GAMMA TECHNOLOGIES

Charting the Future: System Simulation for Next-Gen Marine Engineering

This eBook will cover the extensive simulation capabilities offered by Gamma Technologies for marine systems

eBook

Learn more

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INTRODUCTION

Mission & Vision

Maritime transport is the backbone of international trade, carrying over 80% of the volume of global goods. As the industry faces mounting pressures—from stringent environmental regulations to the integration of alternative fuels and hybrid propulsion systems—the complexity of marine vessels continues to grow. This complexity necessitates a deeper understanding of individual components and their interactions within the broader system.

Simulation is no longer a luxury—it's a necessity. By leveraging multi-physics, system-level simulation, engineers can design, optimize, and validate complex marine systems long before they set sail. This includes detailed component modeling—from engines and batteries to fuel injection and thermal systems—that ensures each subsystem performs reliably under real-world conditions. Simulation enables smarter decision-making, faster development, and compliance with evolving international standards. As marine systems grow more interconnected and data-driven, the need for digital twins becomes increasingly critical—supporting continuous performance monitoring, predictive maintenance, and lifecycle optimization.

In this eBook, we explore how GT-SUITE empowers marine engineers to tackle modern challenges across the vessel lifecycle. You'll find insights on optimizing engine room systems, implementing alternative fuels, integrating thermal & energy management systems, mastering battery safety, and enabling predictive maintenance with digital twins. Whether you're designing the next-generation ship or retrofitting existing fleets, this guide will help you chart a smarter course.

ENGINE ROOM SYSTEMS ON-BOARD: A COMPLEX HEART OF MARITIME SYSTEMS

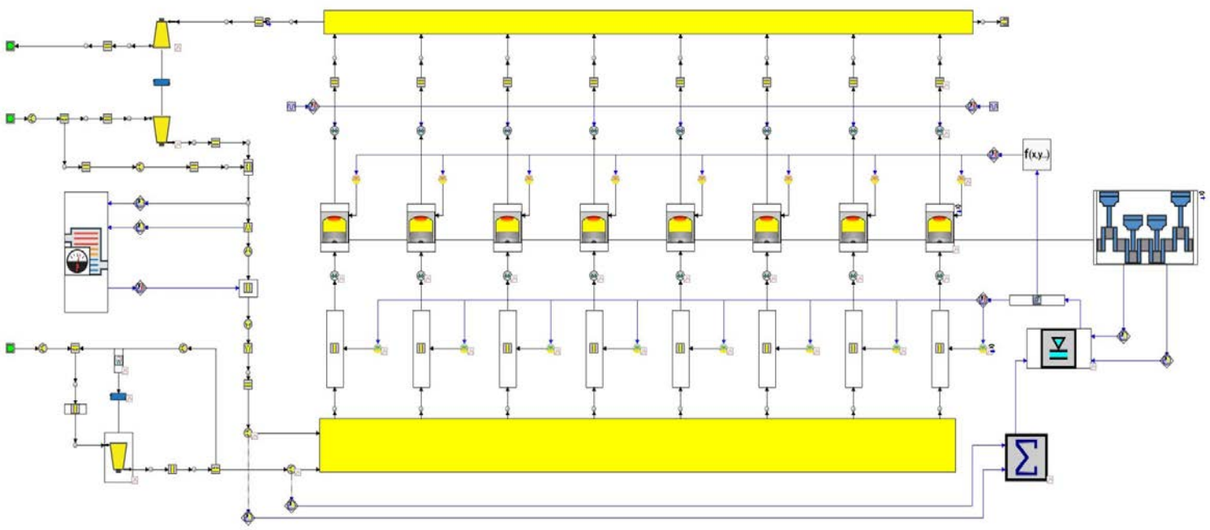
The engine room is the core of any marine vessel, housing a wide array of critical systems—including internal combustion engines, thermal and lubrication units, fuel supply, cooling systems, exhaust treatment, and more. Operating under demanding conditions, these systems must function seamlessly to ensure efficiency, safety, and regulatory compliance. With GT-SUITE, engineers can simulate and optimize these interconnected components within a single platform—enhancing performance, minimizing emissions, and enabling smarter, more reliable marine system design.

Internal Combustion Engine (ICE) Optimization

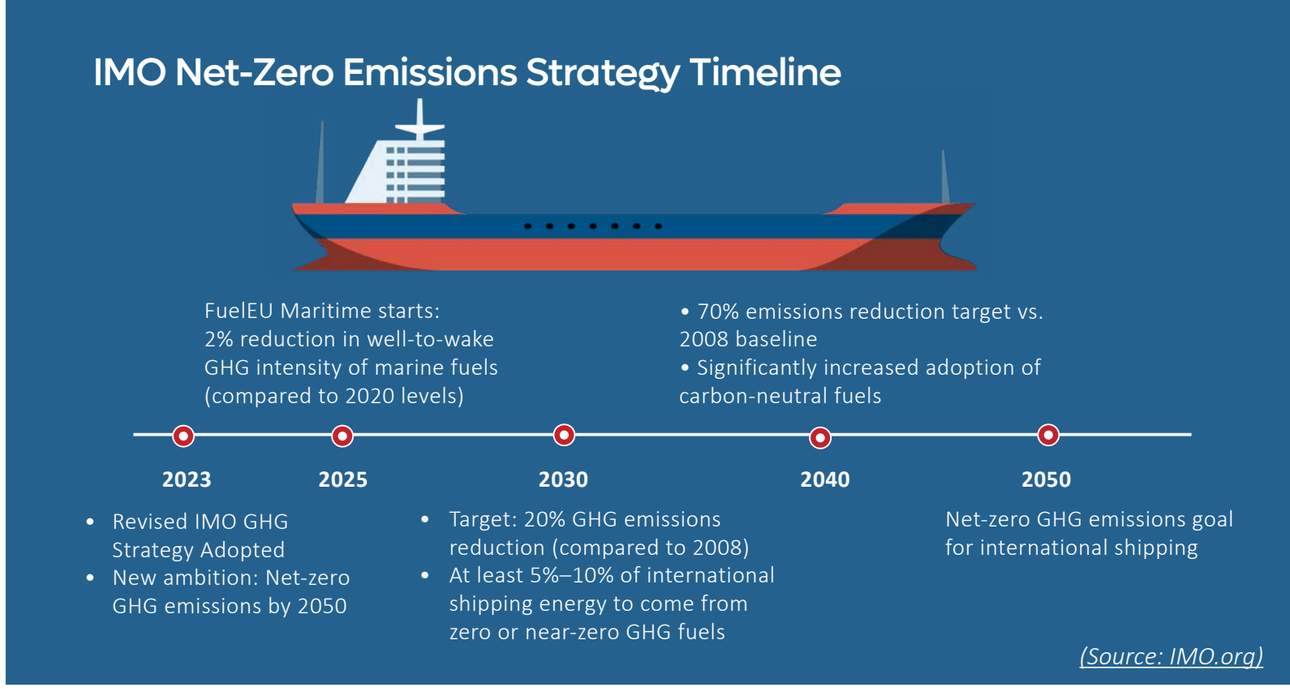
With GT-SUITE, engineers can push the limits of fuel efficiency by running simulations across multiple fidelity levels. Whether it's detailed combustion modeling for optimizing engine design or real-time models in GT-POWER-xRT for control strategies, GT-SUITE provides the flexibility needed at every stage. The fast, physics-informed models help estimate fuel use and emissions, giving you a clear view of performance across an entire operating cycle while keeping costs and development time in check.

Large marine engines are particularly expensive to run during calibration. GT-SUITE helps minimize that by allowing early calibration with a hybrid setup: a single-cylinder test bench, a real-time multi-cylinder model, and airflow dynamics in GT-POWER-xRT. This enables engineers to assess and fine-tune how the intake and exhaust setup—specific to the ship's layout—will affect engine performance.

By combining high-fidelity physics models with data-driven tools like the Advanced Combustion Toolset and Machine Learning Assistant, GT-SUITE supports precise prediction of engine-out emissions. This, in turn, ensures optimized design and calibration of Exhaust After-Treatment Systems (EATS), meeting both performance targets and regulatory demands.



Internal Combustion Engine Model Example in GT-SUITE



Alternative Fuels: LNG, Ammonia, Hydrogen Optimization

Internal combustion engine modeling in GT-SUITE is designed to support a wide variety of fuels, making it a flexible platform for exploring alternative fuel options. While the modeling framework is adaptable across different fuel types, it accurately captures specific combustion behavior through dedicated submodels — such as laminar flame speed for turbulent flame propagation, and ignition delay for combustion phasing in compression ignition(CI) engines and knock prediction in spark-ignited systems.

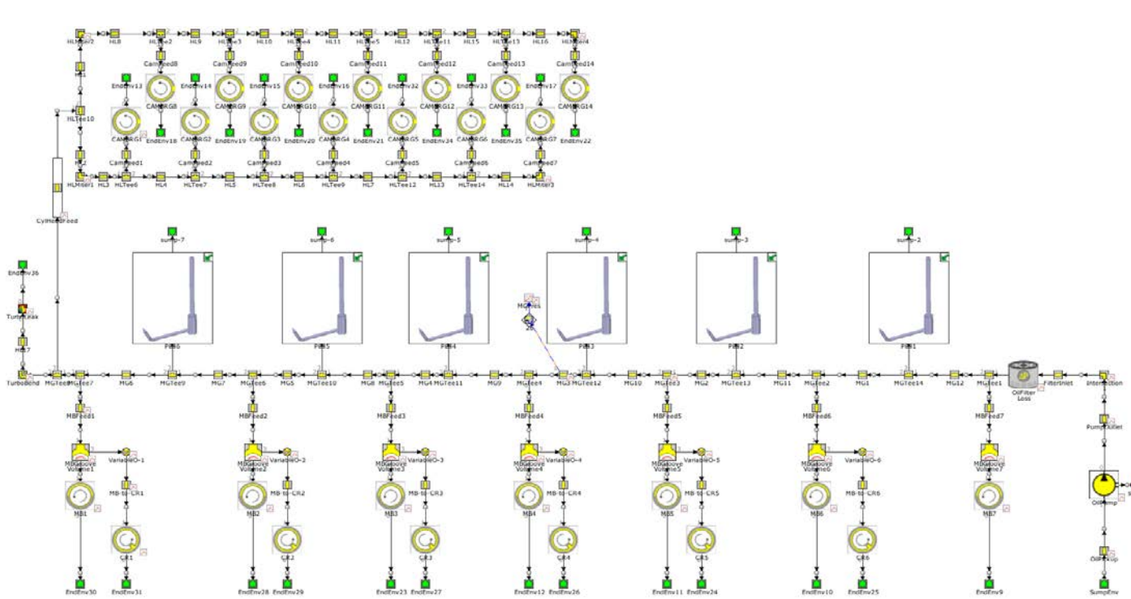
To go beyond standard libraries, GT-SUITE offers flexibility through user-defined subroutines and metamodels—created using the GT Machine Learning Assistant. This allows engineers to expand modeling capabilities to match evolving fuel technologies.

Currently, GT-SUITE includes built-in support for combustion modeling with alternative fuels such as Ammonia, Hydrogen, and Methanol. For the v2026 release, support is being developed for blends such as Ammonia+Hydrogen and Natural Gas+Hydrogen.

Each fuel presents unique modeling challenges. Methanol, for instance, vaporizes rapidly when injected as a liquid, significantly affecting the gas exchange process. GT-SUITE addresses this with predictive spray and evaporation models that help balance evaporation completeness and charge cooling. Ammonia, known for its high NOx formation potential, is handled through detailed chemical kinetics simulations—giving a full picture of its combustion impact and enabling targeted emissions control strategies.

Lubrication and Thermal Systems

In marine applications, lubrication systems are essential for ensuring the long-term reliability and efficiency of engines and auxiliary equipment. These systems must operate under harsh conditions, withstand extended duty cycles, and comply with stringent safety and emissions regulations. Effective lubrication not only minimizes friction and wear but also plays a critical role in enhancing engine performance and lifespan. GT-SUITE enables detailed system-level modeling of lubrication circuits, capturing components such as oil pumps, coolers, galleries, and filters. It also accounts for dynamic behaviors like cold starts, ship motion-induced flow variation, and contamination effects—factors particularly relevant in marine environments.



Piston Cooling Jets System Model

With its multi-physics simulation capabilities, GT-SUITE allows for seamless integration of lubrication (fluid systems), component cooling (thermal systems), and mechanical wear modeling. This holistic approach supports more accurate predictions of system performance and durability, enabling marine engineers to design robust solutions that perform reliably over long missions.

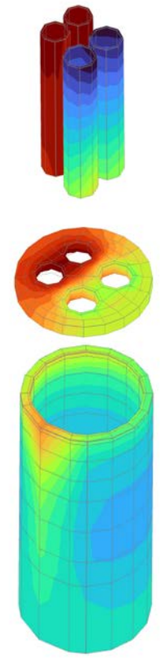
Fuel Supply and Storage Systems

GT-SUITE enables comprehensive modeling of marine fuel systems, from supply components to complex storage dynamics. For fuel supply, detailed 1D models of pumps, rail lines, injectors, and heat exchangers can be built to perform predictive estimation of performance, aiming to reduce pressure losses, and ensure robust fuel delivery under dynamic load conditions. GT-SUITE offers a compressible, Navier-Stokes-based solver that captures pressure wave propagation and water hammer effects, helping engineers design reliable, high-precision systems. The software also supports the modeling of fueling and defueling operations, offering prebuilt libraries covering a wide range of fuel types and properties used across the industry. These libraries enable quick and reliable model setup, spanning from conventional to innovative fluids, and can be customized to align with supplier data when needed.

The multi-physics environment allows integration of fluid, thermal, mechanical, electrical, and control domains—enabling the simulation of virtually any fuel system architecture, including those for novel or low-viscosity fuels.

GT-SUITE includes advanced capabilities to simulate sloshing within fuel tanks. This helps predicting internal pressure variations in fuel storage systems, and assessing the impact on ship balance and delivery consistency. Complex fuel tank geometries can be modeled to simulate draining during vessel acceleration or tilting, ensuring reliable fuel access. In addition, users can incorporate tank segregation and heating systems to support multiple fuel types and ensure optimal fuel viscosity prior to injection.

Marine Powertrain Heating and Cooling



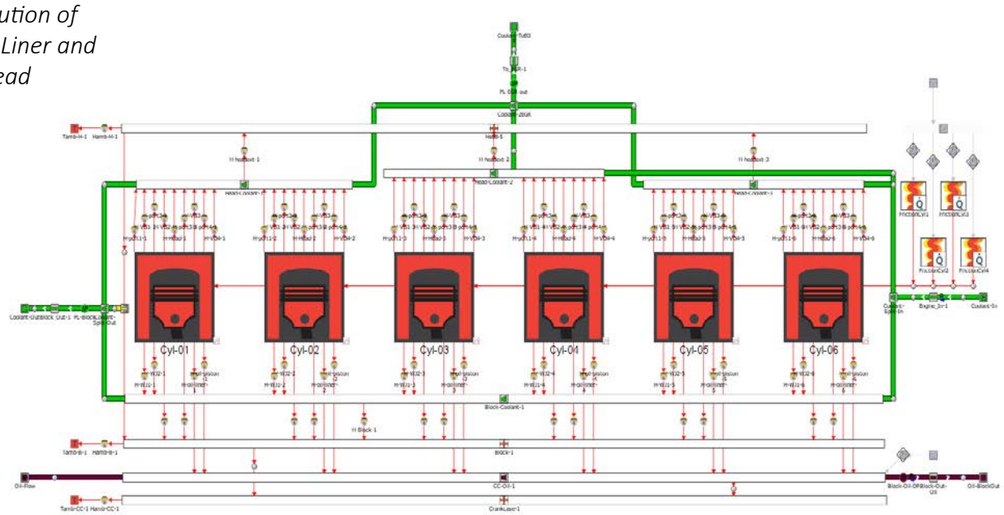
Spatial Thermal Distribution of Cylinder Liner and Head

GT-SUITE provides robust capabilities for modeling powertrain thermal management in marine systems. Whether the engine uses direct seawater cooling or an indirect closed-loop system with freshwater or antifreeze, GT-SUITE can accurately predict coolant heat rejection across various operating conditions. For large marine engines, cold start heating is critical—these engines require preheating to reach optimal temperatures before startup, and GT-SUITE allows users to simulate and optimize this process.

Another key aspect is waste heat recovery. Heat generated by the engine can be repurposed to warm fuel (especially important for heavy fuel oils), cabins, or cargo areas. GT-SUITE enables detailed modeling of exhaust gas economizers to recover and utilize this waste heat, contributing to overall system efficiency.

GT-SUITE offers both 3D and 1D approaches to engine structure thermal modeling. The built-in 3D Finite Element Method (FEM) solver predicts temperature distribution across the engine under steady-state and transient conditions. This helps identify conduction paths and hotspots, and it integrates seamlessly with cooling, lubrication, and fuel supply subsystems to support holistic fuel economy analysis.

For system-level design, component selection, and control strategy development, GT-SUITE also provides 1D lumped thermal mass models. These are computationally efficient and ideal for simulating broader thermal behaviors without compromising on predictive accuracy.

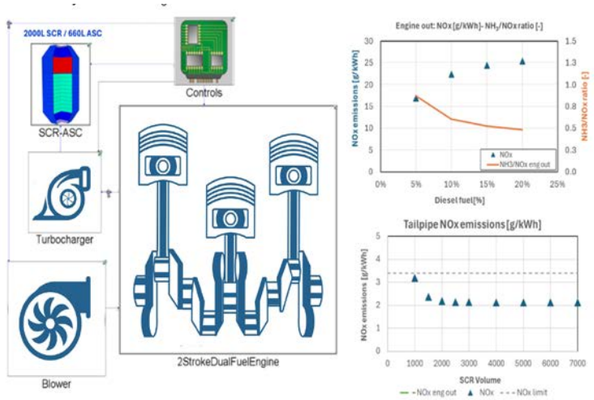


Model of an Engine Lubrication System including Piston Cooling Jets

Exhaust Gas Treatment

Meeting marine emissions regulations such as IMO Tier III and EPA Tier 4 requires advanced aftertreatment strategies especially with challenges like high-sulfur fuels, fuel variability, and strict space and weight constraints. GT-xCHEM module, delivers high-fidelity modeling of exhaust aftertreatment systems (EATS) to support optimal design and controls development.

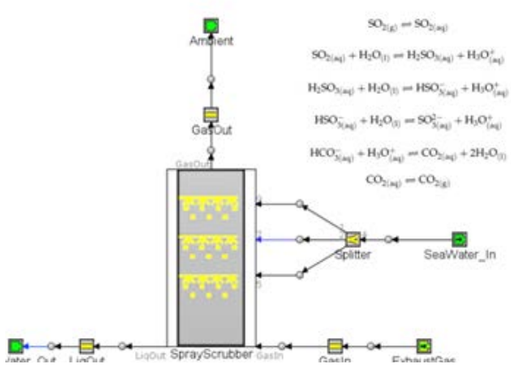
It enables detailed SCR modeling to fine-tune urea dosing strategies, reducing NO_x emissions while controlling ammonia slip across a wide range of engine loads. Advanced DPF models help evaluate particulate matter accumulation, regeneration strategies, and backpressure effects on engine performance.



Exhaust system for NH_3 Internal Combustion Engine

Predictive chemical kinetics models assess catalyst poisoning mechanisms, such as sulfur-induced degradation, supporting more robust catalyst formulation and regeneration strategies. GT-SUITE also supports compact system design optimization and high-efficiency operational strategies.

Compatibility with conventional fuels (e.g., HFO, MDO) can be evaluated, while also supporting the development of ATS solutions for alternative fuels like LNG, methanol, ammonia, and hydrogen. Additionally, wet scrubber models in GT-SUITE simulate SO_x removal through seawater absorption, with features like absorber column sizing available starting in v2026.



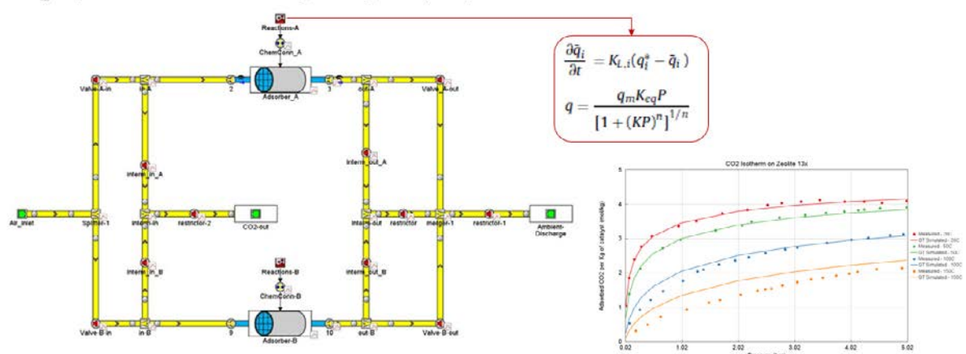
Spray Scrubber Model example in GT-SUITE

CO2 Capture

CO_2 capture faces challenges such as high costs, significant energy demands for solvent regeneration or CO_2 compression/liquefaction, and large space requirements—leading to added weight that impacts fuel efficiency. Additionally, efficient operation under variable load conditions is a major challenge during development and demands complex control strategies for the entire propulsion system.

GT-xCHEM offers solutions for CO_2 capture technologies in the marine industry, enabling system-level simulations to optimize designs with reduced space requirements and identify operating conditions that minimize energy consumption. It also supports material selection and sizing optimization to maximize system efficiency. Robust solvers enhance model predictiveness under transient conditions, ensuring optimal performance even with variable loads.

For Pressure or Temperature Swing Adsorption (PSA/TSA) systems, GT-xCHEM offers detailed flow, thermal, and chemical models that predict adsorbent behavior, optimize adsorption/desorption phases, and fine-tune valve actuation strategies under varying pressures and temperatures. These high-fidelity models allow cycle time and energy use optimization—critical for meeting performance targets while minimizing energy use and volume.



Pressure Swing Adsorption model in GT-SUITE

In Amine-Based CO_2 Absorption, GT-xCHEM simulates key processes such as solvent thermodynamics, reaction kinetics, and mass/heat transfer in packed columns, spray towers, or membrane-based systems. These capabilities, available in GT-SUITE v2026.0, help engineers optimize solvent usage and column performance for both conventional and next-gen shipboard capture systems.

Together, these features enable virtual prototyping of CO_2 capture solutions—reducing development costs, accelerating compliance with evolving maritime carbon regulations, and supporting the transition to greener propulsion systems.

Systems Integration

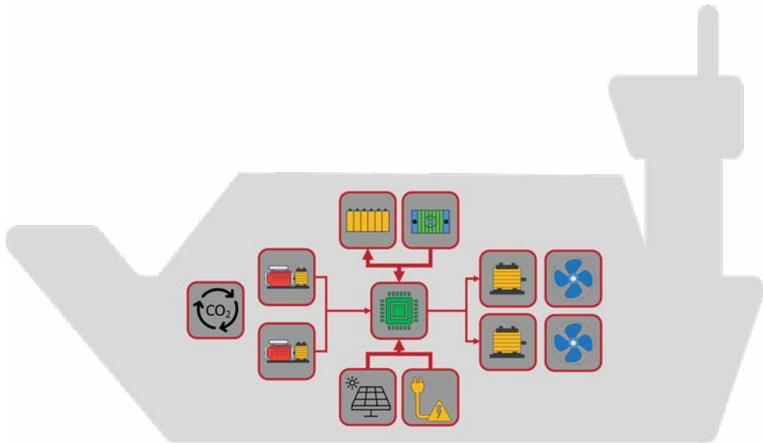
Developing vessel systems presents significant challenges in control and system integration due to the complexity of system configurations and interactions among subsystems. Effective energy management strategies and control mechanisms are crucial for advancing modern vessels, as they directly impact energy consumption and system longevity. To ensure a comprehensive and realistic representation of vessel systems and operations, it is essential to use physics-based models that accurately reflect validated subsystem behavior. A wide range of real-world operating scenarios must be considered to validate energy management strategies and achieve a resilient design.

The GT-SUITE system integration workflow facilitates the development and testing of control logic and strategies within a simulation environment, allowing seamless extension to various XiL platforms through fast-running, integrated vessel system models.

GT-SUITE offers a comprehensive set of component libraries to support the development of integrated vehicle plant models for control applications. These libraries cover a wide range of vessel subsystems, including engines, fuel cells, batteries, power electronics, electric motors, and their associated thermal management systems, as well as the vessel driveline, body, and surrounding environment.

Components are available as GT Object Libraries, Compounds, and External or Internal Subsystems, making it easy to distribute and share models across users or teams via a network or local repository.

To further streamline the process, GT-SUITE also provides ready-to-use system-level control solutions, enabling quicker and more efficient model setup for a variety of marine applications.



Systems Integration of Marine Sub-Systems

THE ELECTRIFICATION OF THE MARINE INDUSTRY

Battery-Powered Ships

Battery-powered ships face several critical design and operational challenges—from energy density limitations to safety concerns and harsh marine conditions. GT-AutoLion, a physics-based battery modeling platform, offers comprehensive tools to address these challenges in marine applications.

Energy density is one of the biggest constraints. Batteries have much lower energy density than traditional marine fuels, which creates a payload penalty—every ton of battery displaces fuel or cargo. For long-range as well as short-range vessels, this directly impacts cargo-carrying capacity and voyage planning.

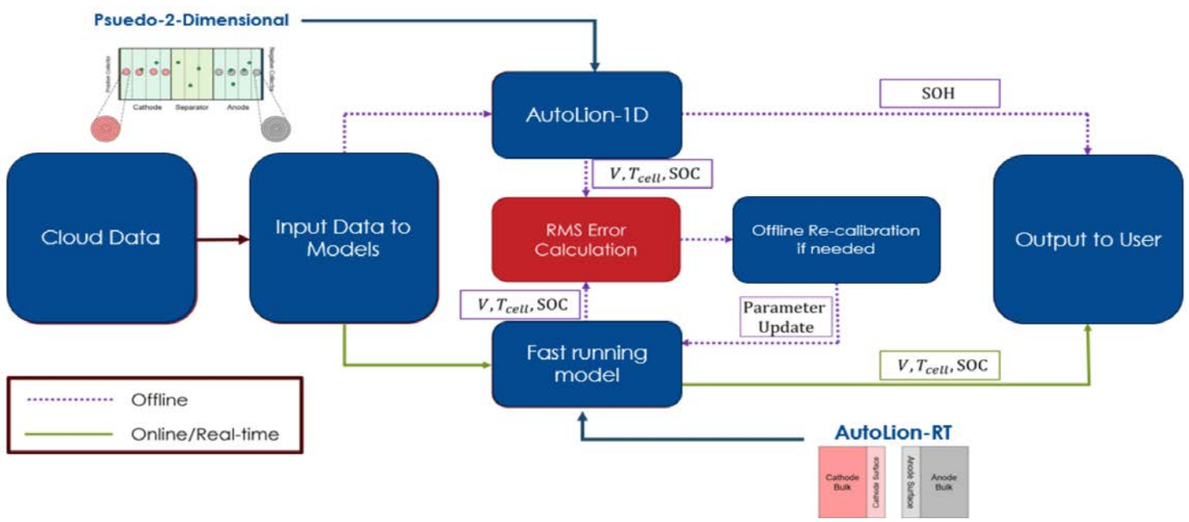
Choosing the right chemistry and pack design is crucial. GT-AutoLion supports common marine chemistries like Lithium Iron Phosphate Oxide (LFPO), Nickel Manganese Cobalt Oxide (NMC), and Lithium Titanate Oxide (LTO), helping engineers balance energy, safety, and cycle life. The platform also supports newer technologies like solid-state and sodium-ion, offering a path to greater safety and longevity in future designs.

Safety risks—both internal and external—are a major concern in the marine environment. Internally, batteries can fail due to short circuits and gas generation. Externally, saltwater exposure, corrosion, and moisture ingress can compromise system integrity. GT-AutoLion accounts for all these factors in its thermal and degradation models to improve reliability predictions.

Marine vessels operate under highly dynamic loads—from high propulsion demands to idle "hotel" loads and emergency maneuvers. GT-AutoLion captures these varying C-rates and thermal effects, helping engineers analyze how batteries respond under real-world conditions, including heating and cell aging.

Frequent cycling is another challenge, especially for applications like ferries that charge and discharge multiple times per day. GT-AutoLion tracks SOC and SOH, and feeds cell-level data into aging models—supporting more accurate end-of-life predictions and proactive maintenance planning.

With GT-AutoLion, marine engineers are equipped to design battery systems that are safe, efficient, and optimized for demanding maritime use.



Semi-real-time Digital Twin Framework for Battery Management System

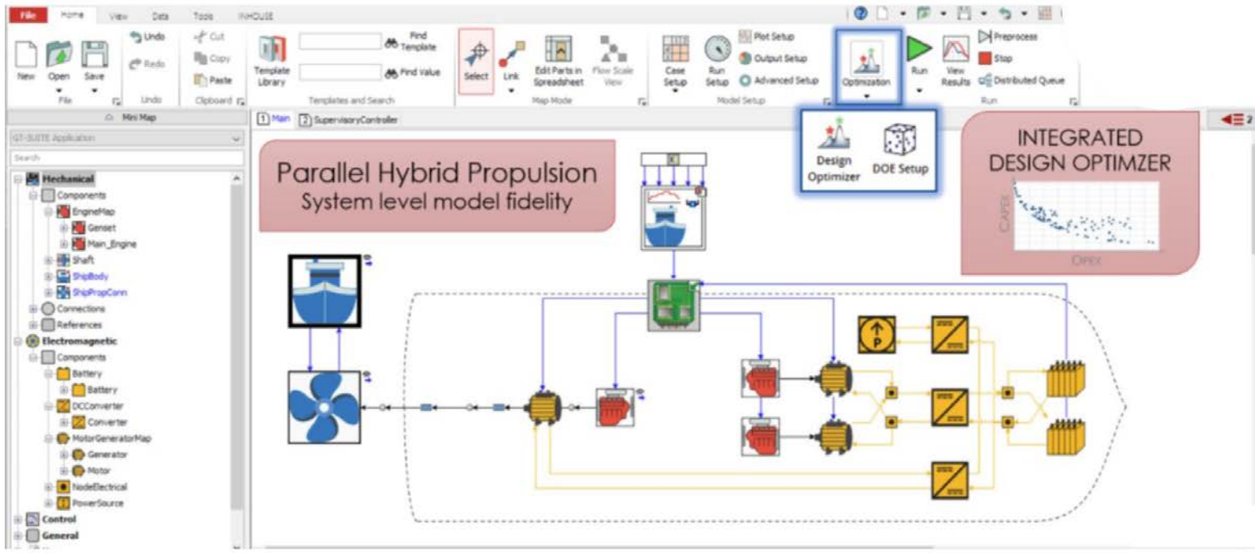
"Simulation is no longer just a tool—it's a strategic advantage that empowers marine engineers and OEMs to design safer, greener, and more efficient vessels. With GT-SUITE, virtual testing and refinement of complex systems becomes possible before physical build, unlocking the full potential of digital assets, virtual commissioning, and intelligent model- and data-based digital twins."

- Michael Zagun
Senior Staff Engineer, Gamma Technologies

Hybrid Propulsion Systems

The development of advanced propulsion solutions to reduce emissions, increase energy efficiency, and maintain manageable costs is the primary motivator for the industry. Hybridization is emerging as a viable solution across a wide range of applications. Vessels with variable operating conditions, working hours, and different power requirements are ideal candidates for hybridization. In fluctuating operating conditions, hybrid systems offer greater flexibility, enabling more efficient use of available power and energy.

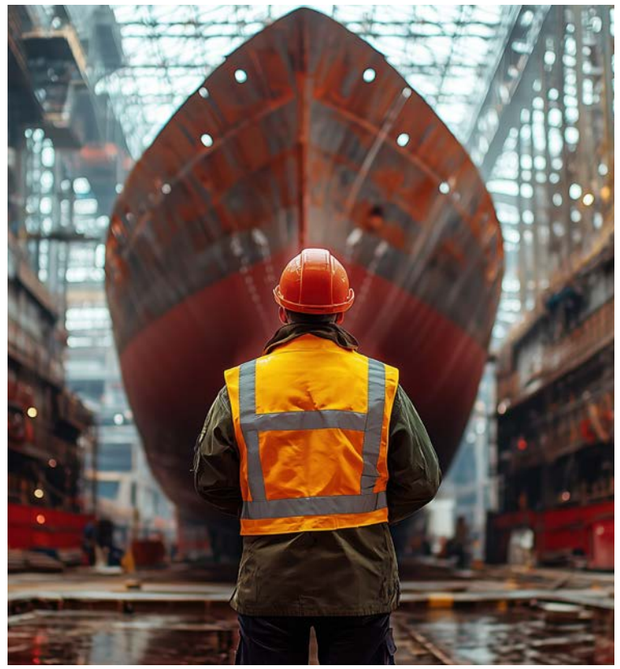
GT-SUITE provides a development platform focused on the design of new hybrid vessel concepts and the hybridization of retrofitted vessels. It allows for an in-depth analysis of the key components of hybrid marine propulsion and energy systems, evaluating the pros and cons of various designs, sizes, and energy management approaches. By using physics-based simulations to model hybrid system components, it ensures a precise representation of their behavior.



Hybrid Propulsion System example in GT-SUITE

SYSTEMS SIMULATION ROLE IN ENSURING SAFETY & RELIABILITY

Predicting & Preventing Failures



Simulation tools are instrumental in predicting potential failures before they manifest in real-world scenarios. By utilizing a dynamic simulation environment provided by GT-SUITE, engineers can model complex maritime systems and subsystems, such as power plants and control systems of autonomous ships. These simulations incorporate real-time data and predictive analytics to foresee mechanical and operational failures.

For instance, dynamic machine learning-based anomaly detection and advanced pre-trained classifiers can be developed within GT-SUITE to monitor the reliability variation of a ship's power plant at both the subsystem and component levels. This model uses historical data and ongoing sensor data to update reliability predictions, enabling the identification of components with higher failure probabilities. This proactive approach allows maintenance teams to prioritize interventions, preventing catastrophic failures and minimizing unplanned downtime.

Mitigating Risk

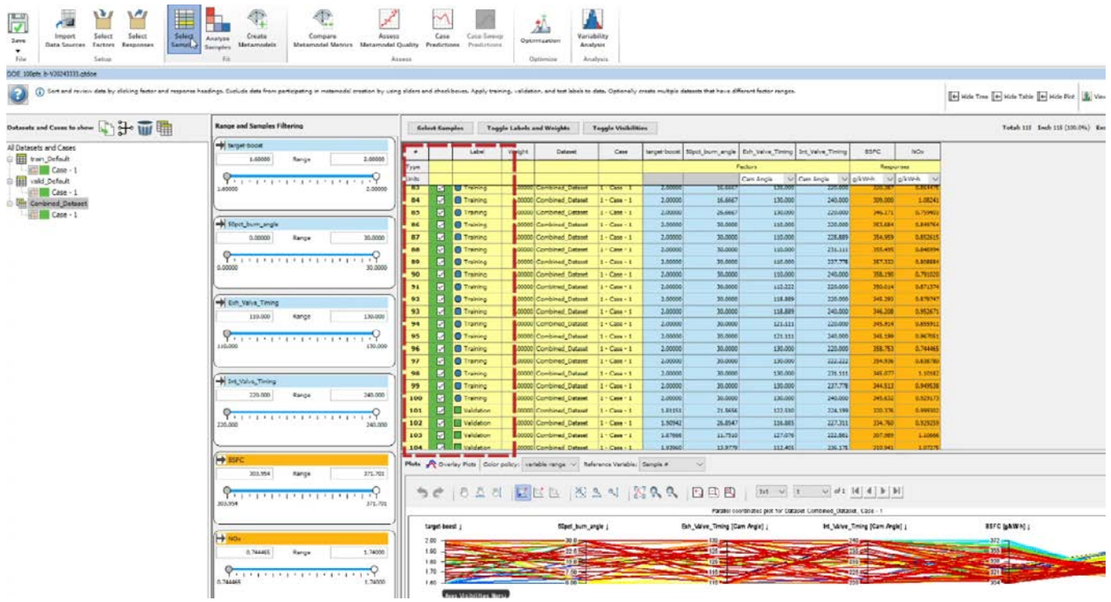
The ultimate goal of employing systems simulation is to mitigate risks and ensure the utmost safety of maritime operations, especially in Maritime Autonomous Surface Ships (MASS). GT-SUITE's simulation capabilities enable the detailed analysis of "what-if" scenarios, testing how systems behave under various failure conditions without the risks associated with physical trials.

Incorporating machine learning algorithms enhances these simulations by enabling the system to learn from past incidents and adapt to new threats more effectively. For example, a digital twin of the ship's power plant can be created to simulate different failure scenarios and their impacts on ship operations. This helps design more resilient systems that maintain functionality even when certain components fail.

Furthermore, integrating these advanced tools supports the implementation of health-aware energy management strategies. Such strategies use data from reliability assessments to optimize the operation of hybrid propulsion plants on ships, reducing the risk of failures while conserving fuel and reducing emissions. By actively managing the health of the ship's systems using GT-SUITE-based digital twins, GT-SUITE helps ensure that ships operate safely while adhering to environmental standards and efficiency.

THE FUTURE OF MARINE: MACHINE LEARNING & DIGITAL TWIN

AI & Machine Learning in Maritime Systems



Machine Learning Assistant in GT-SUITE

As maritime operations grow more complex, AI and machine learning are unlocking new levels of efficiency and reliability. At the center of this shift is GT's Machine Learning Assistant (MLA), enabling smarter and more predictive vessel systems.

A key use case is predictive maintenance—MLA uses simulation data and on-board sensors to identify early failure signs and anticipate maintenance needs. This minimizes downtime, lowers costs, and extends system lifespan.

For fleet-wide operations, the MLA provides a comprehensive analysis platform, aggregating data across both virtual and real vessels. This holistic perspective enables engineers and operators to optimize maintenance schedules, evaluate design trade-offs, and make informed decisions that enhance the overall efficiency of maritime assets.

By combining simulation expertise with intelligent data analysis, GT's AI and machine learning solutions are reshaping the future of maritime operations—enabling smarter fleets, reduced risks, and more sustainable performance at sea.

What is a Digital Twin? – Creating Virtual Replicas of Ships, Ports, and Fleets

A Digital Twin is a digital replica of physical systems in the maritime industry, including ships, ports, and entire fleets. Using GT-SUITE simulation models and real-time sensor data, these replicas provide dynamic simulations of real-time status, working conditions, and performance. Integrated with machine learning and systems simulation, GT-SUITE enhances the predictive accuracy and operational efficiency of these models.

In maritime applications, Digital Twins serve various functions. For ships, they model vessel mechanics and operations to optimize performance

Marine Vessel Digital Twin Framework

across various conditions, such as navigation and fuel consumption. For ports, they help manage energy resources, including fuel provisions, hydrogen storage, and charging infrastructure, supporting sustainability initiatives. For fleets, Digital Twins optimize maintenance schedules and improve route management, offering a comprehensive view for strategic decision-making.

These Digital Twins continuously update with new operational data, enabling them to reflect current conditions and predict future states, including potential failures. This capability empowers informed decision-making, minimizes downtime, and enhances safety.

GT's Digital Twins are versatile in deployment and accessible through GT-PLAY, GT's cloud solution, directly on ships, or through other cloud services. This flexibility ensures they can be effectively utilized across different maritime environments, enhancing operations with crucial insights and analytics.

CONCLUSION

Although the path to a more robust, intelligent, and clean maritime sector is not simple, it is also full of opportunities. Intelligent, system-level simulation is more important than ever as vessels get more complex and the need to decarbonize increases.

GT-SUITE prioritizes such capability, allowing engineers to make better decisions faster. Simulation is now a necessary tool for innovation, whether it is for developing hybrid propulsion topologies, researching new fuels, or improving engine room system performance.

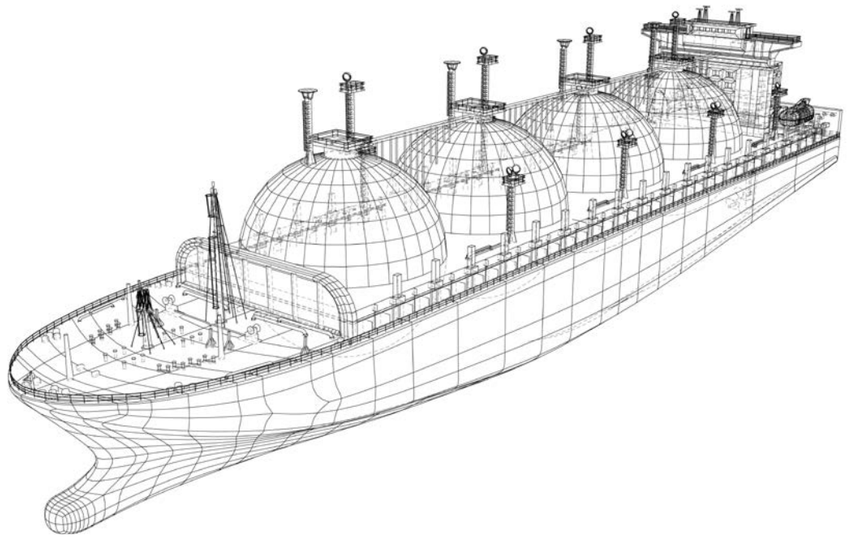
Future developments like machine learning and digital twins will amplify the impact even more. With the right resources, the maritime industry can move forward with assurance—toward safer operations, lower emissions, and a more sustainable future for sailing.

GT-SUITE IN ACTION: PROVEN SOLUTIONS FOR MARINE SYSTEMS

System-Level Modeling and Operational Optimization of LNG Carriers Using GT-SUITE

GT-SUITE has been successfully applied to simulate the complex energy systems of LNG carriers, enabling system-level modeling that supports operational optimization. The digital model calculates the vessel's complete energy balance across various operating conditions, with a modular design that allows easy switching between different machinery components, such as engine types. Through robust post-processing capabilities, the tool estimates total fuel consumption and emissions over specific periods—be it per voyage or annually. Most importantly, it identifies on-board energy losses, helping define strategies for machinery usage optimization that lead to significant fuel savings. This approach has proven to deliver up to ~3% reduction in CO_2 emissions with no additional cost, offering a practical solution for meeting global efficiency and environmental regulations. The GT-SUITE model also serves as a platform for evaluating new technologies—such as engine retrofitting packages, waste heat recovery, and carbon capture systems—and for optimizing auxiliary systems and comparing energy architectures in new ship designs.

Learn more



Digital Integration of Marine Powertrain Systems using GT-SUITE

GT-SUITE has found impactful application in the shipping industry, as demonstrated by advanced research from MTI Co., Ltd. and Toyota Motor Corporation presented to JASNAOE (The Japan Society of Naval Architects and Ocean Engineers). In marine applications, especially large-scale systems like marine powertrains, physical test benches are far less accessible than in the automotive sector. To overcome this, the teams adopted a digital engineering approach—leveraging GT-POWER as a system-level plant model to simulate and analyze marine propulsion systems efficiently and cost-effectively.

Learn more

GT APPLICATIONS

GT-SUITE

GT-SUITE is the industry-leading simulation tool with capabilities and libraries aimed at a wide variety of applications and industries. It offers engineers functionalities ranging from fast concept design to detailed system or sub-system/component analyses, design optimization, and root cause investigation.

GT-AutoLion

GT-AutoLion is the industry-leading lithium-ion battery simulation software used by cell designers and OEMs to predict performance, degradation, and safety for any Lithium-ion cell. It predictively models the electrochemical processes within Lithium-ion cells using a fast and reliable, electrochemical, physics-based approach.

GT-xCHEM

GT-xCHEM is an advanced simulation tool within GT-SUITE, designed for modeling complex chemical reactions in exhaust aftertreatment and chemical systems. It excels in simulating intricate interactions, offering flexible reaction mechanism templates, thermal management, and system integration.

GT-Play

GT-Play is Gamma Technologies' web-based platform that makes GT-SUITE simulations accessible across your organization. It allows users of all experience levels to run models, perform parameter sweeps, and analyze results directly from any web-connected device without the need for specialized hardware or licensing. Developers can easily tailor and publish model interfaces using GT-Play's intuitive tools.

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CONTACT US

Chart the course of progress with GT-SUITE, integrated systems simulation software for a sustainable marine future.

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