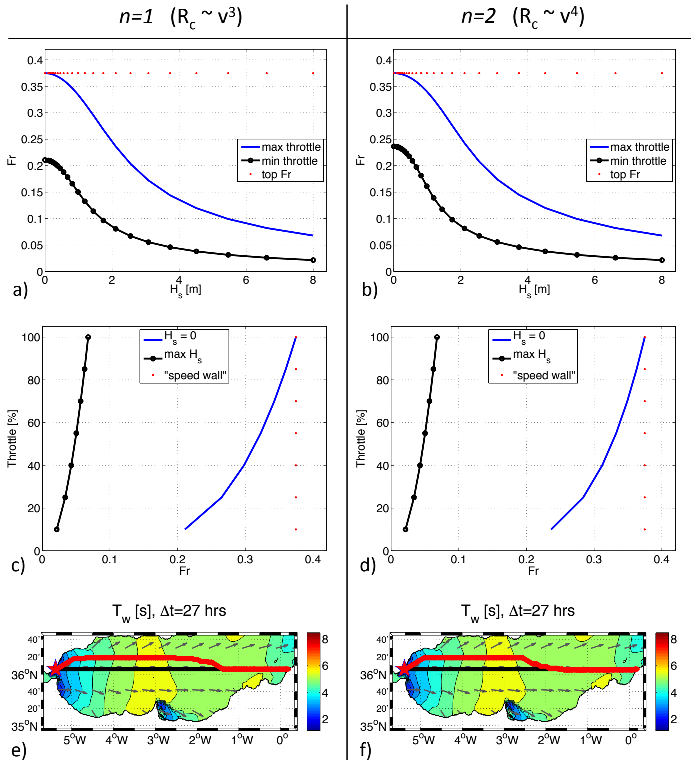

Fig. 1. Row 1: Froude number Fr at a constant engine throttle vs. significant wave height. Row 2: engine throttle needed for sustaining a given Fr. Row 3: the final time-step of the routes of case study #3.