Challenges of modeling interceptors on a planing hull

Final Project for 2.29

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Outline

- Background
  - Theory of planing
  - Interceptors
- Previous work – Experimental testing
- Original Objective
- InterFoam - VOF
- Challenges to modeling
- Conclusions

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Background – Theory of planing

- Displacement – Buoyant forces dominate

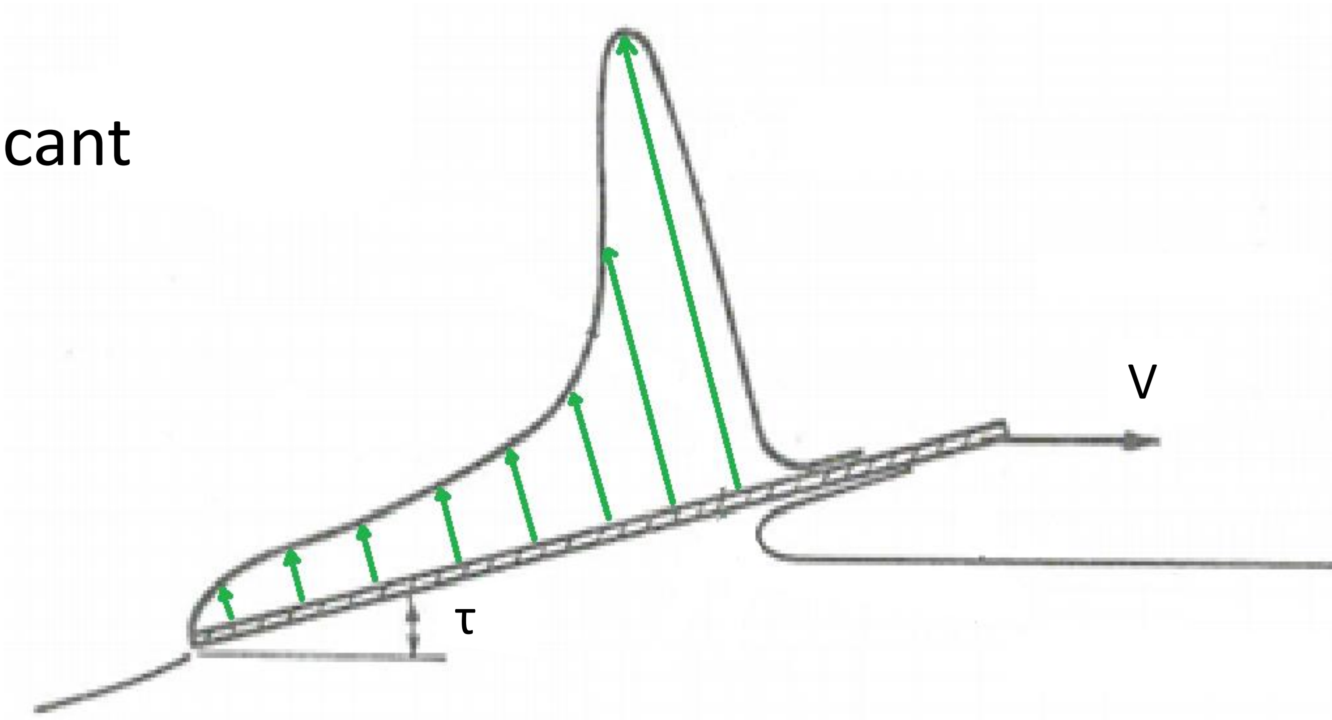
$$\text{Boyant Force } = \rho g \nabla$$

- Planing – Dynamic lift also significant

$$\text{Lift force } \propto \frac{1}{2}\rho V^2 A_P$$

- Volumetric Froude Number

$$A_P \propto \nabla^{2/3} \;,\; F_\nabla = \frac{V}{\sqrt{g\sqrt[3]{\nabla}}}$$

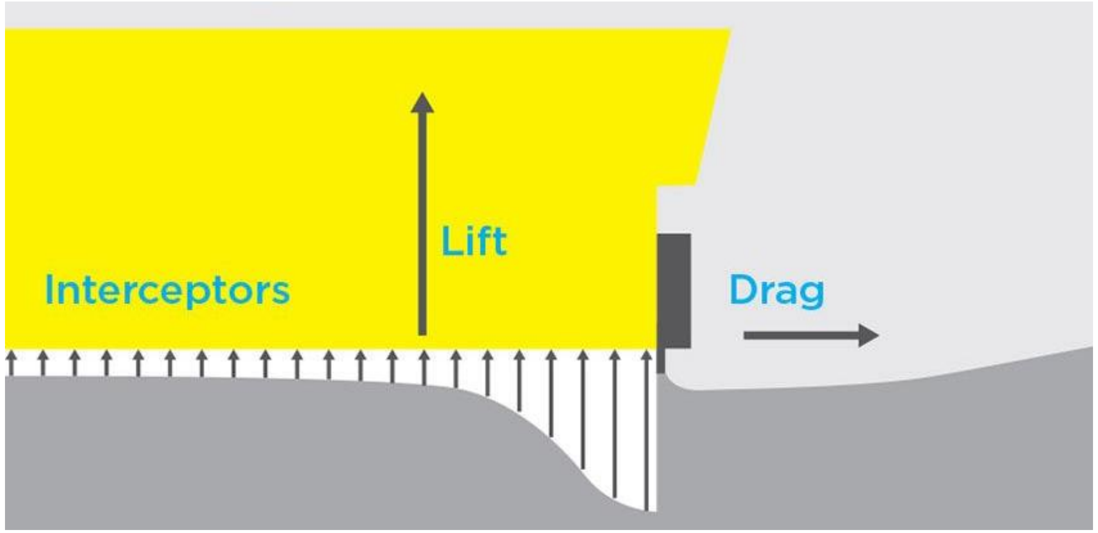


Adapted from Savitsky (1964)

Background – Interceptors

$F_\nabla \sim 2\ to\ 3$

- Transitional speeds
  - Large bow up trim
  - Significant pressure drag
- Large pressure drag during transition to planing
- Interceptors
  - Create stagnation point
  - Lifts transom
  - Decrease resistance



Source: Zipwake.com

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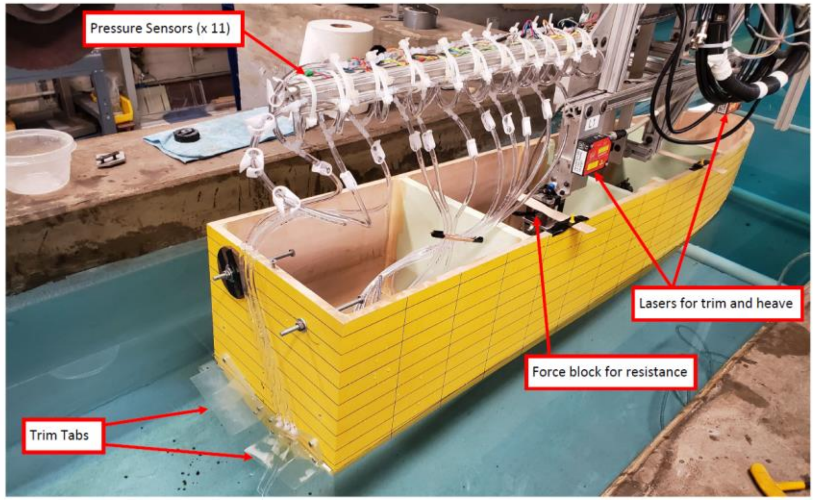
Previous Work – Experimental Tests

- Model:

  LOA= 1.524m
  Beam= 0.305m

- Interceptors and trim tabs
- F_{∇} 1.11 – 3.14
- Multiple deployments
- Longitudinal pressure forward of interceptor



Source: Gaylo Roske (2019)

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Objective

- Model one speed and interceptor deployment. Validate with experimental data and compare results using different turbulence models.

- Choose largest deployment and mid-range speed

$F_{\nabla} = 2.40 \quad (U \approx 4\frac{m}{s}) \qquad L_{deployment} = 1.143mm \qquad \tau = 0.8°$

- From underside images calculated mean wetted length

$$Re_L = 4.7\ X\ 10^6$$

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InterFoam – Volume of Fluid method

- VOF – track free surface using a continuity equation
- InterFoam implementation:
  - Very close to machine precision mass conservative
  - Iteration brings closer

- Machine precision VOF methods exist.

*Ignored surface tension

$$\alpha(\vec{x}) = \begin{cases} 1, \vec{x} \in fluid\ 1 \\ 0, \vec{x} \in fluid\ 2 \end{cases}$$

$$\int_\Omega \alpha(\vec{x})dV / \int_\Omega dV \in [0,1]$$

$$\rho(\vec{x}) = \alpha(\vec{x})\rho_1 + \left(1 - \alpha(\vec{x})\right)\rho_2$$
$$\mu(\vec{x}) = \alpha(\vec{x})\mu_1 + \left(1 - \alpha(\vec{x})\right)\mu_2$$

$$\frac{\partial \alpha}{\partial t} + \frac{\partial\left(\alpha u_j\right)}{\partial x_j} = 0$$

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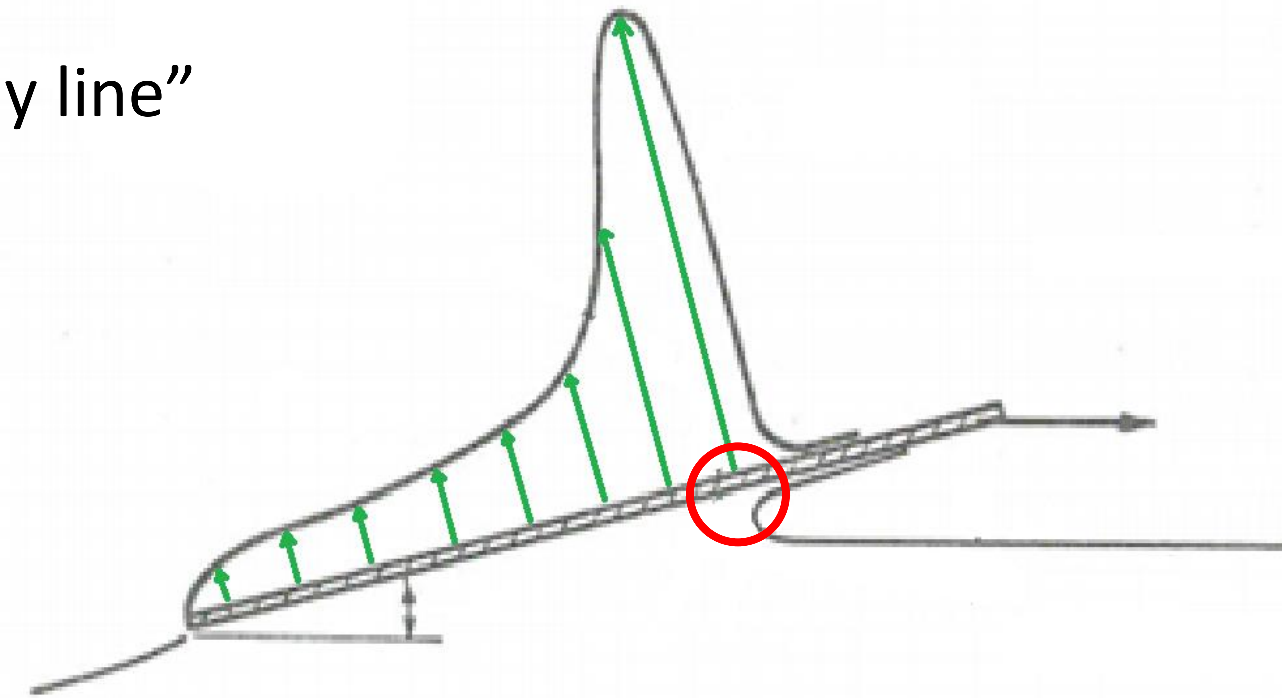
Challenges – Adverse pressure gradient

- Stagnation point near bow – "Spray line"
- $k - \epsilon$, accumulates epsilon
- $k - \omega$, better

- Spray line needs grid refinement
  - location difficult to predict
- Switched to 2D simulation
  - Modeled forward top boundary condition as a symmetry plane.



Adapted from Savitsky (1964)

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Challenges – Grid Resolution

- $\frac{L_{deployment}}{L_{hull}} \approx 1000$ Minimum Domain Length $= 3\ L_{hull}$
- For planing hulls, much larger domain lengths often needed.

- To model interceptor, layers near nearby would need aspect ratios near 1, unlike typical boundary layer cells.
- Difficult to maintain reasonable grid sizes, aspect ratios, and cell expansion rates.

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Challenges – Wall and Interceptor refinement

- Using ITTC-1957 friction coefficient,

$$y^+(L_{deployment} = 1.143mm) \approx 180$$

- For wall functions, first cell center $30 < y^+ < 100$.
- Only three cells to capture interceptor deployment.

- To accurately model interceptor, would likely need to use near wall, $y^+ \approx 1$.

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Challenges – Courant Restriction

- Transom usually fully ventilated

$$p_{front} \approx 0.3\ \frac{1}{2}\rho V^2 + \rho g z \qquad\qquad p_{back} \approx 0$$

- Velocity near tip of interceptor O(V)
- For $\Delta x \sim L_{deployment}/3$ $\qquad V = 4\, m/s \qquad$ and $CFL = 1$

$$\Delta\mathrm{t} \sim 10^{-6} s$$

Assuming $T_{converge} \sim 10\, L_{Domain}/V$, need $O(10^7)$ timesteps

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Conclusions

- Due primarily to stagnation points close to the free surface, planing creates a very computationally expensive problem.
- $k - \epsilon$ is not stable in simulations with strong adverse pressure gradients, and can become unstable at stagnation points.

- Numerically modeling realistic model scale interceptor deployments adds significant computational cost.

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Questions?