EXAMPLE

URANS Simulations of Static and Dynamic Maneuvering for Surface Combatant

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Modeling

General flow field: RANS equations and continuity equation

Turbulence: Blended k-ω/k-ε 2-equation model

Free surface: Single-phase level-set method

$$\frac{\partial \mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v}=-\nabla p+\nabla\cdot\left[\frac{1}{\mathrm{Re}_{eff}}\left(\nabla\mathbf{v}+\nabla\mathbf{v}^{T}\right)\right]+\mathbf{S}$$

$$\nabla\cdot\mathbf{v}=0$$

$$\frac{\partial k}{\partial t}+\left(\mathbf{v}-\sigma_k\nabla\nu_t\right)\cdot\nabla k-\frac{1}{P_k}\nabla^2 k+s_k=0$$

$$\frac{\partial \omega}{\partial t}+\left(\mathbf{v}-\sigma_\omega\nabla\nu_t\right)\cdot\nabla \omega-\frac{1}{P_\omega}\nabla^2 \omega+s_\omega=0$$

$$\frac{\partial \phi}{\partial t}+\mathbf{v}\cdot\nabla\phi=0$$

6DOF: Equations of motion for rigid-body linear transformation/rotation

$$m\left[\boldsymbol{\omega}\times\mathbf{v}_0+\boldsymbol{\omega}\times\left(\boldsymbol{\omega}\times\mathbf{r}_G\right)\right]=\mathbf{F}_0\text{: Linear transformation, }\boldsymbol{\omega}\times\left(\mathbf{I}_0\boldsymbol{\omega}\right)+m\mathbf{r}_G\times\left(\boldsymbol{\omega}\times\mathbf{v}_0\right)=\mathbf{M}_0\text{: Rotation}$$

Propeller modeling: Axisymmetric body force propeller model

Numerical Method

Discretization: Finite Difference Method

- Time: 2nd-order Euler backward, predictor-corrector scheme
- Space: 2nd-order upwind for convection term, and 2nd-order central for diffusion term

Velocity-pressure coupling : PISO

Dynamic overset grid: SUGGAR, USURP

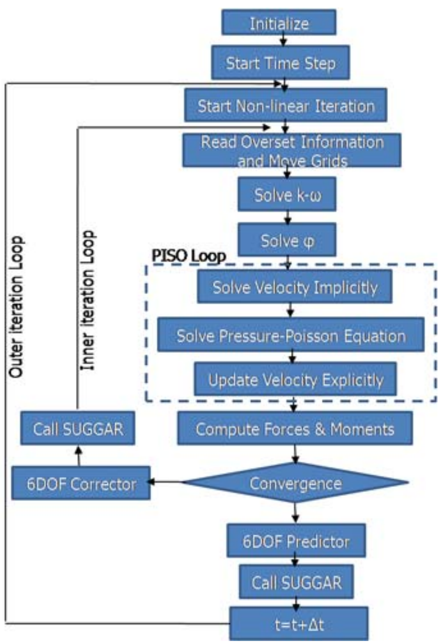
Iterative solvers: ADI line solver, PETSc

High Performance Computing

Computational expense:

- 4.04M (fine), 1.40M (medium), and 0.61M (coarse) grid points
- 42hrs CPU time to complete 1 yaw period by MPI parallel computing environment using 32 blocks decomposition for fine grid (DoD MSRC, IBM P4+ 1.7GHz, Distributed memory)

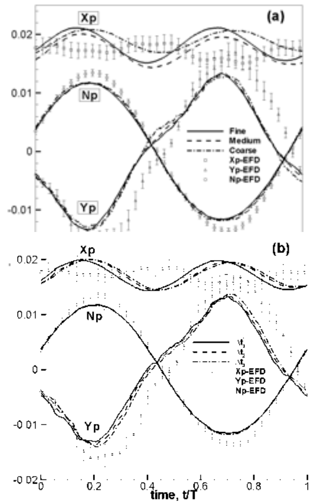
Overall Solution Strategy



Verification

Hydrodynamic coefficients

Pure yaw, Fr=0.28, r'=0.3

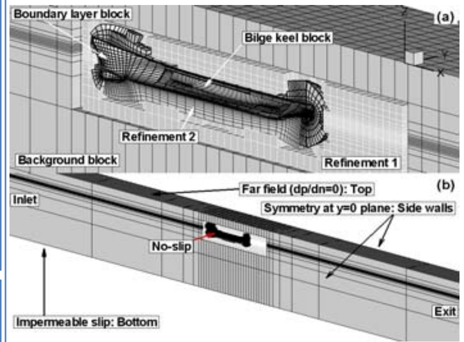


		R	p	C	U_{SN} %*
G	X_p	0.624	1.359	0.601	59.397
	Y_p	0.646	1.263	0.549	4.854
	N_p	0.553	1.708	0.807	1.306
T	X_p	2.596	-	-	-
	Y_p	0.889	0.339	0.125	45.436
	N_p	0.810	0.608	0.234	4.092

G: Grid study, T: Time-step study

*: %solution-range of fine-grid solution in one yaw period.

Grid, Domain, Boundary Conditions and Test cases



	Motion parameters					Running condition
	β	S_{max}	ω	r'	R	
Pure drift	10	-	-	-	-	FEK, DST
Steady turn	-	-	-	0.3	3.33	DST
Pure sway	10	0.1039	1.6721	-	-	EFK, DST, 3DOF
Pure yaw	-	0.0537	1.6721	0.15	-	FEK
		0.1073	1.6721	0.3	-	
		0.1299	2.1499	0.6	-	
		0.1073	1.6721	0.3	-	DST, 3DOF

FEK: Fixed even-keel condition, DST: Dynamically sunk and trimmed condition

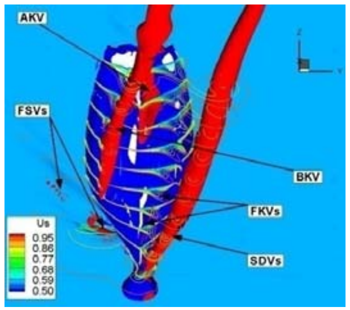
3DOF: Free to pitch, heave and roll

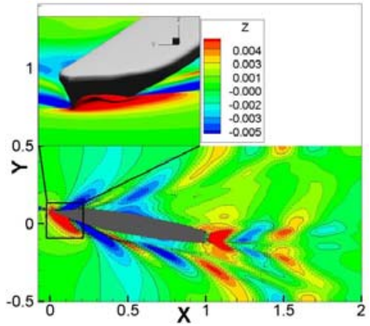
Results (All cases at Fr=0.28)

Pure drift, β=10º, DST

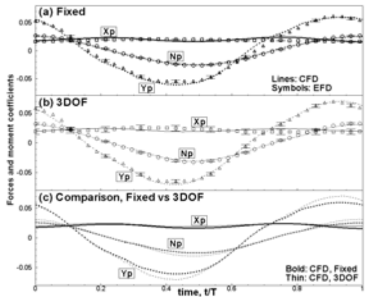
	EFD	CFD	E (%D)
X_p	0.0188	0.0230	-22.7
Y_p	0.0611	0.0602	1.53
N_p	0.0287	0.0281	2.25

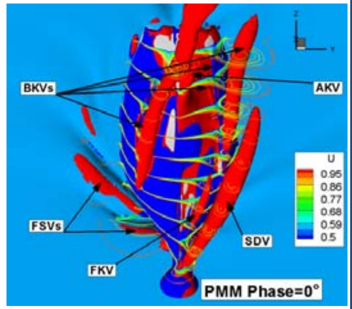
E=(D-S)/D*100

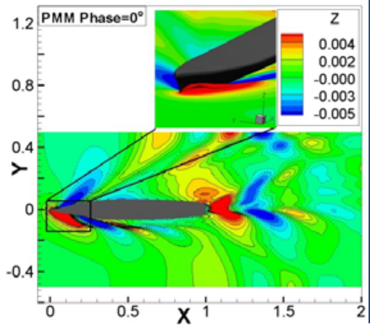




Pure sway, β_{max}=10º, S_{max}=0.1039, FEK







Pure yaw, r'_{max}=0.3, S_{max}=0.1073, ω=1.6721, FEK