The application of physics-based 3D modelling software in ship design and manoeuvrability trials

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Synopsis

Design of naval vessels goes through rigorous preliminary design, critical design, and detailed design phases. Although experience is essential for designers and engineers during ship upgrade, the use of block diagrams and charts to represent the design challenges in maritime application often results in misconceptions, with the required outcome not fully realised. The integration of 3D modelling and visualisation in ship design and operation is favourable when presenting complex design and procedures. These methods aid in observing technical limitations that might otherwise be obscure. The use of physics-based 3D modelling is a continuously growing hybrid modelling technique that blends particle effects with ship design. These procedures allow for a holistic representation of the asset in its natural environment and under predictable sets of conditions. The research presented in this paper illustrates how 3D modelling can accurately be used to represent and evaluate a surface ship under simulated working conditions. Selective serials and protocols were recreated based on mock-up vessel in a marine environment in adherence to classification rules. The use of particle physics extension related to water and weather effects were added to simulate real-life fog formation during channel transit. The use of 3D configuration was applied to a patrol boat to demonstrate the changes implemented instantly without the need for reengineering, particularly at earlier stages of the contract.

Keywords: 3D Design, Blender 4.1, manoeuvrability test, random seed, wake generation, classification rules,

1. Introduction

Naval architects leverage advanced three-dimensional (3D) modelling software to create intricate digital representations of ship hull and complex geometries. By simulating various design configurations and operating conditions, designers can iteratively refine vessel designs, optimising hydrodynamic and other performance metrics such as speed, stability, and fuel efficiency while ensuring compliance with regulatory standards and safety requirements.

Moreover, the integration of 3D design technologies allows for interdisciplinary collaboration of specialised project teams. DNV has founded the Open Class 3D Model Exchange (OCX) which allows 2D drawings to be replaced with 3D model in the ship publication . This standard has already planted its roots with major marine and offshore players such as NAPA, Lloyds Register, Bureau Veritas, and DAMEN and further endorsed by classification rules (IMO, 2002) (ABS, 2017).

The designing of a ship goes through a design spiral (Wang & Pegg, 2022) (Paik & Thayamballi, 2006) which lays down a sequential set of requirements. A digital twin becomes a more relevant approach, (Wang & Pegg, 2022). In a study (Uzcategui, et al., 2018) focusing on pipe fitting and assembly during different stages of assembly, the complexity of the measurement process resulted in uncertainties. A 3D scanning gave accurate representation of the open ends where the pipes would be fitted. The deviation of connections are relatively regular resulting in a nonuniform closure with spools, these anomalies might appear during fine coordination with the manufacturing and workshop teams. The visualisation achieved in the study was sufficient to determine potential misalignment of the mock-up assembly.

A study focusing on submarine design by (Fernandez, 2020) highlights the importance of submarine design using a concept of the internet of things (IoT) where Computer Aided Designs (CAD) is seamlessly integrated with Product Lifecycle Management (PLM) of a new submarine design. The aspect of industry 4.0 refers to a database of CAD approved calculations and boundary conditions which help with future designs and limiting computational effort and human dependence. This technique allows individual teams to visualise the isolated system with more focus, and with the use of 3D design, the possibilities of oversight are considerably minimised.

Author's Biography
Dr.Eng. Talal M. Alhajeri is a Principal Naval Architect, Marine and Petrochemical Engineer. He is the Founder and Chief Technology Officer of Mekhtaf Design and Engineering Firm., Abu Dhabi, UAE. A Member at IMarEST, Affiliate Member at IChemE, and Member at SPE. He has a background in Naval Architecture and Marine Engineering, Chemical Engineering, and Petroleum Engineering. His experience includes holding the position of the Head of Engineering Integration Programme, Class Refit Manager, Senior Ship Class Engineer, Marine Engineering Officer, and Damage Control Engineer. He worked on several major projects ranging from CODAD power and propulsion system for a Naval Corvette vessel, Ship retrofit, conversion, and overhaul, design and integration of advanced weapons system on surface ships.

The techniques used in this study are intended to showcase the application of 3D tools in ship design and modification, ship test and trials with emphasis on maritime operations (Ffooks, 1993), and simulating limited visibility weather conditions.

2. Vessel Manoeuvrability using a Simulation

The use of 3D tools to demonstrate sea acceptance trials (SAT) is intended as a visual isometric representation of the operation plan. Due to the excessive size of the cache and the exceedingly long animation rendering periods, the animation was captured using viewport resolution set to 1024p sample size running a timeline of 100 frames. The optimum application for higher resolution production would be applying the baking feature to embedded textures and materials followed by rendering using a cycle engine with 4096p sample size and enable denoise feature.

Table 1: Ocean and Wake Properties

Setting	Variable	Value	Units
Ocean	Viewport Resolution	10	px
	Render Resolution	10	px
	Time	0.05-5.05	s
	Depth	3.00	m
	Size	200 x 200	m^2
	Spatial Size	50	
	Random Seed	0.00	
Wave	Scale	1.00	
	Smallest Wave	0.00	m
	Choppiness Factor	1.00	
	Wind Velocity	30	m/s
	Spectrum	Established Ocean	
Simulation (Ship)	Velocity	20	m/s
	Particle Density	250	
	Age	200	
	Particle Radius	0.02	m
	Ocean Velocity	1.00	m/s
	Noise Amount	0.002	
	Secondary Noise	0.100	

The properties of the simulation from Table 1 were used as presets to observe ship motion instead of inforgraphic representations. For the simulation the ocean parameters viewport and render resolutions were set to

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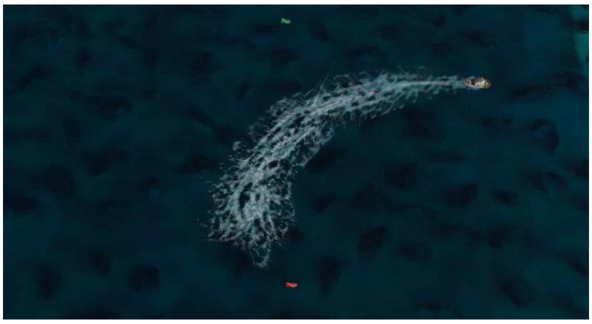
10 pixels, this value makes the assets sharper in the viewport but can also affect simulation period. The time for the ocean simulation ran from 0.05-5.05 seconds, which is equivalent to 100 simulation frames, the delay is mainly due to loading assets into the viewport. The ship path was also simulated over the same 5 second period and for 100 frames, with the aim of capturing the effect of ship wake on ocean surface. The depth of the ocean domain was set to 3.0 m, and the size of the ocean surface was set to 200 x 200 m^2, which is equivalent to 4.00 in viewport grid measurement. The spatial size was set to 50 and the random seed value which controls details in the scene was set to 0, indicating randomness at default value.

The wave parameters were set to closely resemble an established ocean surface. The choppiness factor is essentially a roughness factor of the wave crest and trough which is set to 1.00. The scale of the wave reflects the cycle of each wave which is set uniformly at 1.00 for all generated waves in the viewport. The size of each wave is determined by the minimum value of 0.00 m and the highest rising crest based on wind velocity set at 30 m/s and direction.

The ship simulation was based on a conventional type of salvage tugboat with a velocity set to 20 m/s which is equivalent to 38.8 Knots. The particle density is set to 250, indicating the wake density when disturbed by generated waves and ship motion. Age refers to the wake particle retention period before complete decimation in the ocean surface domain. The particle radius is set to 0.02 m; the wake particle size would be bigger closer to the source, however due to the impact it would have on simulation and its dependency on randomness factor it was sufficient to rely on the Age variable to illustrate wake behaviour. The ocean velocity is set to 1.0 m/s when excited by ship movement where the highest value is for particles close to the ship submerged surface and displaced water. The noise amount was set to 0.002 which is another variable that affects wake behaviour, the higher this value the more pronounced the wake becomes. Noise is also directly correlated with Age; if the wake has a longer Age and a low noise amount, this will translate to a subtle but elongated footprint. The effect of these two dependent variables becomes more noticeable in a turning circle manoeuvre after completing 540° turn.


Turn STBD


Turn PORT

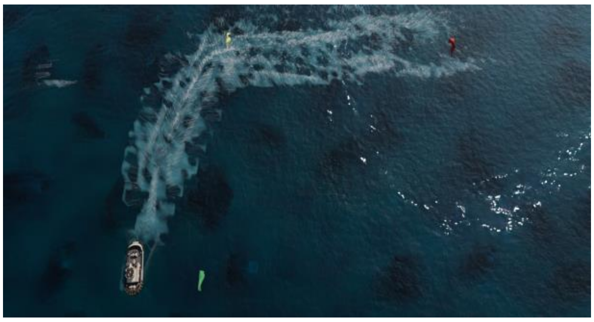

Straight Line


Full Astern

Stopping Distance

Turning Circle

10/10 Zigzag



Pullout Test

Figure 1: Sea Acceptance Trials

The images from Figure 1 demonstrate the different sea acceptance trials conducted using blender to model ship behaviour in an established ocean environment. The red and green flags represent the start and finish points over a distance 100 m approximately. The principal idea behind these productions is to give a detailed look at manoeuvrability crossings and ship behaviour.

The wave and wind conditions were based on the values presented in Table 1 which demonstrate the flexibility to adhere to various desired specifications. The ship path in both the starboard and port direction was drawn with approximately 10 vertices. The specific degrees of freedom including heave, roll, and pitch were handicapped to limit dynamic interference with wave motion. Moreover, the floating domain around the ship to model buoyancy requires integrating a shrinkwrap modifier which is not compatible with the wake generation pipeline.

The turning ability is a trial used to determine the vessel’s wheelover using hard-over rudder in the starboard and port direction. Normally these types of trials are used to examine the rudder performance and ship handling and stability criteria including a follow-up shipwright ability particularly when used with a pullout test.

The straight-line trial is intended to measure the ability of the ship to stay due course regardless of environmental factors. The heading of the ship might change from the forward bow, however the deviation of course at different speeds is measured to determine the appropriate corrective actions. The simulation test conducted shows some deviation from course due to a uniform maximum ship speed and a preset wind and wave speeds.

The Full astern test conducted shows excessive veering off path, which is to be expected since the ship submerged volume is not designed to have a course keeping straight profile. The images demonstrate excessive wake on the port section indicating a ship resistance against incoming lateral wind. The results have successfully captured an accurate representation of the full astern trial.

The stopping distance trial was used to establish the number of ship lengths required before the ship comes to a complete stop by turning the rudder to full astern position from maximum forward speed. The results from the simulation show the head reach manoeuvre with an approximate 10 ship lengths, a similar trial can be achieved for the standard of 15 but not exceeding 20 ship lengths in addition to the track reach manoeuvre (ABS, 2017).

The turning circle trial was used to demonstrate a hard-over rudder in both the starboard and port direction with a 540° turn. One of the challenges associated with demonstrating this track was related to the effect of wake from the first circle on ship motion on the second half turn, this could not be demonstrated accurately in our trials. Moreover, self-collision between generated wake profiles at higher frames is not pronounced, however this could be due to the age value and low noise amount. In a practical sense these discrepancies are often neglected in operations and are only ever considered in hydrodynamics testing facilities.

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The 10/10 zigzag manoeuvre is a slimmed down version of the 20/20 trial both of which are conducted at various rudder angles and in both the starboard and port direction (ABS, 2017) (IMO, 2002). The simulation was able to demonstrate a fraction of the 10/10 wake profile but not the entirety of the run. The limitation of the simulation run to 100 frames mandated a short profile; alternatively, the ship speed could have been increased beyond 30 m/s to capture the entire run.

The turning ability followed by a pullout test is demonstrated to indicate a lighter version of consecutive trials. The IMO standards require a detailed calculation of the first and second overshoot angle in a 10/10 zigzag manoeuvre (IMO, 2002); it is therefore possible to integrate the expected readings into the simulator to provide a more accurate result.

3. Simulation Based Channel Visibility During Channel Transit

The effect of sea state and wind although equally important, are generally manageable and predictable. Dangers associated with fog manifest in hazards related to collision, grounding, moisture build-up in sensors, and GPS. Navigational aid following rules of the road, and helmsman orders become increasingly relevant throughout this period. Extra hand at the bridge for lookout affects the sea trial inspection process as it is likely that the bridge would be overburdened with personnel carrying out duty watch whilst conducting a set number of trials.

The simulating of fog effect prior to the scheduled trials is difficult to produce, and although weather forecasts can predict visibility levels using curated meteorological databases, the actual visualisation of the fog density effect cannot be captured with readings. Moreover, since the specified vessel needs to navigate tight corridors and waterways outside the channel into open waters, it is likely that port control station (PCS) and the harbour master will be involved. The allocation of a pilot and possibly a salvage boat for this operation becomes part of the of hazard mitigation plan; all these preparations, increase the associated cost to conduct those trials without completely emitting the possibility of a retrial.

The methodology prepared in this section is intended to show how procedure generated fog in a 3D simulated environment can be used as an intermediate solution to vector maps generated by expensive computational fluid dynamics software. To better understand the situation at hand the viewport assets consisted of a channel buoy at 50m from the cursor (resembling the bow of the ship). The channel buoy is fitted with a light (green) emission source. The location of the buoy is on the starboard side indicating a downstream transit. The light specification of the emission source follows the standard commercially available lighting aids at 400 W. The simulation domain resembling the boundary conditions was created with the dimensions of (68m x 55m x 24m). Further details related to fog simulation specification have been selected based on presets and indirect correlation with visibility using trial and error.

Table 2: Fog Seeding Simulation Details

Fog	Seed	Scale	Details	Roughness	Distortion	Min	Max
Fog 1	Variable	0.680	4.700	0.669	0.000	0.750 – 0.500	0.000 – 49.840
Fog 2	0.500	0.680	10.700	0.669	0.000	0.590 – 0.000	0.000 – 49.840

The presets of the procedurally generated fog are presented in Table 2 which shows the parameters used in the simulation to study visibility of a channel buoy at 50m away from the surface asset. Fog 1 indicates a sea surface cluster and Fog 2 represents the upper cluster formation in the domain boundary box. The seed value is a dimensionless parameter used to identity the fog density in the sample volume, the scale is overall cluster expansion with a preset value of 0.680. The details factor represents the clarity of the fog particle; considering the effect this value has on image generation the values were set to default. Roughness is the inverse to the smoothness factor of the fog particle which also affects render time and quality, therefore set at default. Distortion is a procedurally dependent factor which randomly populates the domain volume based on the minimum and maximum bounds. The minimum bound is a range that determines where the minimum distribution is observed and the maximum bound is used to designate the highest fog density limits.

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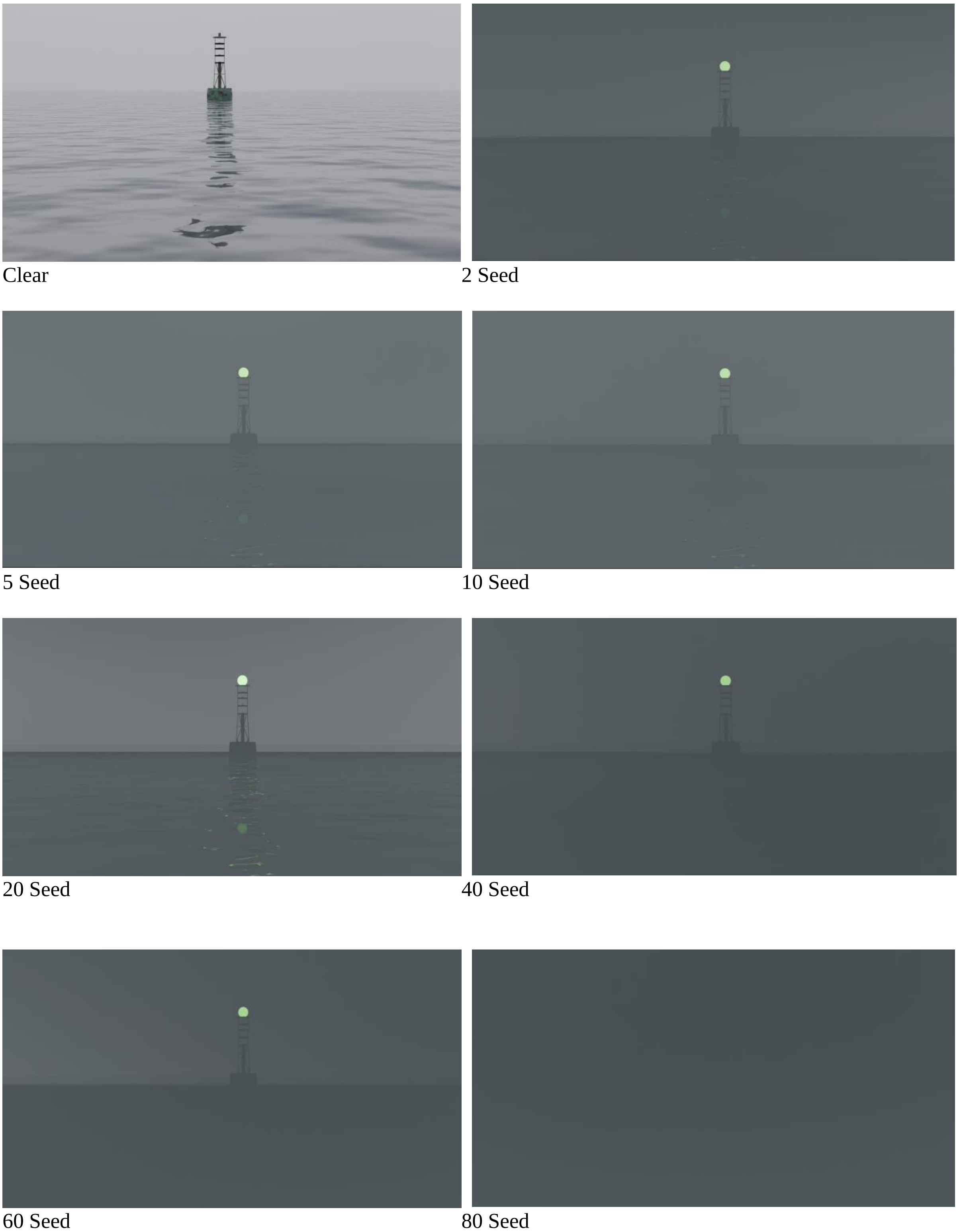

Figure 2: Fog Density Based on Seed Value

The images from Figure 2 show the fog density as determined by the seed value using a procedurally generated scatter distribution system. It is important to note that an increase in seed value should result in higher fog density and subsequently less visibility; however, due to the randomness of the system, the vantage point selected might show a cluster that is less dense when viewed from a different angle. This observation is particularly noticeable when moving from a 10 seed render to 20 seed render result, the immediate observation show clearer water surface

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with light reflection at higher seed value. The only feasible explanation to this condition would be that from the current viewpoint at 20 seed, the fog density appears less; after changing to incremental values of 24 seed the values restored to normal with the expected visibility shortage. At other incremental instances the values turned the buoy visibility to completely blind, similar to what is observed at 80 seed.

Although the fog simulation is not a direct representation of a physics based realistic metrological model, it is designed to provide a visual representation of conditions that are comparable to those encountered in an operational environment that might otherwise be difficult to represent.

4. 3D Vessel Configuration of a Petrol Boat

The use of 3D visualisation has a crucial role in modern ship design, offering several benefits throughout the design process. In this study the use of Blender 4.1 and Autodesk Fusion 360 was sufficient in providing a high-fidelity conceptualisation of various design iterations.

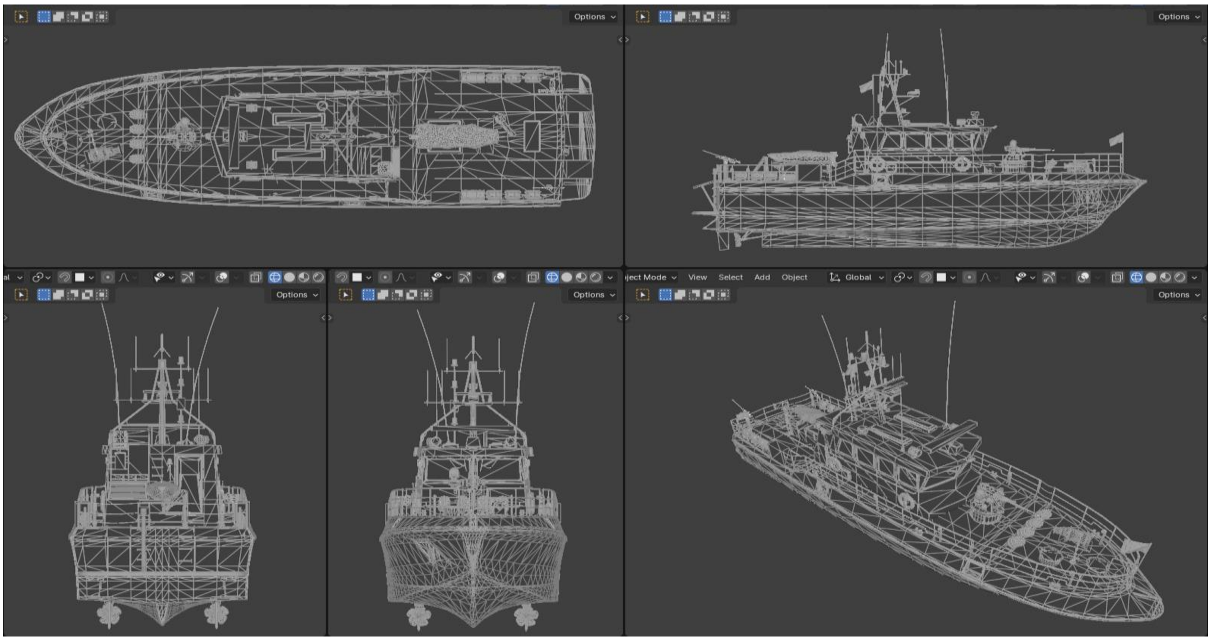
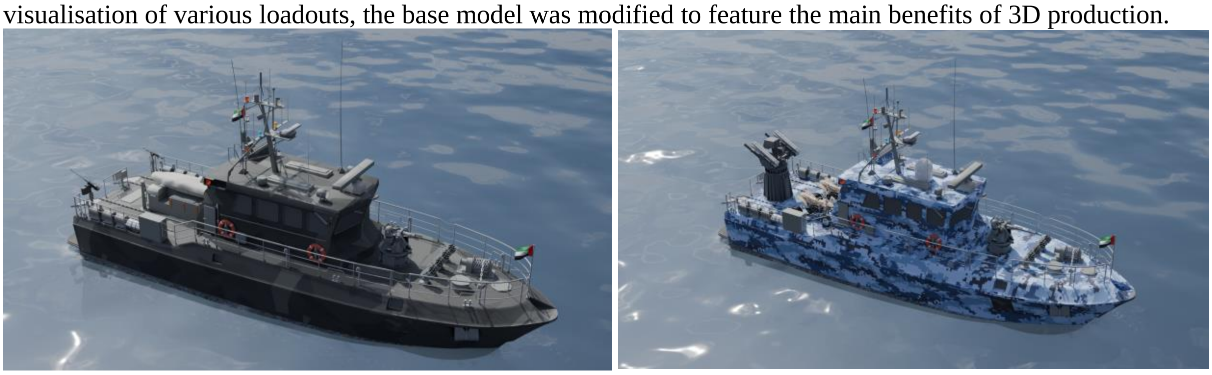


Figure 3: Patrol Boat Viewport Line Diagram

Figure 3 above the viewport shows the line drawing of a patrol boat in native format, the principal dimensions of the asset have been prepared using standard stereolithography (.stl) format which is a common form for 3D printing and CAD. The template was exported using .fbx and .obj files with embedded textures. The availability of the conversion extensions to the drawing file enables direct implementation of the visualisation tool and modification using various loadouts. The direct availability of the .stl format allows the user to modify the hull mesh and may also be used for detailed engineering studies that include stability, hydrostatics, and computational fluid dynamics (CFD). Moreover, the same file format when associated with 3D printing enables a low-cost model production using domestic 3D printers. These features can all be considered as passive advantages of 3D designs which ought to be mentioned but are not considered in this part of this study. In reference to the case related to visualisation of various loadouts, the base model was modified to feature the main benefits of 3D production.



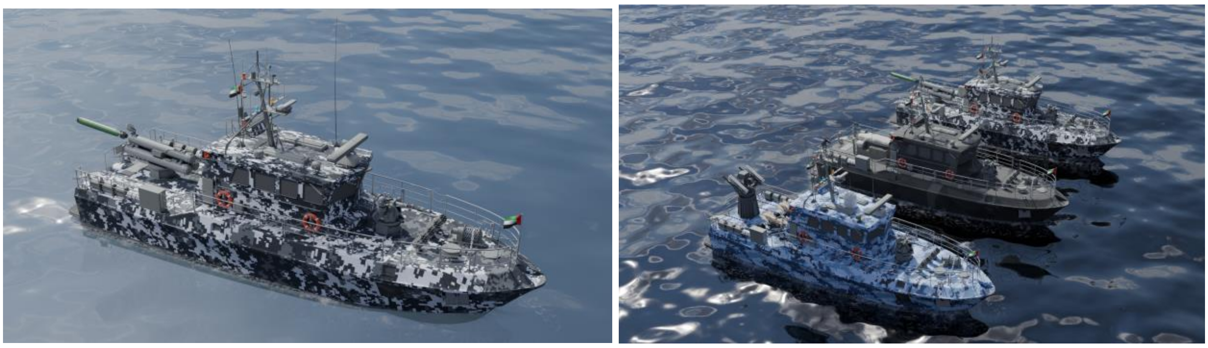


Figure 4: Patrol Boat Loadout, (a) Patrol Boat for surface intervention, (b) Patrol Boat for anti-air warfare, (c) Patrol Boat for anti-submarine warfare, (d) Heterogenous Patrol Boat Squadron.

Figure 4a shows a patrol boat fitted with a standard small caliber armament and modified to include a 25mm M242 Bushmaster remote weapon system. The specific loadout has been reworked to account for close quarter intervention particularly those associated with coastguard. The basic premise of this modification is to enable a detailed look at main gun upgrade whilst ensuring the vessel can conduct regular missions associated with maritime security, search and rescue, law enforcement, drug interdiction, and patrolling.

Figure 4b shows a version with a similar forward (SCG) but with a modified aft that removes a dedicated rigid hull-inflatable boat (RHIB) and crane and replaces it with a short range Pantsir-M close in weapon system (CIWS). The boat has been fitted with a satellite communication antenna on the superstructure and loaded the special operations all-terrain vehicles (ATV). The hull paint has also been applied with a blue electronic camouflage coating to illustrate the level of configurations that can be applied to the base model.

Figure 4c shows a version fitted with a similar (SCG) forward gun and with B515 ILAS-3 torpedo launching tube loaded with a A244S Mod-3 torpedoes. The hull has been layered with a black-white digital camouflage coating to identify it as an anti-submarine (ASW) surface vessel.

Figure 4d attempts to view all three variations in an ocean environment, which provides a visual queue of the effectiveness of the camouflage decal in a bright semi-cloudy HDRI backdrop. The endless permutations and possibilities using a 3D visualisation tool makes it possible to experiment with higher order loadouts without incurring any of the penalties associated with cost and engineering. It is also possible to reach a definitive selection of the required changes and the expected vessel roles when demonstrated using a life-like environment. This level of flexibility in design gives an otherwise missing feature to the end user in defining their requirements.

5. Conclusions

In the marine industry it is common for ships to undergo various tests and acceptance trials before they are approved for sea operation. Weather conditions play an instrumental role in defining the circumstances appropriate by an acceptance committee and the design changes to prepare for future growth. The necessity of these changes requires detailed approach in project management to mitigate the chances of unpredictable risks.

The first case study was based on showing how a visual representation of a sea-acceptance trial following the standard rules of classification societies. The visual production proved to be extremely useful in allowing any team to resort to visuals compared to a set of vector diagrams. The use of a 3D modelling software was able to capture different viewpoints of the trial complete with animation and wake generated by the surface ship. It is possible to extend these models to include more complex trials and to also alter wave and wind conditions for a more detailed simulation.

In second case study focused on using a physics-based pipeline to model a first-person point of view of fog surrounding the entrance of a channel. A navigation buoy was modelled at 50m distance from the ship bow and equipped with a light source to demonstrate how visibility is affected. The attempt to use a 3D modelling technique proved to be a solid transitional solution when a dedicated software is not readily available. The extent of the dependency on the fog generated model was intended as a demonstration of the capabilities in mimicking real-life situation thereby allowing necessary personnel to identify hazard situations that may require rescheduling.

The final case study was based on showcasing the various possibilities associated with selection of ship roles and armaments using a 3D modelling software. Considering the appropriate files are available, any type of ship modification can be applied for a quick loadout and saved in the asset browser for future use. The use of visualisation software in this study to prepare various loadouts of a patrol ship is a cost-effective method in displaying short term engineering changes without having to prepare detailed CAD drawings, this method is extremely effective when trying to find a commonality between the shipyard and the end user.

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3D software has continued to evolve over the years, allowing users accessibility that is otherwise locked behind an enterprise license. Digital solutions have emerged that now ensures all parties are directly involved in the design process as well as test and trials, where traditionally those have been confined by a knowledge barrier and experience. When decisions are made based on a shadow understanding of the situation, they become biased, the use of a 3D modelling technique in this research successfully attempted to replace the uncertainties that might have been present.

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