Submarine Delivery Agency

An Investigation on Capsize Dynamics with CFD and Time Domain Methods

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Agenda

- Introduction
- Methodology
- FREDYN Simulations
- CFD Simulations, Results & Discussion
- FREDYN vs CFD Results Comparison
- Conclusions
- Future Work & Recommendations

Introduction

- The stability of naval vessels traditionally been assessed against static measures (eg. GM, GZ)

- This approach is generally successful, but it doesn’t take the dynamic effects in a seaway.

- In the recent years there has been increasing interest how to implement these dynamic effects.

- Naval Authority and Technology Group (NATG) is working with Collaborative Research Navies (CRN) to develop dynamic stability criteria for Large and Small Combatants to minimise the capsize risk.

- In the recent years CRN released dynamic stability criteria for large combatants by using GZ area, by using the time-domain seakeeping & manoeuvring assessment tool FREDYN.

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Introduction

- This presentation investigates potential use of CFD Capsize estimation of a self-propelled OPV in rough seas

- This assessment aims to:
    - Minimize the reliance on tank tests for validation
    - Obtain validation data to develop FREDYN motion estimations (Global)
    - Obtain validation data to gain further understanding on appendage contributions (Local)

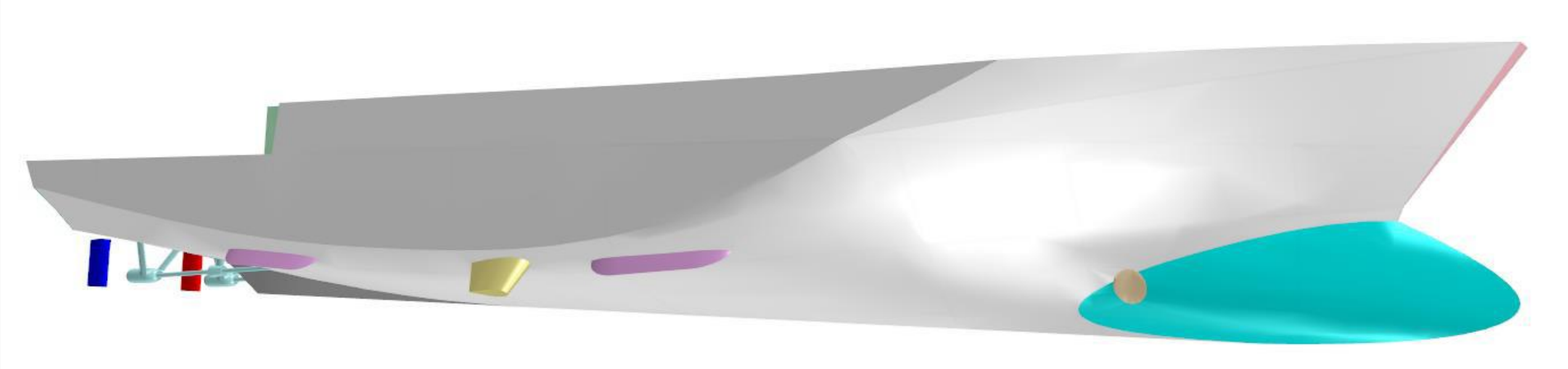
Methodology

FREDYN Simulations

- Identification of two worst case capsize scenarios by performing FREDYN simulations in regular waves for UK OPV.

CFD Simulations

- Perform CFD simulations for the two identified worst case simulations in regular waves.



FREDYN Simulations

- Loading conditions were selected as:
  - Light Seagoing with Operational KG
  - Light Seagoing with Critical KG
- Loading conditions have been tested in regular waves at following wave conditions and speeds in stern quartering seas:

				Wave steepness (H/λ)		
				0.06	0.08	0.10
λ/L	Wave Length, λ (m)	Wave period (s)	Wave frequency (Hz)	Wave Height (m)		
1.00	73.6	6.9	0.15	4.4	5.9	7.4
1.25	92.0	7.7	0.13	5.5	7.4	9.2
1.50	110.4	8.4	0.12	6.6	8.8	11.0
1.75	128.8	9.1	0.11	7.7	10.3	12.9
2.00	147.2	9.7	0.10	8.8	11.8	14.7

Ship speed (kts)	Ship speed (m/s)	RPM in FREDYN	Froude number
16	8.23	132.5	0.31
20	10.29	155.1	0.38
24	12.35	214.2	0.46

FREDYN Simulations

- FREDYN simulation results were interrogated
- The table of dynamic instability event measures was used to extract information relating to capsize probability from each simulation. A run summary table was produced
- Runs were conditional formatted and interesting/dynamic cases were highlighted based on different dynamic instability events & capsizes.
- 2 Critical KG Cases were identified with only change in the wave steepness.

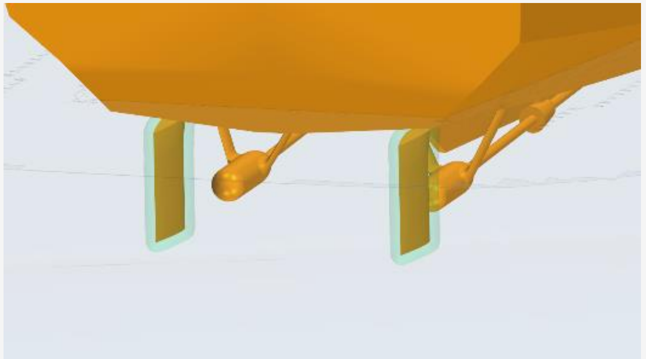
Event	Time (s)	Ship Speed (kts)	Yaw angle (deg)	Yaw rate (deg/s)	Roll angle (deg)
Surf Riding	Speed increase is maintained for 10s or greater (full scale)	Ship speed is within 10% of the wave celerity.	N/A	N/A	N/A
Major Broach	N/A	N/A	Yaw angle deviates 25deg from intended heading.	Yaw rate is above 3.0deg/s	N/A
Minor Broach	N/A	N/A	Yaw angle deviates 15deg from intended heading.	Yaw rate exceeds 1.5deg/s.	N/A
Extreme Roll / parametric roll	N/A	N/A	N/A	N/A	Repeated instances of roll angles exceeding 30deg.
Capsize	N/A	N/A	N/A	N/A	Roll angle exceeds 70deg

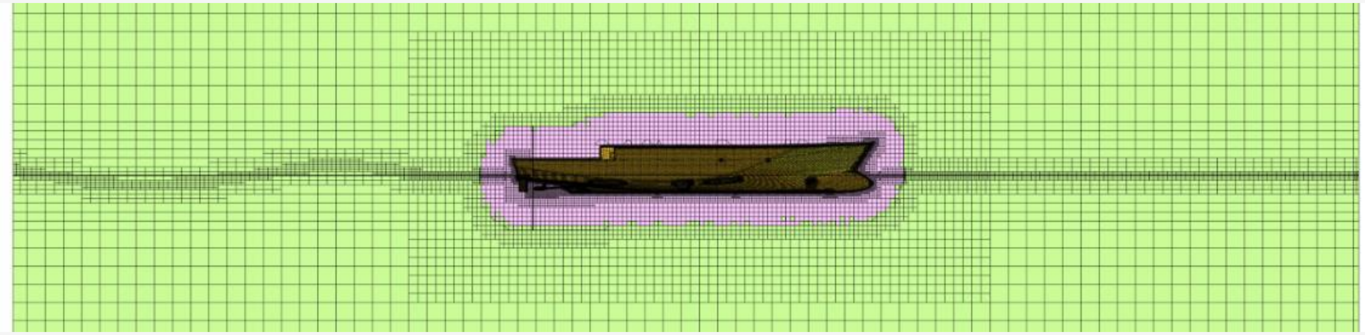
	Wave Period (sec)	Wave Height (m)	Wave Steepness (H/λ)	Speed (kts)	Heading (deg)	Run Status	Max Time (sec)	Max Roll (deg)
Case 1	6.9	5.88	0.08	20.0	30.0	CAPSIZE	48.5	88.3
Case 2	6.9	4.41	0.06	20.0	30.0	UPRIGHT	500.0	54.1

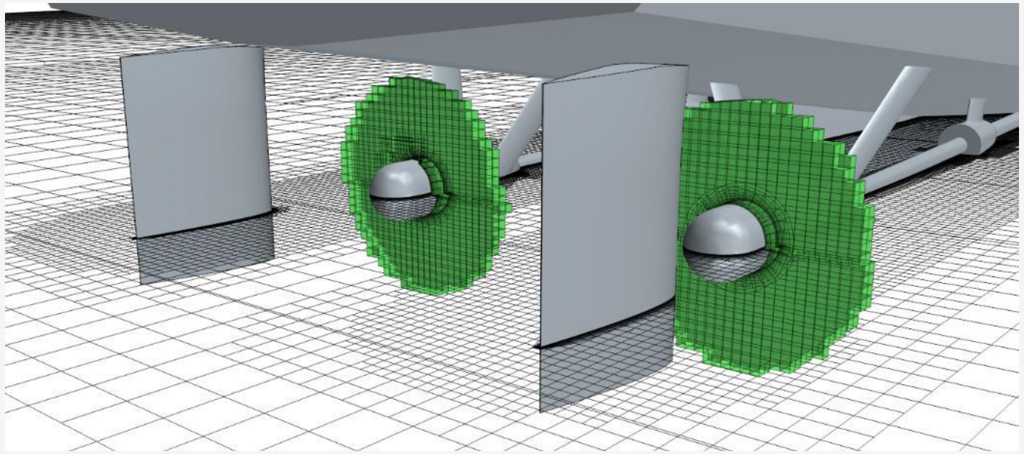
CFD Simulations

Following simulation settings were applied:

- Full-Scale, 6DoF, Dynamic Fluid Body Interaction (DFBI) Model
- Overset domains for the hull and rudders.
- URANS, SST K-Omega Turbulence Model
- Wall function treatment
- Adaptive Mesh Refinement (AMR)
- Actuator Disk with constant RPM
- Rudder Autopilot

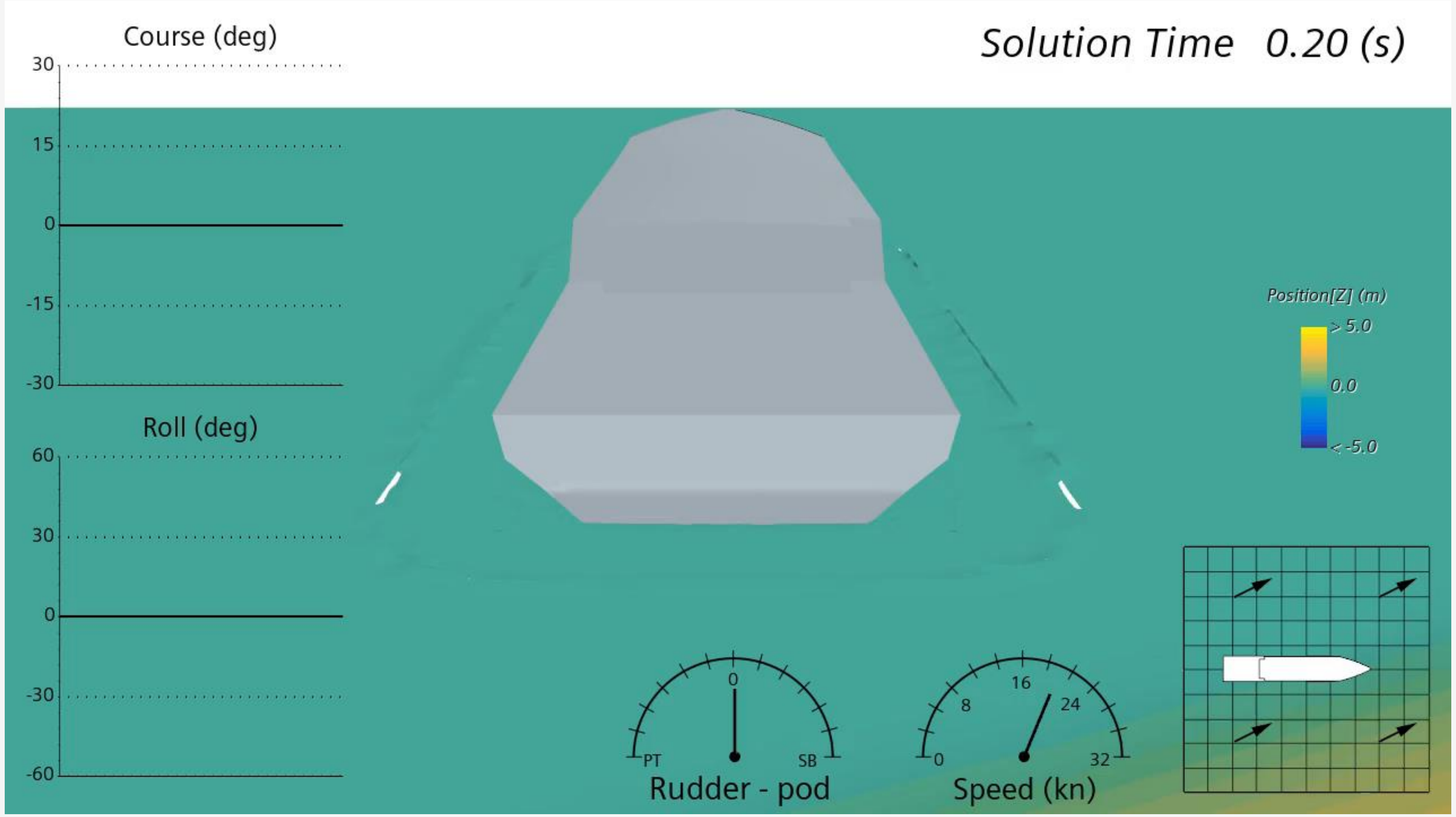






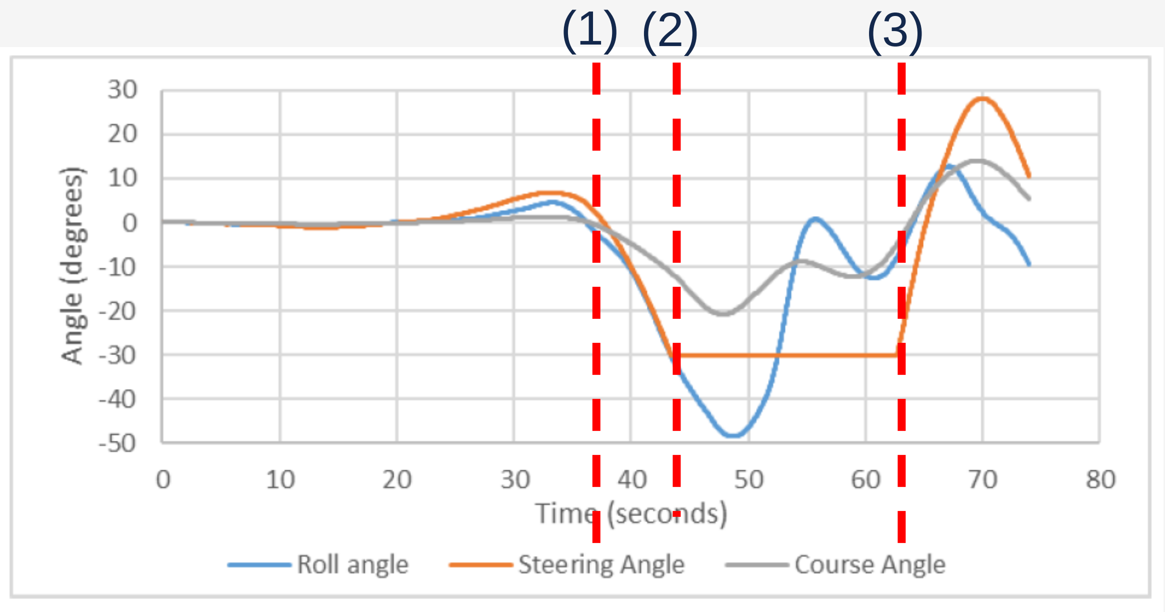
Results and Discussion: Case 1

- Case 1 – FREDYN predicted capsize at 48.6s, but CFD did not!



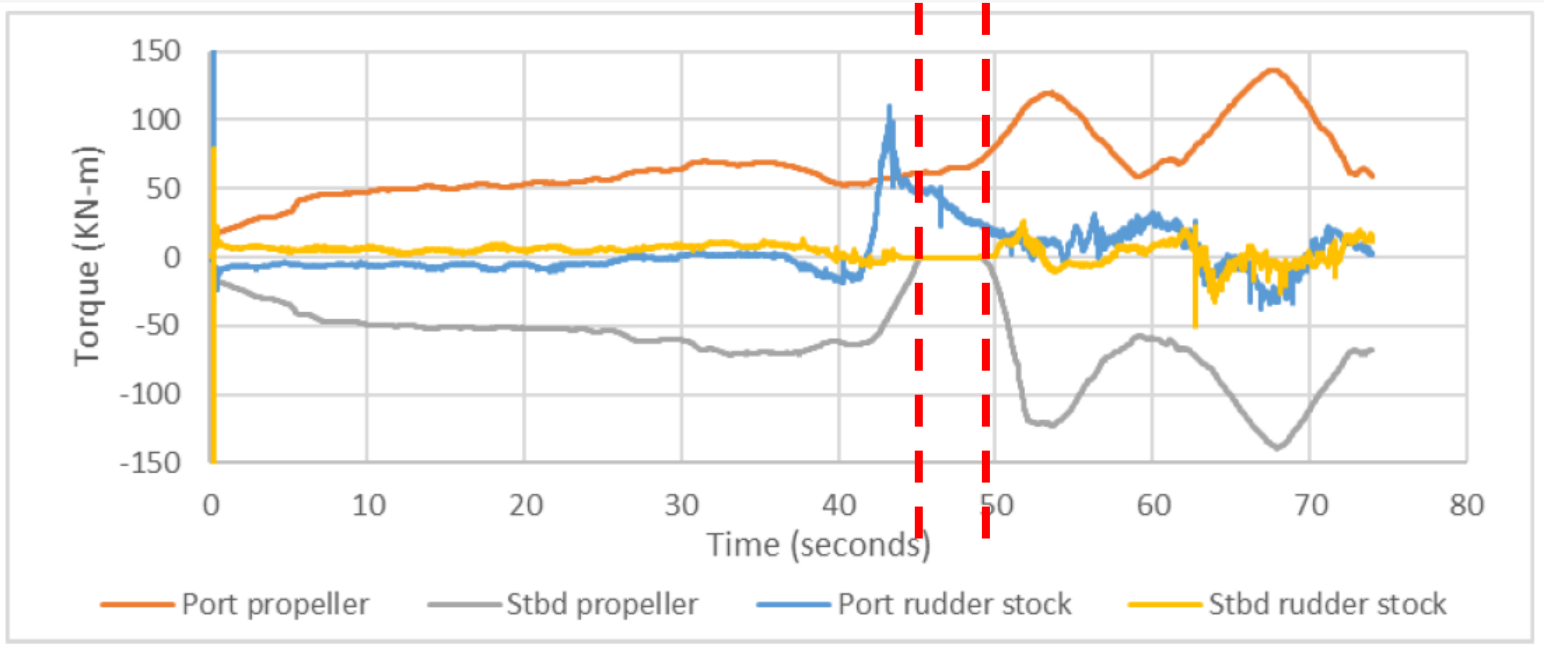
Results and Discussion: Case 1

- Figure below plots time histories of roll, rudder steering and course angle.
- At 37s vessel begins to roll to port and turn starboard due to approaching wave from astern. (1)
- As motions increase autopilot effects are more pronounced and at 44s rudders fully locked to port.(2)
- Wave propagates towards bow the vessel begins to right itself
- Once the bulb is submerged, vessel regains its intended course. (3)



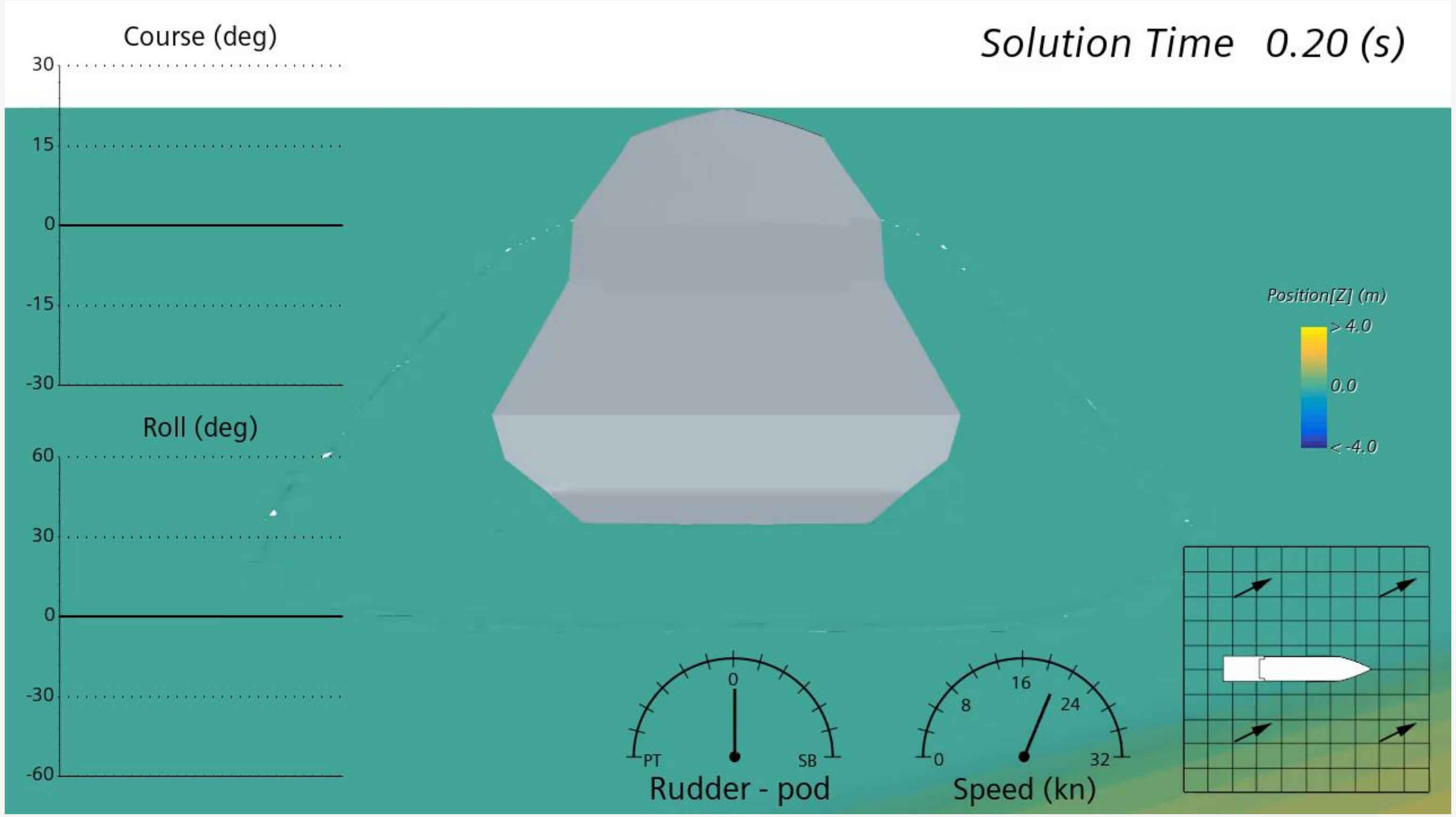
Results and Discussions: Case 1

- Figure below plots time histories of propeller and rudder stock torque.
- Between 44-50s when the vessel is rolled over to port, starboard rudder and propeller is completely out of water.



Results and Discussion: Case 2

- Case 2 – Both FREDYN and CFD Estimations were UPRIGHT.



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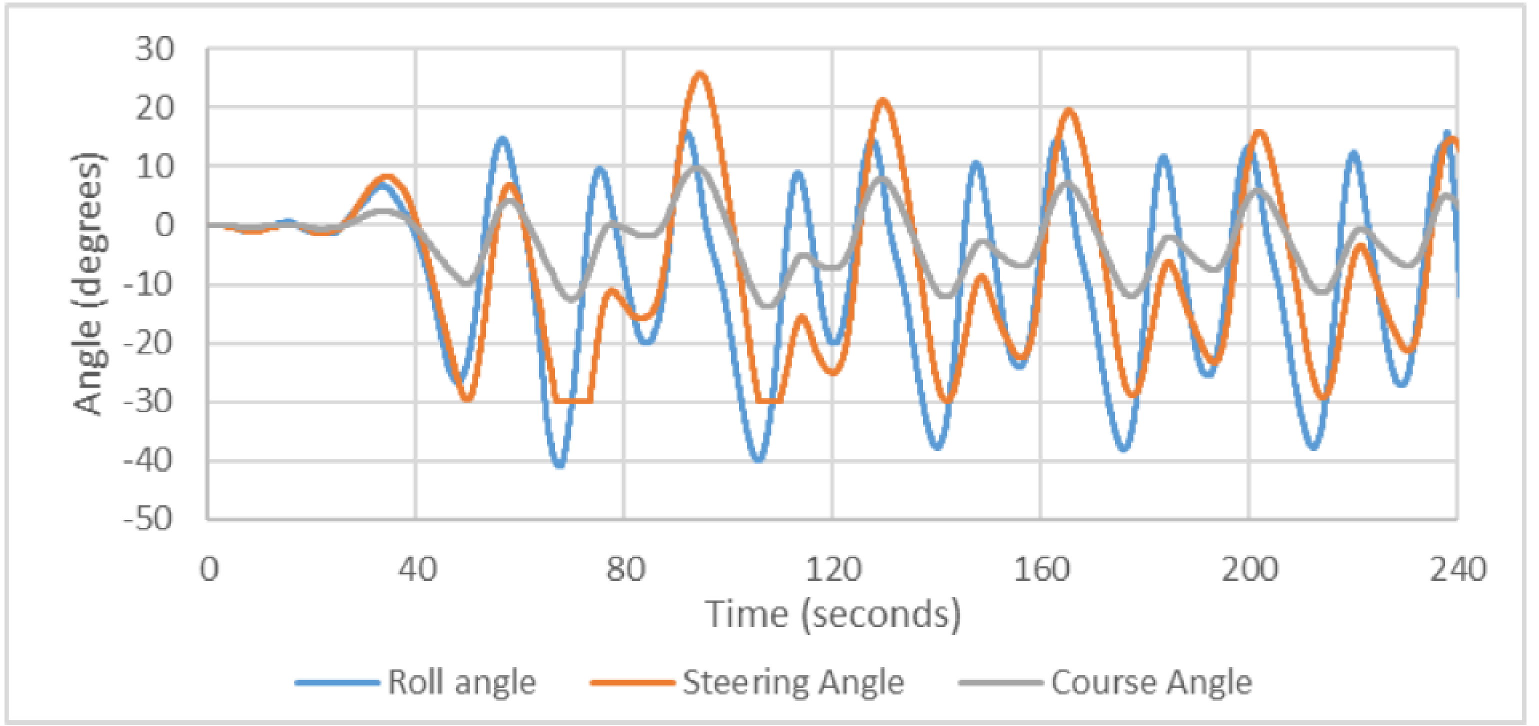
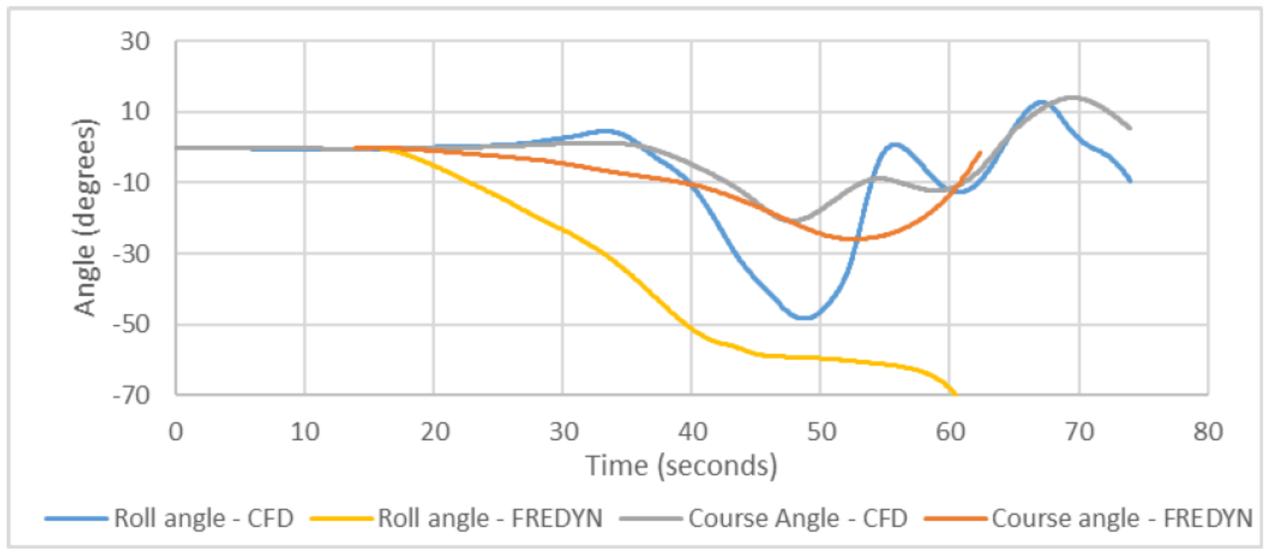
Results and Discussion: Case 2

- Case 2 is more stable, while starboard propeller and rudder is partially submerged in most times.
- Figure below plots time histories of roll, rudder steering and course angle.
- First observed large roll was 26°, after each wave pass vessel rolls ~40°.
- At large roll instances, rudders only fully lock a for a short time, while the vessel able to maintain its course.

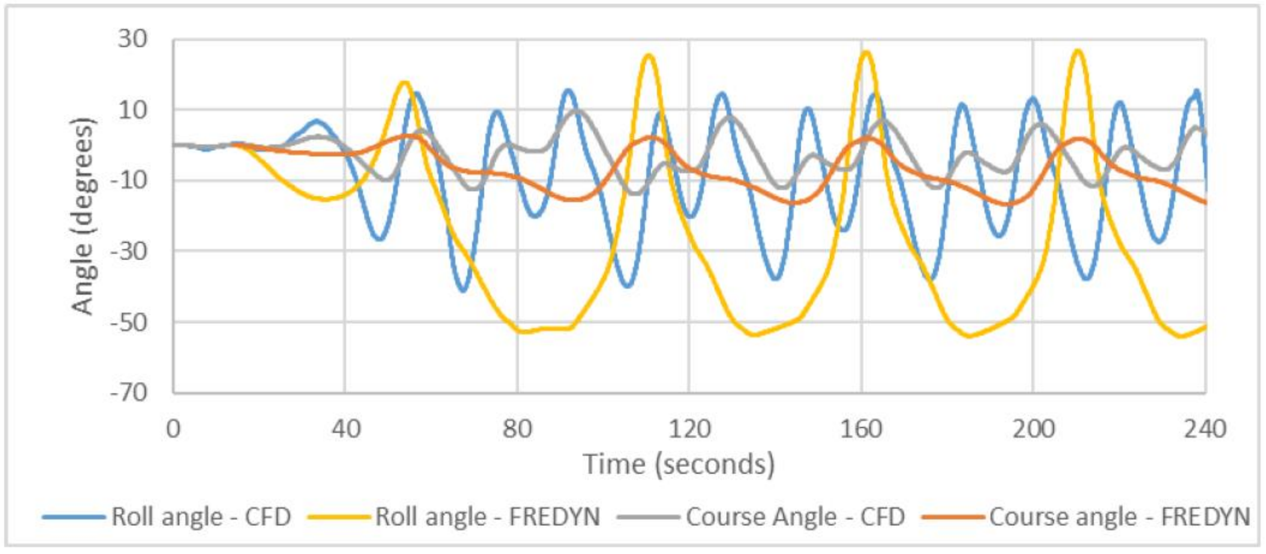


FREDYN vs CFD: Case 1&2

- Figures show roll and course angle estimations for CFD and FREDYN.
- Case 1, Evidently, the vessel rolls significantly in the first developed wave and FREDYN cannot recover while CFD recovers.
- Case 2, Both tools constantly right themselves following significant roll angles.



Case 1



Case 2

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Conclusions

- A CFD methodology has been developed for simulating a self-propelled OPV in 6DoF with rudder Autopilot.
- Relying on similar OPV model tests CFD shows better accuracy compared to FREDYN.
- CFD simulations are promising for future assessments, however they are not without issues:
  - Turbulence related instabilities
  - Non-linear iteration instabilities
  - Overset mesh interpolation errors
  - Adaptive Mesh Refinement issues
  - Wave breaking mesh refinement issues
- Sensitivity Analysis: Mesh size and non-linear iterations effect were higher compared to time step.
- CFD takes a lot time, (eg. Case 1 ~85 hrs and Case 2 ~130 hrs with 256 cores!)
- FREDYN each simulation takes less than 5mins!

Future Work & Recommendations

- Comparison of CFD and FREDYN results with actual model tests.
- Developing methodology to directly compare hull and appendage forces in CFD and FREDYN.
- Better use CFD for FREDYN development and in-depth investigation of critical cases, where model test cannot provide data.
- Reduce computation time with larger meshes and advance use of AMR.

Questions?