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Low-level rudder models

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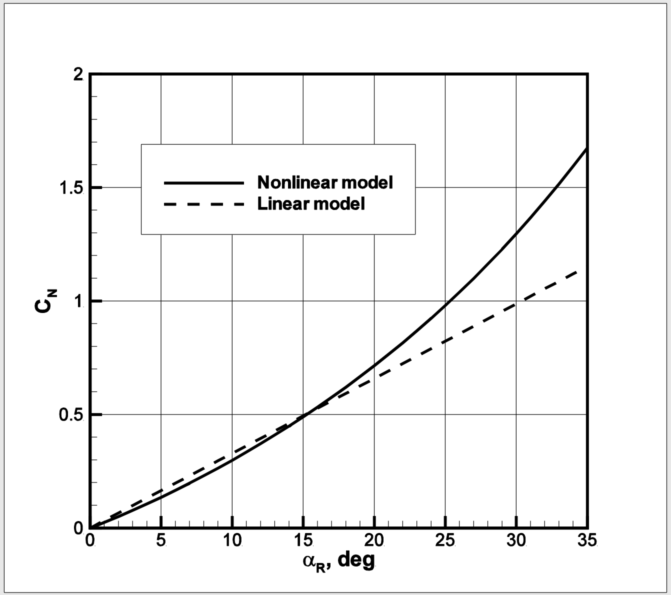
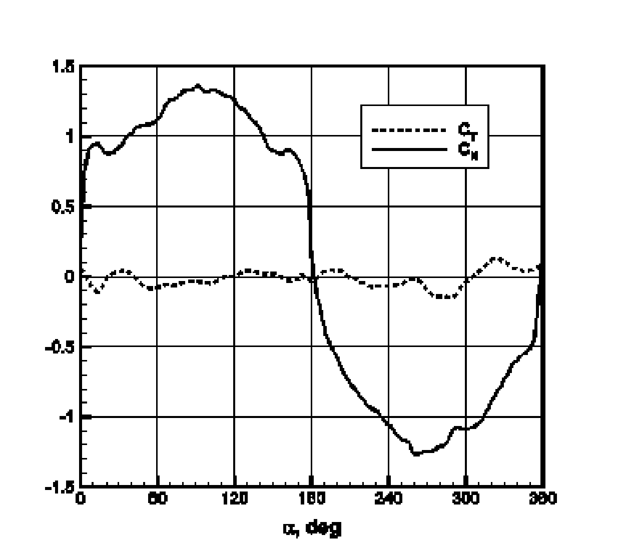
General remarks on simple rudder models

1. **The rudder blade is considered as a small-aspect-ratio wing whose characteristics are estimated using experimental data and lifting-line theory relations.**
2. **In the pre-stall region the lift dependence on the attack angle is slightly nonlinear but maybe reasonably linearised with intersection at** $\approx 15^{\circ}-20^{\circ}$
3. **Instead of the couple Drag+ Lift, the Normal Force may be considered**





Further remarks

- **Rudder normal force:** $N_R = C_N(\alpha_R)\frac{\rho V_R^2}{2}A_R, \quad \alpha_R = \delta_R - \beta_R$
- **Main sources of uncertainty are: the effective rudder velocity V_R and the effective rudder sidewash angle β_R influenced by the hull wake and by the propeller slipstream**
- **Hull wake: in low-level methods empiric data are used for the rudder wake fraction and flow straightening factors**
- **Slipstream: actuator disk theory + (semi)empiric corrections + load separation principle**
- **Remark: there are models/studies where is assumed $\beta_R = 0$. These models/studies are useful for structural design of rudders and selection of the steering gears but are inadequate for any manoeuvrability problems**

MMG model for rudder inflow (Ogawa)

$$\beta_R = C_{Rs} C_{Rp} \left(\beta - 2x'_R r'\right); \quad C_{Rs} = \min\left\{0.5, 0.45\left|\beta - 2x'_R r';\right|\right\};$$

$$C_{Rp} = \left[1 + 0.6\frac{D_P}{h_R} \cdot \frac{\left(2 - 1.4s\right)s}{\left(1 - s\right)^2}\right]^{-1/2}; \quad V_R = u_R / \cos\beta_R;$$

$$u_R = u\frac{1 - w_R}{s - 1}\sqrt{1 - 2s\left(1 - d_{PR}k_{PR}\right) + s^2\left[1 - d_{PR}k_{PR}\left(2 - k_{PR}\right)\right]};$$

$$w_R = w_{R0}\exp\left(K_1\beta_P^2\right); \quad d_{PR} = D_P / h_R; \quad k_{PR} = 0.6\frac{1 - w_P}{1 - w_R};$$

Söding's model extended to 4 quadrants

$$N = C_N(\alpha_R)\frac{\rho V_{RA}^2}{2}A_{R0} + C_N(\alpha_{RP})k_d\frac{\rho V_{RP}^2}{2}A_{RP},$$

$$V_{RA} = \sqrt{u_{RA}^2 + v_{RA}^2},$$

$$u_{RA} = V_{RA}\cos\beta_R, \quad v_{RA} = -V_{RA}\sin\beta_R.$$

$$u_{RA} = u_R(1-w_R) = u\,(1-w_R),$$

$$v_{RA} = \kappa_v(\bar{\beta}_R)\,v_R,$$

$$v_{RP} = \frac{\bar{x}^2}{a+\bar{x}^2}v_{RA}$$

$$r_{RP} = \frac{D_P}{2}\sqrt{|u_0 / u_{RP}|}.$$

$$u_{RP} = u_{PA} + w_a, \quad v_{RP} \equiv v_{RA},$$

$$w_a(\bar{x}) = \frac{1}{2}\kappa k_w(\bar{x})w_{a\infty},$$

$$k_w(\bar{x}) = 1 + \frac{\bar{x}}{\sqrt{1+\bar{x}^2}},$$

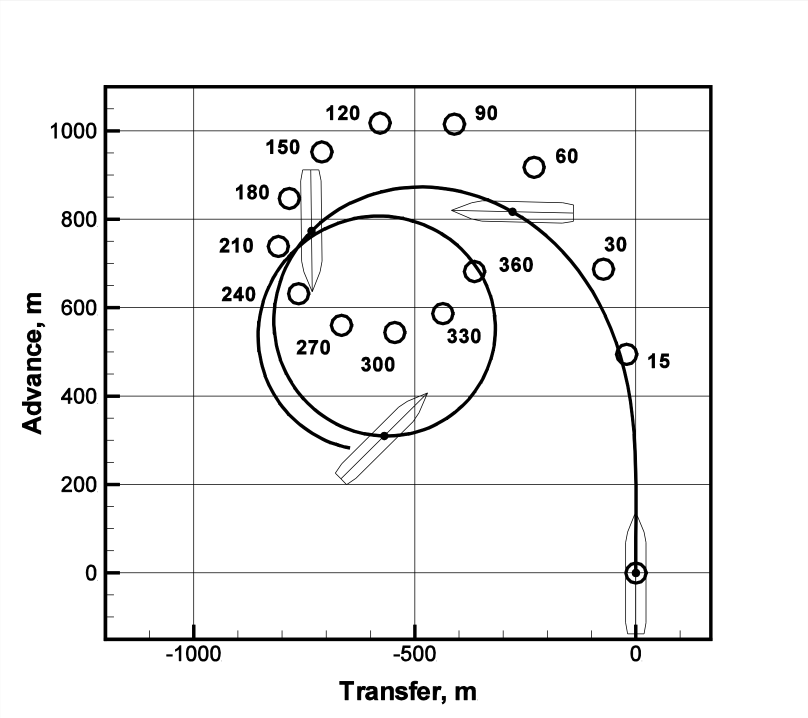
$$\bar{x} = \frac{2(x_P - x_R)}{D_P},$$

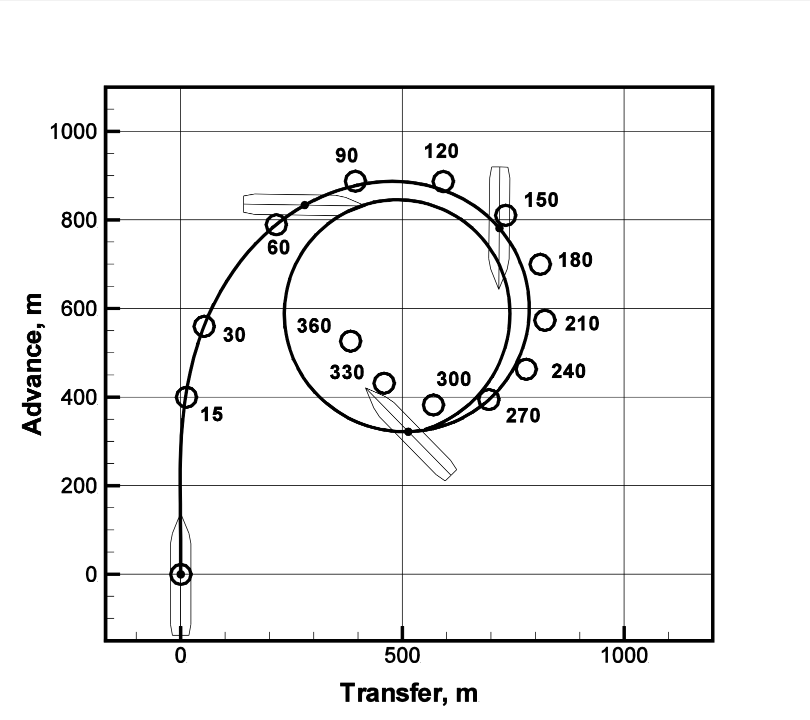
$$w_{a\infty} = u_\infty - u_{PA}, \quad u_\infty = \sqrt{u_{PA}^2 + w_{a0\infty}^2},$$

$$w_{a0\infty}^2 = \frac{2|T|}{\rho A_0},$$

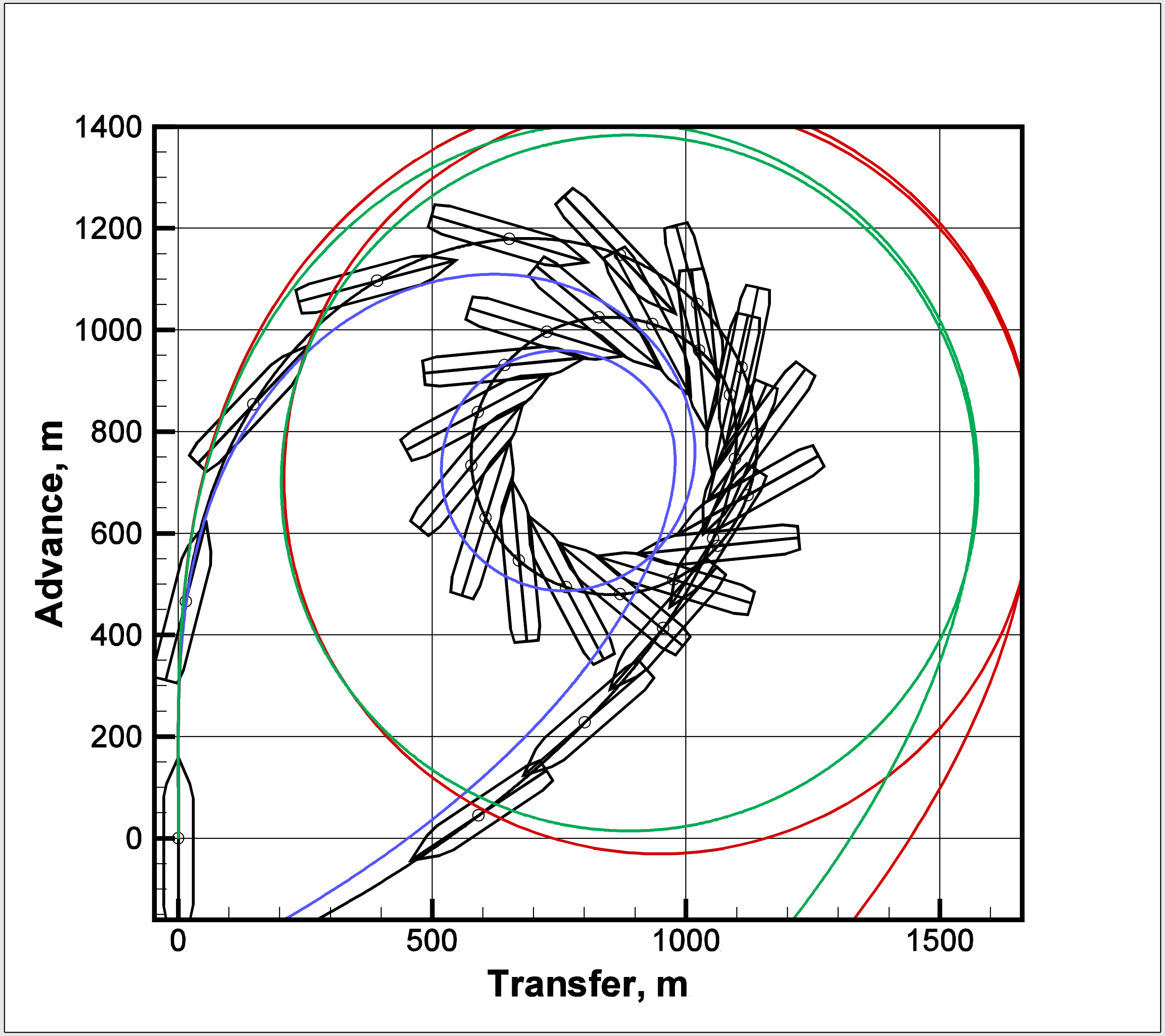
$$k_w(\bar{x}) = \left[\left(1 + \frac{\bar{x}}{\sqrt{1+\bar{x}^2}}\right)\kappa(T)\right]\operatorname{sign} T$$

Turning circles for shuttle tanker *Galea*





Turning circles for KVLCC2 (SIMMAN)



Conclusions

- **A low-level rudder model must be developed for arbitrary (within certain limits) sidewash happening in arbitrary curvilinear motion of the ship.**
- **No sense to refine too much low-level rudder models as long as substantial uncertainties in interaction coefficients remain.**
- **While the model must be qualitatively consistent, its quantitative accuracy in standardizing problems is less important as finel requirements must be faired against the existing fleet anyway.**
- **However, collection of data on the interaction coefficients and numerical investigation of sensitivity of predicted rudder forces with respect to various parameters are of considerable interest and importance.**