Development of a Method for Weather Routing of Ships

A Master Thesis in Hydrodynamics

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Introduction

When a vessel sails it is influenced by multiple conditions caused by the weather. Waves, wind and currents will influence the ship's resistance and fuel consumption. The main objective of weather routing is to find a sailing route that will minimize time, fuel or cost. Weather routing is also used in order to exclude specific routes where the ship is exposed to rough sea.

A thanks to my supervisor Sverre Steen who has guided me and asked the difficult questions.

Objective

- Develop a minimal fuel routing software
- Include added resistance from irregular waves and wind
- The program should include routing limitations with regards to seakeeping
- The program should work for different ships and routes

Methodology

- Matlab program developed to conduct route suggestions and calculate fuel consumption
- A 3500 TEU container vessel is used for analysis
- ShipX is used to perform hydrodynamic calculations
- Historic weather files are obtained from European Centre for Medium-Range Weather Forecasts (ECMWF)
- Network optimization is used to find the minimum fuel path

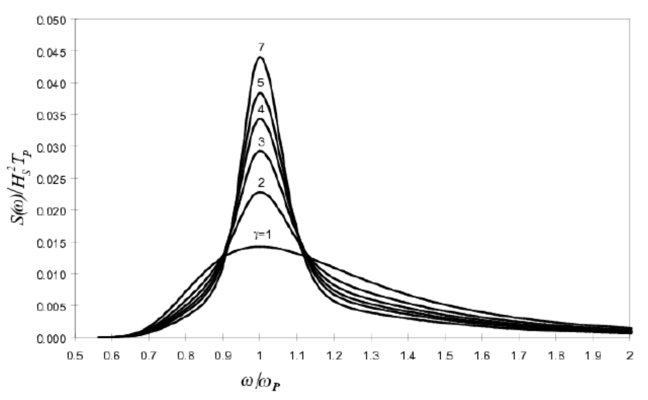
Hydrodynamic Theory

The total resistance of a vessel is defines at the sum of the calm water resistance, added wave resistance and added wind resistance: $R_T = R_{calm} + R_{wind} + R_{wave}$. The calm water resistance is not influence by the weather, but the wind and wave resistance is.

$$R_{wind} = C_D \frac{1}{2} \rho_A (V_{wind}^2 + 2V_{wind}V) A_T$$

$$\overline{R}_{wave} = 2\int_0^\infty C_{wave} S(\omega) d\omega$$

$$S(\omega) = \alpha g^2 \omega^{-5} e^{-\frac{5}{4}(\frac{\omega_p}{\omega})^4} \gamma^{e^{-\frac{1}{2}(\frac{\omega-\omega_p}{\sigma\omega_p})^2}}$$



S(ω) is the spectral parameter depended on the peak period and the significant wave height.

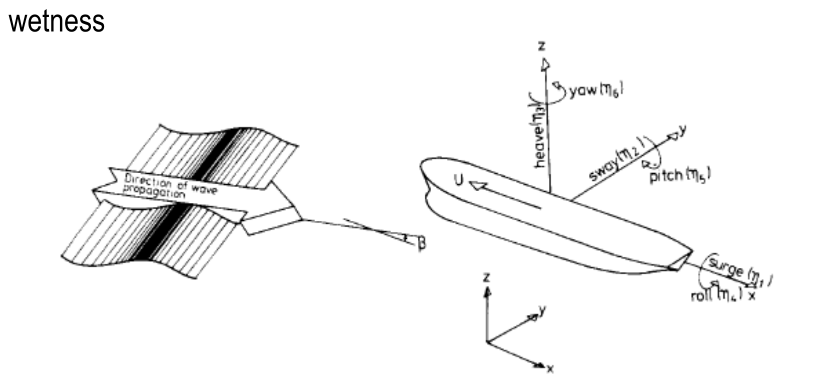
The safety of cargo and crew is taken into account by calculating the standard deviation of roll and vertical acceleration, as well as probability of slamming and deck wetness

$$H_j(\omega) = \frac{\eta_j(\omega)}{\zeta_a} \quad j = 1, 2, ...6$$

$$\sigma_n^2 = \int_0^\infty \omega^n S(\omega) |H(\omega)|^2 d\omega \quad n = 0, 2, 4$$

$$P(slamming) = e^{-(\frac{V_{cr}^2}{2\sigma_2^2} + \frac{d^2}{2\sigma_0^2})}$$

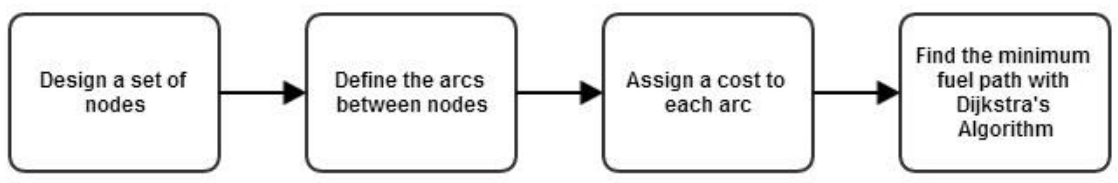
$$P(water\ on\ deck) = e^{-\frac{d^2}{2\sigma_0^2}}$$



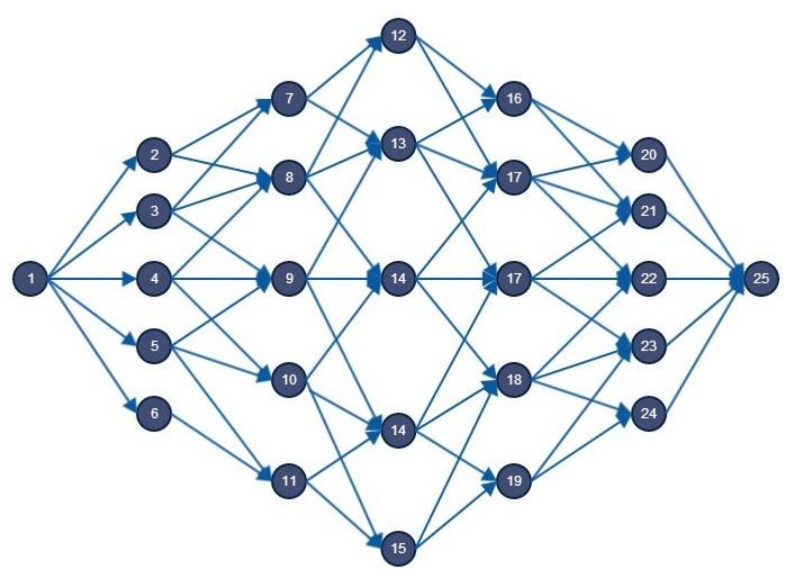
H(ω) is the transfer function for the respective degree of freedom

Optimization Method

The weather routing problem is treated as a network optimization problem. A network consisted of nodes, geographical coordinates, and arcs, paths between nodes. Each arc is assigned a cost, in this case the cost is the fuel consumption. Dijkstra's algorithm is applied to find the minimal fuel path between arrival and departure.

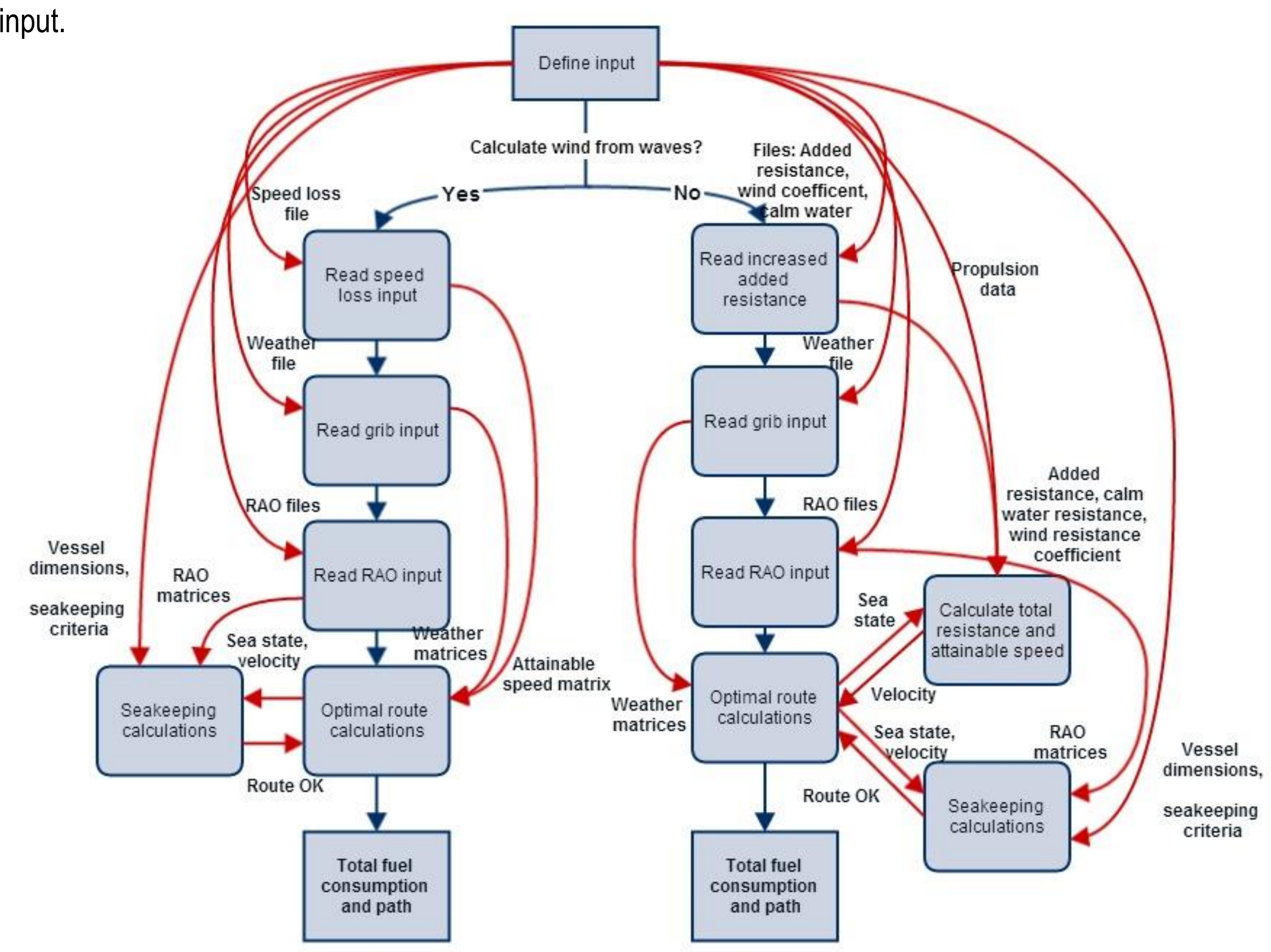


A network example for the routing problem:



Matlab Program

The program provides the opportunity of finding the optimal route for estimated wind velocity, and actual wind velocity. The flow of the program is presented by the flow chart below: The red lines defines flow of output and input.

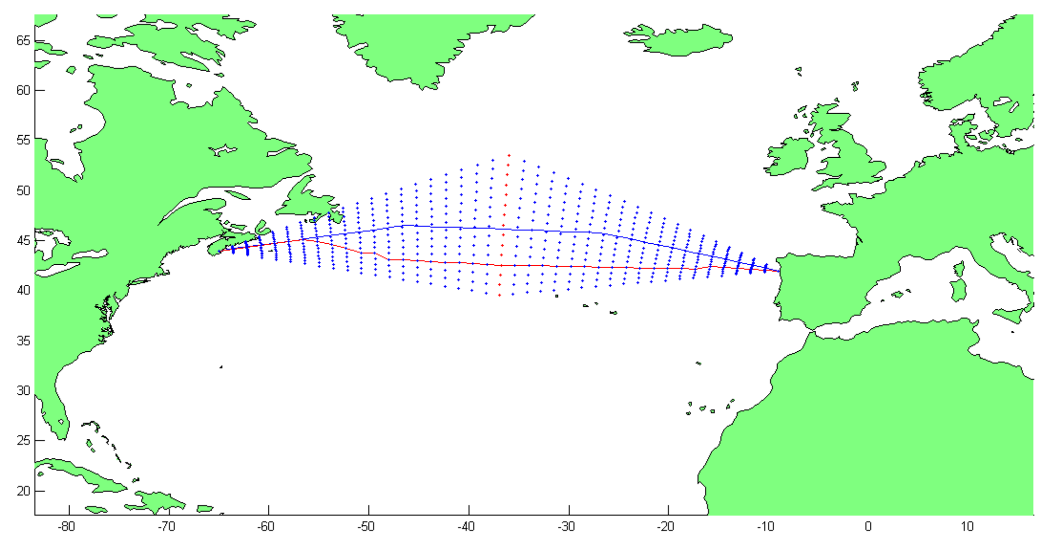


The functions in the program is divided into read functions and calculate function. ShipX is used to create input files for the program. ShipX calculates the added resistance operator and the transfer functions for the vessel. The running time of the program is high for actual wind, but acceptable for estimated wind

Results and Conclusion

Results North Atlantic in January:

The figure shows the optimal route over the North Atlantic in January. The blue line is the calm water route, great circle route, the red line is the optimal route and the dots denotes the feasible region



	Great circle fuel	Optimal fuel estimated wind	Optimal fuel actual wind
FC [ton]	503.2	512.6	499.9

The results in January show that the fuel consumption for the optimal route is higher, this is because the roll motions exceed critical values along the great circle route, and the optimal route is defined as the best possible route. The fuel consumption calculated with actual wind is lower than estimated wind.

General results and conclusion

- Weather routing has no effect on fuel savings
- Fuel savings are not season or ocean dependent
- The actual distance on the sphere has much higher impact on fuel consumption than wind and waves
- Estimated wind gives higher fuel consumption than actual wind
- Estimated wind gives the same optimal route as actual wind
- The program can be used to avoid rough sea where the seakeeping criteria are exceeded.

Main references

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