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Electric Ship Drivetrain – Virtual Design for Mission Success

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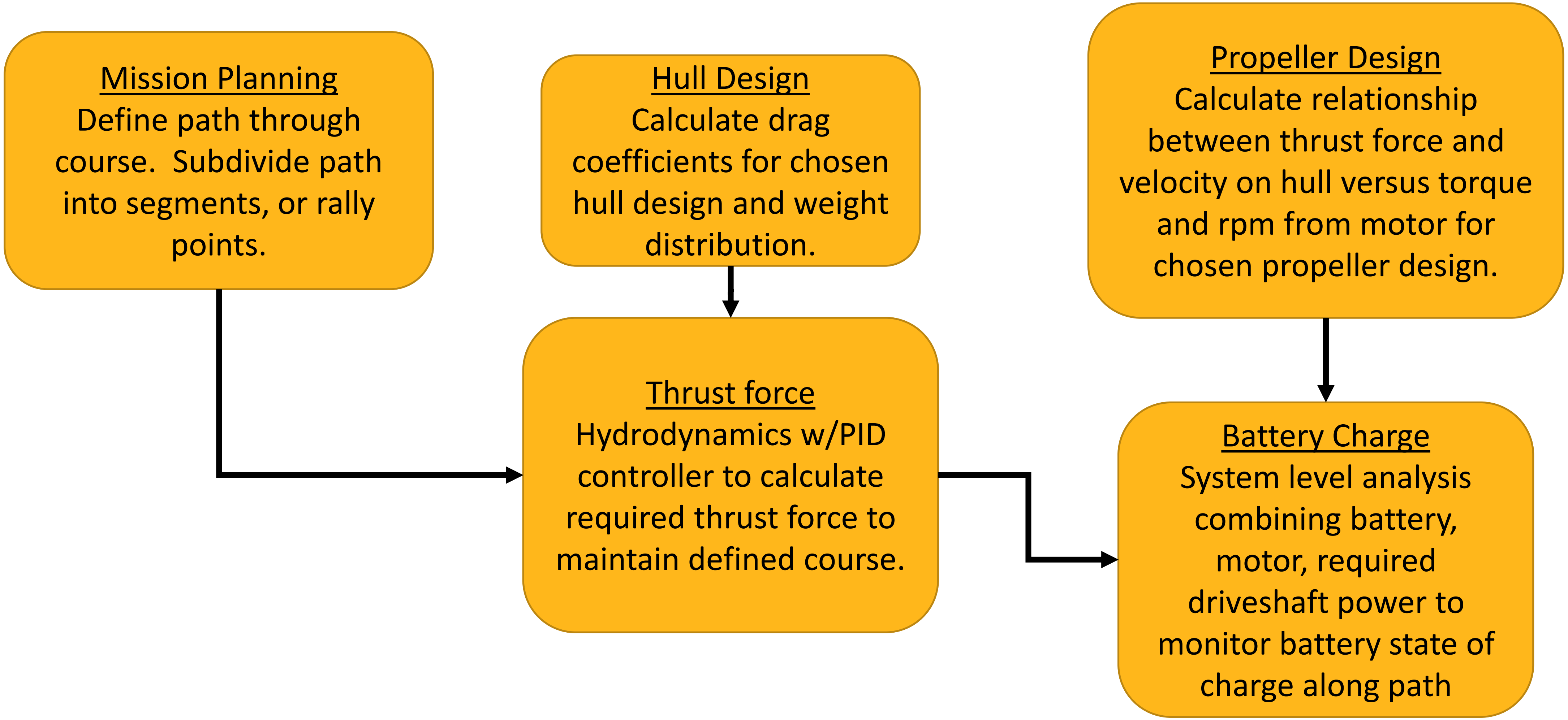
Outline

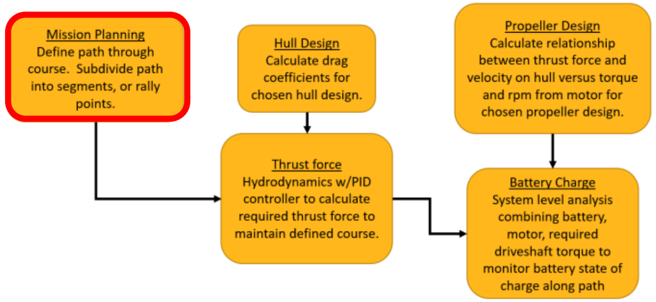
- Extensible physics based simulation workflow to enable
  - System planning, monitoring and execution
  - Sub-system trade-off exploration: hull, motor, battery, propeller

- Components of the simulation workflow
  - Path definition on imported map
  - Calculate thrust and velocity to navigate defined path
  - Relate hull thrust and velocity to propeller power
  - Monitor battery state of charge along path

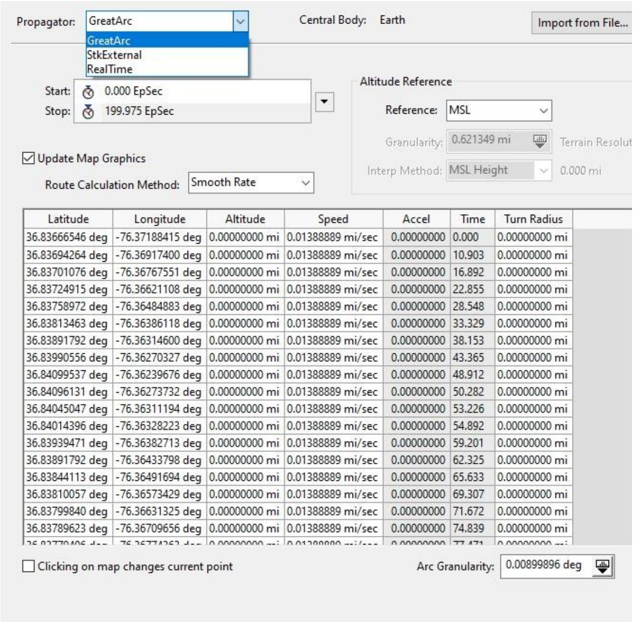
High Level Workflow



Course Definition



- STK propagators for path
  - Define position, speed and acceleration on an imported map
  - Visualize path and create reports for metrics of interest
  - Generate reports



Latitude	Longitude	Altitude	Speed	Accel	Time	Turn Radius
36.83666546 deg	-76.37188415 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	0.000	0.00000000 mi
36.83694264 deg	-76.36917400 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	10.903	0.00000000 mi
36.83701076 deg	-76.36767551 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	16.892	0.00000000 mi
36.83724915 deg	-76.36621108 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	22.855	0.00000000 mi
36.83758972 deg	-76.36484883 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	28.548	0.00000000 mi
36.83813463 deg	-76.36386118 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	33.329	0.00000000 mi
36.83891792 deg	-76.36314600 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	38.153	0.00000000 mi
36.83990556 deg	-76.36270327 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	43.365	0.00000000 mi
36.84099537 deg	-76.36239676 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	48.912	0.00000000 mi
36.84096131 deg	-76.36273732 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	50.282	0.00000000 mi
36.84045047 deg	-76.36311194 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	53.226	0.00000000 mi
36.84014396 deg	-76.36328223 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	54.892	0.00000000 mi
36.83939471 deg	-76.36382713 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	59.201	0.00000000 mi
36.83891792 deg	-76.36433798 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	62.325	0.00000000 mi
36.83844113 deg	-76.36491694 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	65.633	0.00000000 mi
36.83810057 deg	-76.36573429 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	69.307	0.00000000 mi
36.83799840 deg	-76.36631325 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	71.672	0.00000000 mi
36.83789623 deg	-76.36709656 deg	0.00000000 mi	0.01388889 mi/sec	0.00000000	74.839	0.00000000 mi

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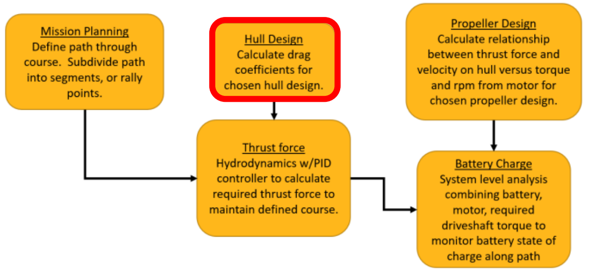
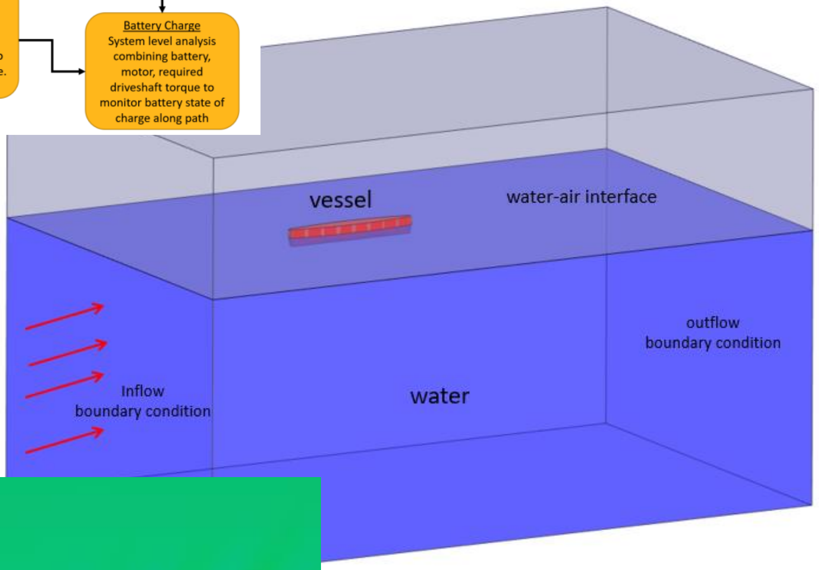
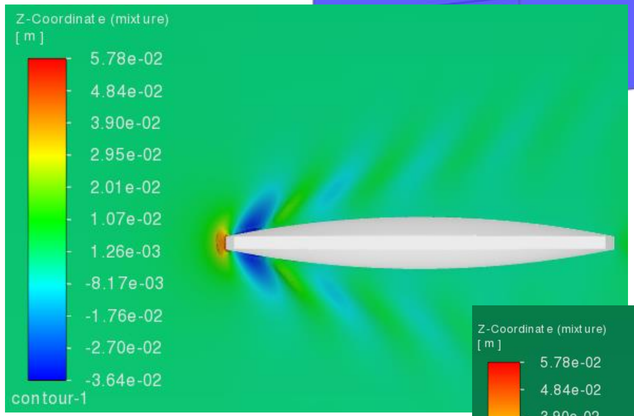
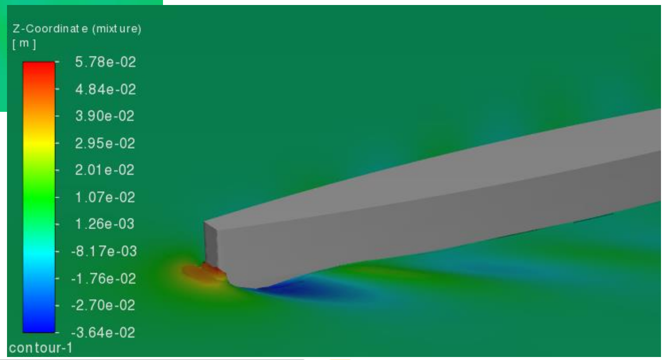
Vessel Hydrodynamics using CFD

Drag Coefficients





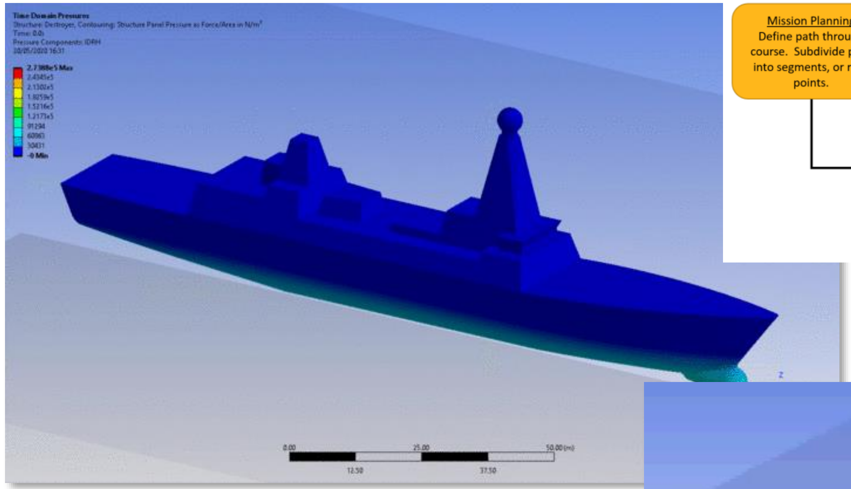


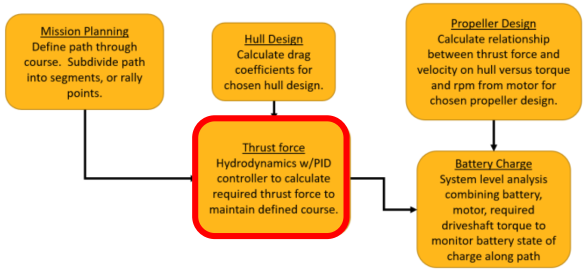


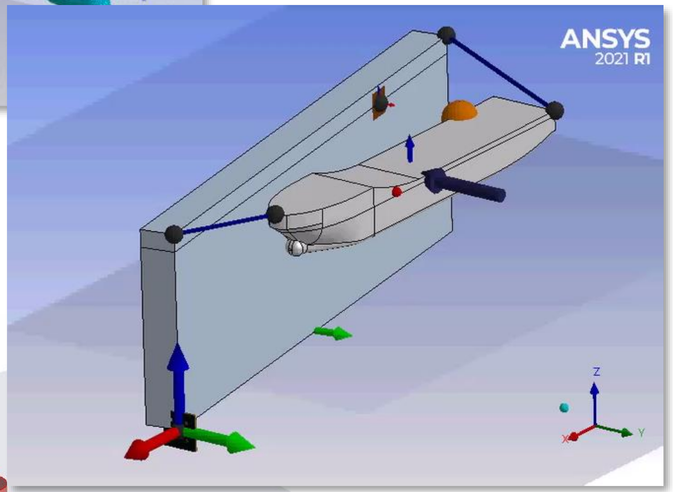
- The hydrodynamics simulation uses steady-state mode and a multiphase approach has been used to capture air and water interaction at the interface.
- Both the hull design and weight distribution are considered and will affect the drag.
- Since the flow involves the presence of a free surface between water and air, we have used the volume of fluid (VOF) formulation and the open channel boundary conditions.
- This model predicts wave propagation, free surface behavior, resistance (pressure and viscous) forces and drag coefficient.

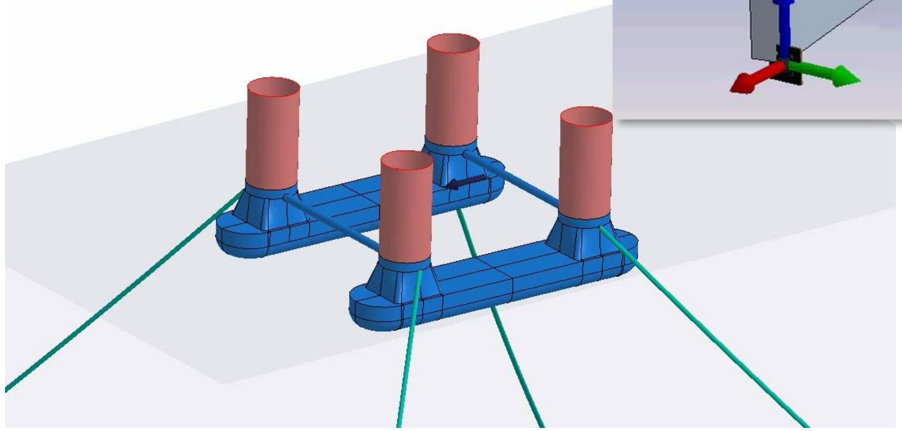
Vessel hydrodynamics
Thrust Force

- Vessel hydrodynamics based around three-dimensional diffraction/radiation methods is used for thrust force and velocity along charted course
- Very efficient and fast compared to CFD with same level of accuracy
- Ansys Aqwa provides a modern engineering toolset for the investigation of the effects of wave, wind and current on floating and fixed offshore and marine structures



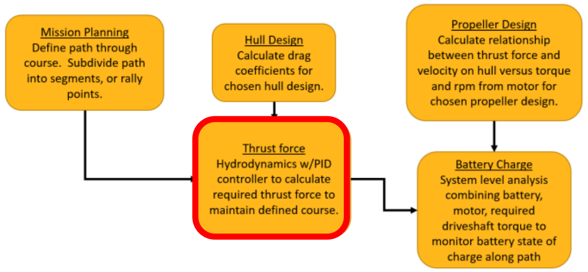




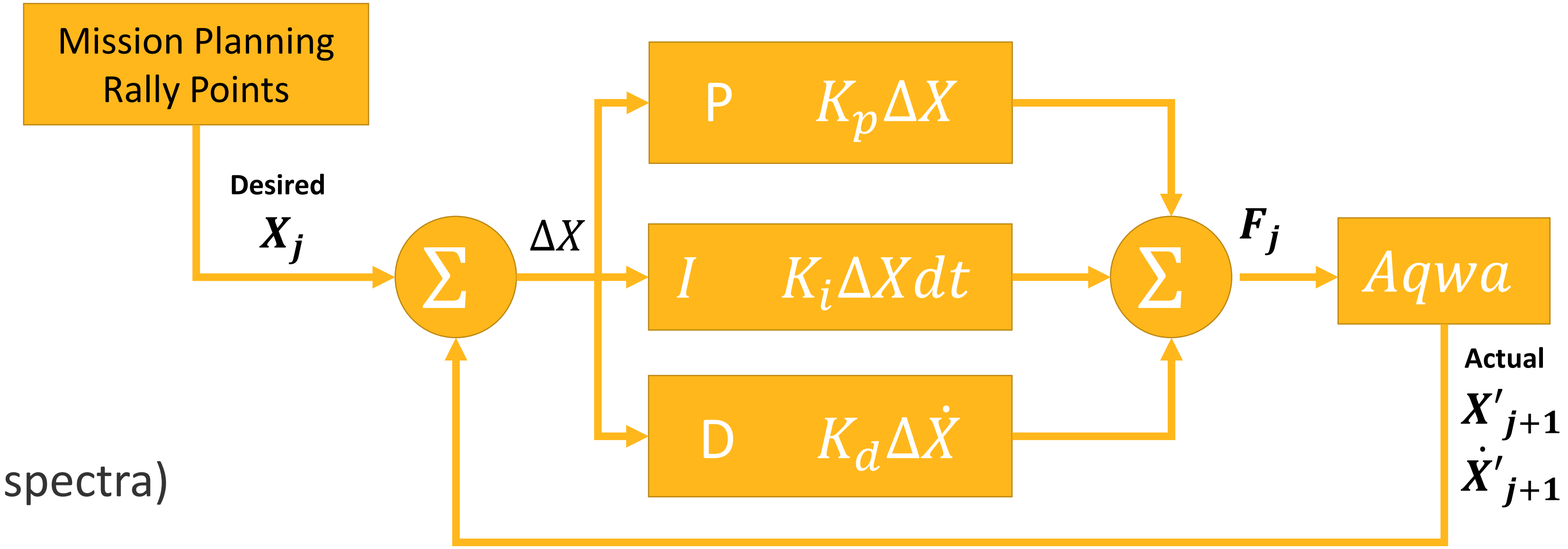


Vessel hydrodynamics

Thrust Force

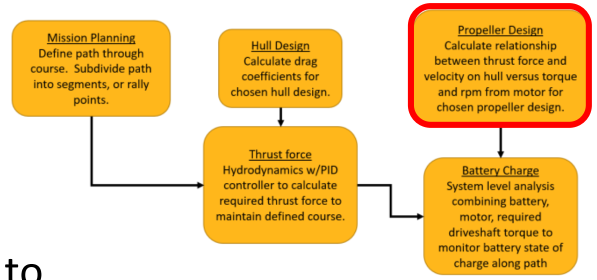


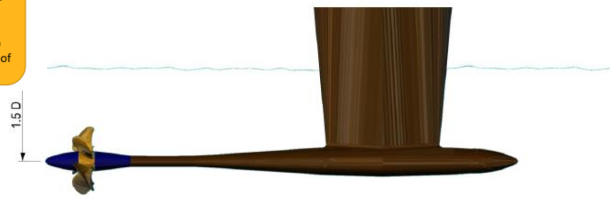
- Model inputs
  - Vessel geometry
  - Mass properties
  - Drag coefficients
  - Rally points
- Environment inputs
  - Wave characteristics (direction, spectra)
  - Current, wind characteristics
- Time, frequency domain results
  - Motion (6DOF): Location, Velocities, Accelerations
  - Forces: Wave, Thrust, Drag



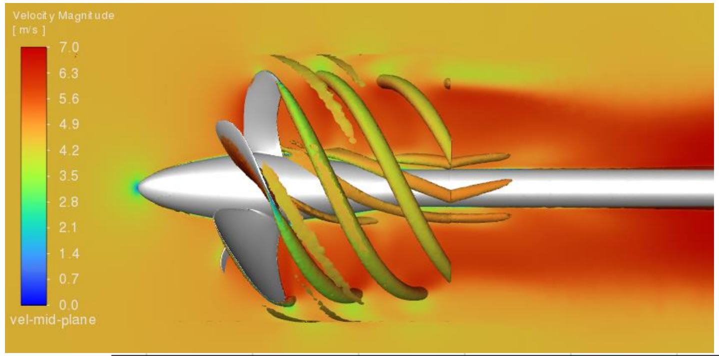
Propeller ↔ Hull

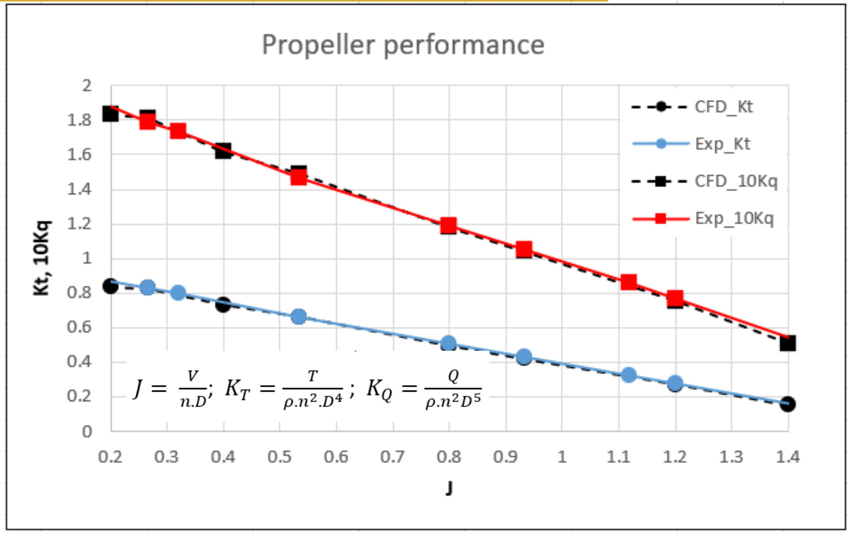
Angular to Linear Power Relationship





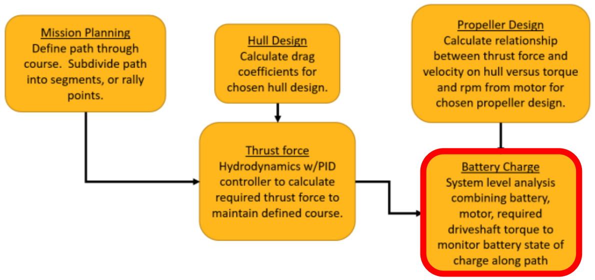
- Relate the power from the motor (torque * ω) to the power needed to navigate the ship (thrust force * velocity) across operating conditions
- The Potsdam Propeller Test Case (PPTC) [1] is simulated and results are validated against experimental data [2]. The propeller model is VP1304.
- The experiment [2] was an open water test in *pull* configuration. The thrust, torque, number of revolutions, and the inflow speeds are measured throughout the tests and results are compared to CFD simulations using Ansys Fluent.
- The comparisons are performed for thrust coefficient (KT) and torque coefficient (KQ) with different propeller advance ratio (J).
- The boat speeds studied in this work range from 0.5-4.5 m/s and propeller rotational speed of 600 and 900 rpm. A reduced order model (ROM) is extracted representing the transfer function between linear and angular power



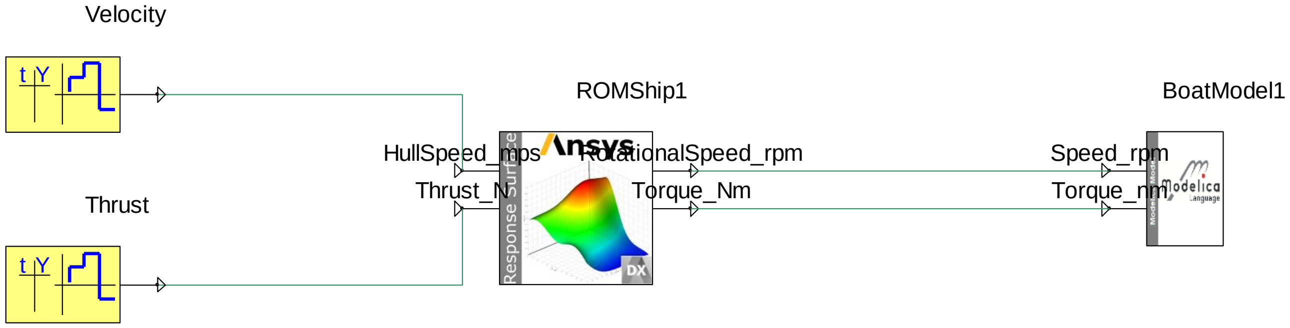


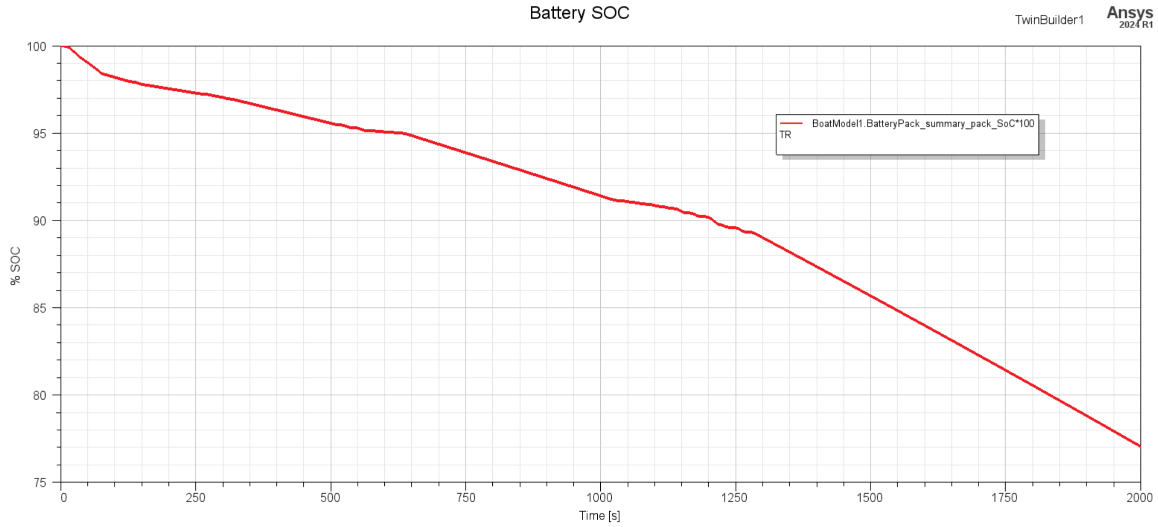
[1]: https://www.sva-potsdam.de/en/pptc-smp11-workshop/#openwater
[2]: https://www.sva-potsdam.de/wp-content/uploads/2016/04/SVA_report_3752.pdf

System Simulation



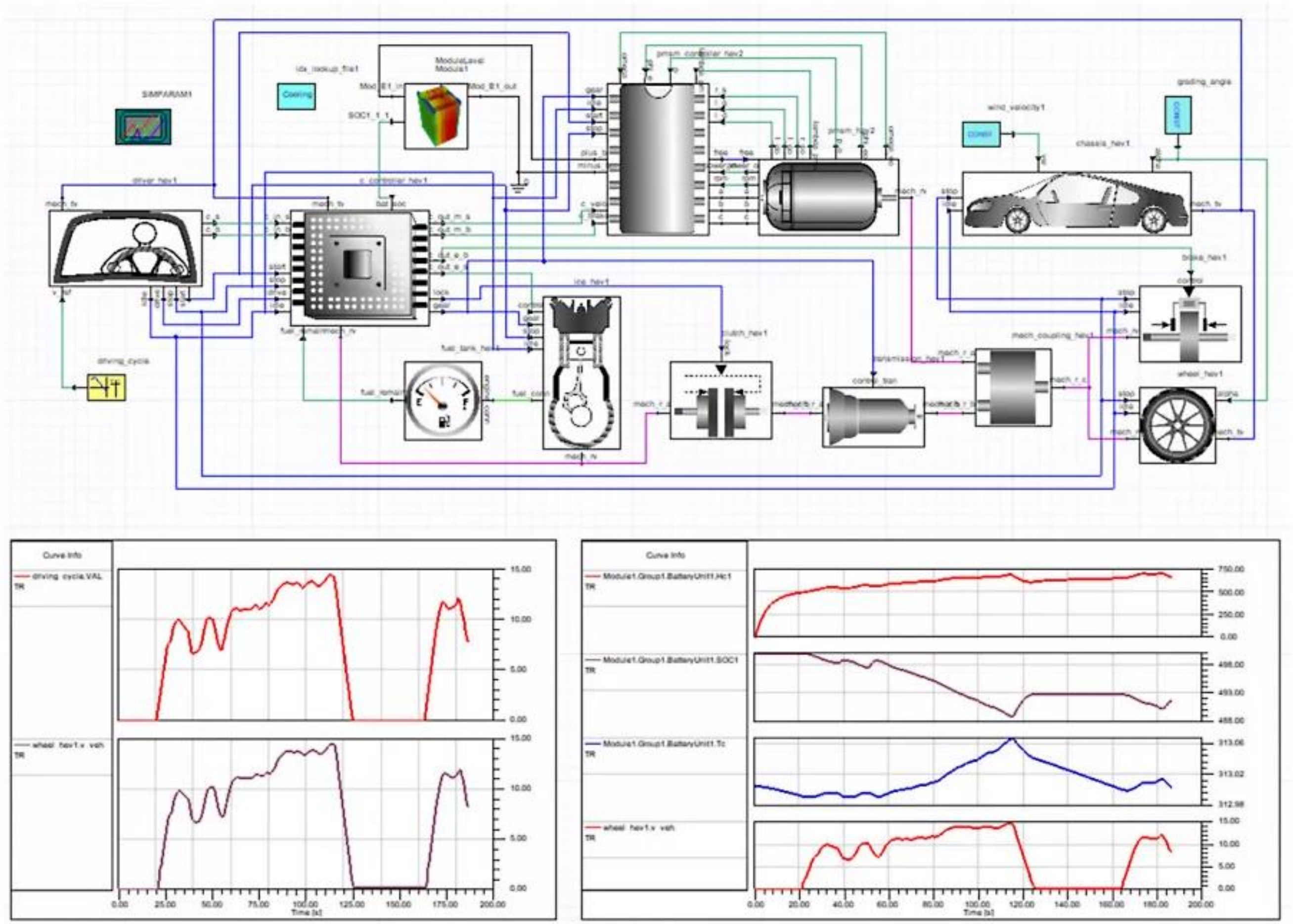
- Input thrust and velocity time history
- Linear vs Angular Power ROM
- Boat Model
  - Motor
    - Inputs: Electrical Load
    - Outputs: Torque (average during segment)
  - Battery
    - Inputs: Capacity, initial charge, load/power demand
    - Outputs: State of charge, voltage, temperature





Extend System Simulation to Digital Twin

- Calibrate system model using T&E data
- Instantiate calibrated system model for each physical asset in the field
- Feed digital models data from each asset
  - Manage thermal issues
  - Create battery mgmt. systems
  - Mission planning
- https://www.ansys.com/blog/charge-up-ev-development-with-battery-digital-twins



Electric Boat – Virtual Planning, Monitoring and Execution

Define path
(X_i, Y_i)

STK

Thrust force
(t_j, Fx_j, Fy_j)

Time domain vessel controller

Control parameters

Thrust force , velocity

AQWA

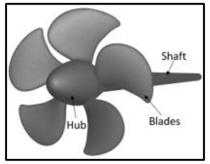
Motor torque and energy demand

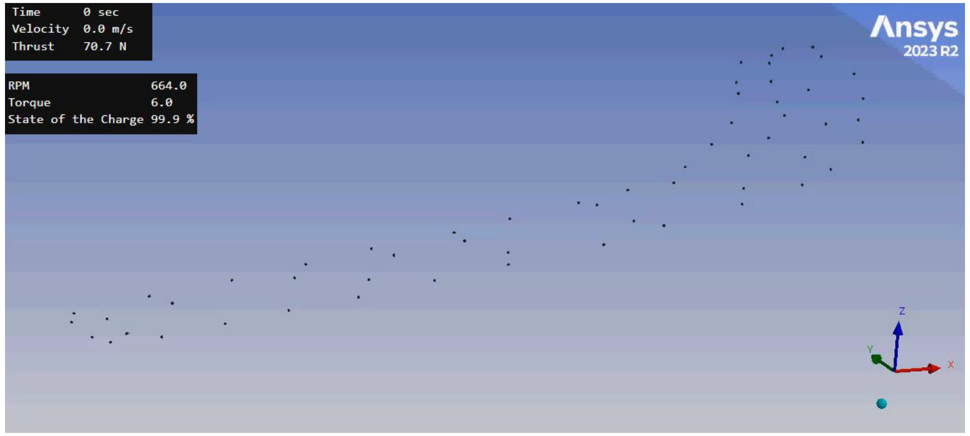
Twin builder

Hull, propeller model
(contains vessel geometry, mass properties)

Fluent

Vessel, propeller ROM





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