Energy Savings from "Just-In-Time" Ship-Route Planning

Objective: For a long voyage with critical arrival time, estimate the energy savings due to just-in-time arrival rather than early arrival.

Assume:

1. The ship sails its route using a combination of two speeds, *high* and *medium*, corresponding to two favoured (efficient) power-plant loadings, allocated along the route by the sail plan so that the ship arrives somewhat *earlier* than a given critical arrival time.
2. Steady-state sailing conditions, ship resistance is proportional to the square of the ship speed through water (Bernoulli's law), and ocean currents are negligible (i.e., avg. speed through water ≈ avg. speed over ground).

Result:
$$\frac{\Delta E}{E} = \left[\frac{V_H V_M (V_H + V_M)}{(V_H^3 - V_M^3)\alpha + V_M^3}\right] \times \left(\frac{\Delta t}{t}\right) \times 100\ \% \qquad (1)$$

$\frac{\Delta E}{E}$ Estimated additional propulsion energy (ΔE) consumed due to sailing at high speed somewhat longer than absolutely necessary (in order to arrive somewhat before the critical arrival time), *relative* to the estimated total propulsion energy (E) consumed when arriving just in time; in other words, the relative energy and fuel savings due to just-in-time arrival.

V_H, V_M High (H) and medium (M) ship speed through water; $V_H > V_M$. The sail plan must have $V_H \geq D/t$ to avoid late arrival, where D is the total travel distance.

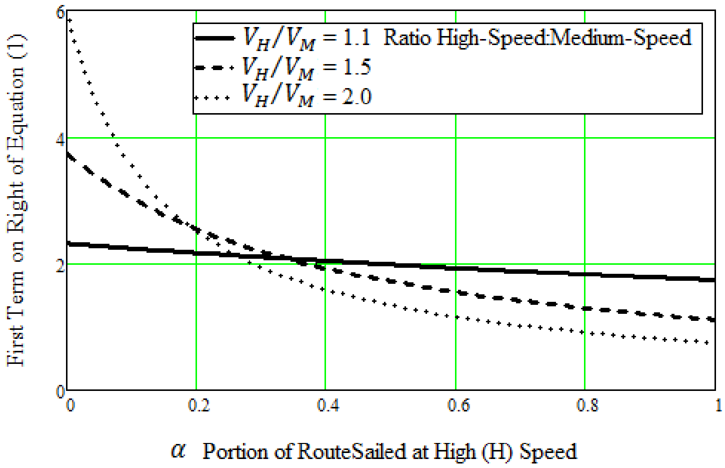
t Maximum allowable travel time after departure. A sail-plan generally aims up to arrive in shorter time, $t - \Delta t$, by sailing at high speed somewhat longer than absolutely necessary, in order to reduce the risk of late arrival.

Δt Planned arrival-time margin (wait time at destination); ideally small, necessarily constrained $0 < \Delta t < (1 - \alpha)(V_H - V_M)D/(V_H V_M)$.

α Portion of distance D sailed at V_H for just-in-time arrival; dimensionless, $0 \leq \alpha \leq 1$.

In practice, the first term on the right in (1) lies between 1.5 and 2.5. The graph below can also be used to estimate this term.

Example: Given 1) $V_H/V_M = 1.5$, 2) just-in-time arrival is forecast to require high-speed sailing for 60 % of the route $(\alpha = 0.6)$, and 3) arrival-time margin of 2 % $(\Delta t/t = 0.02)$, then by the dashed curve in the graph the first term on the right in (1) is 1.52, and the expected energy and fuel reductions for just-in-time arrival is $\Delta E/E \approx 1.52 \times 0.02 \times 100\ \% = 3.0\ \%$.



Conclusion: Every 1 % reduction in travel-time margin, due perhaps to the reduced uncertainty in computerized route planning with numerical weather products, produces 1.5 to 2.5 % savings in energy and fuel.

Disclaimer: Equation (1) was developed and is under test in NAVTRONIC. It is floated here for discussion purposes. Its derivation and elaboration are in NAVTRONIC deliverables.

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