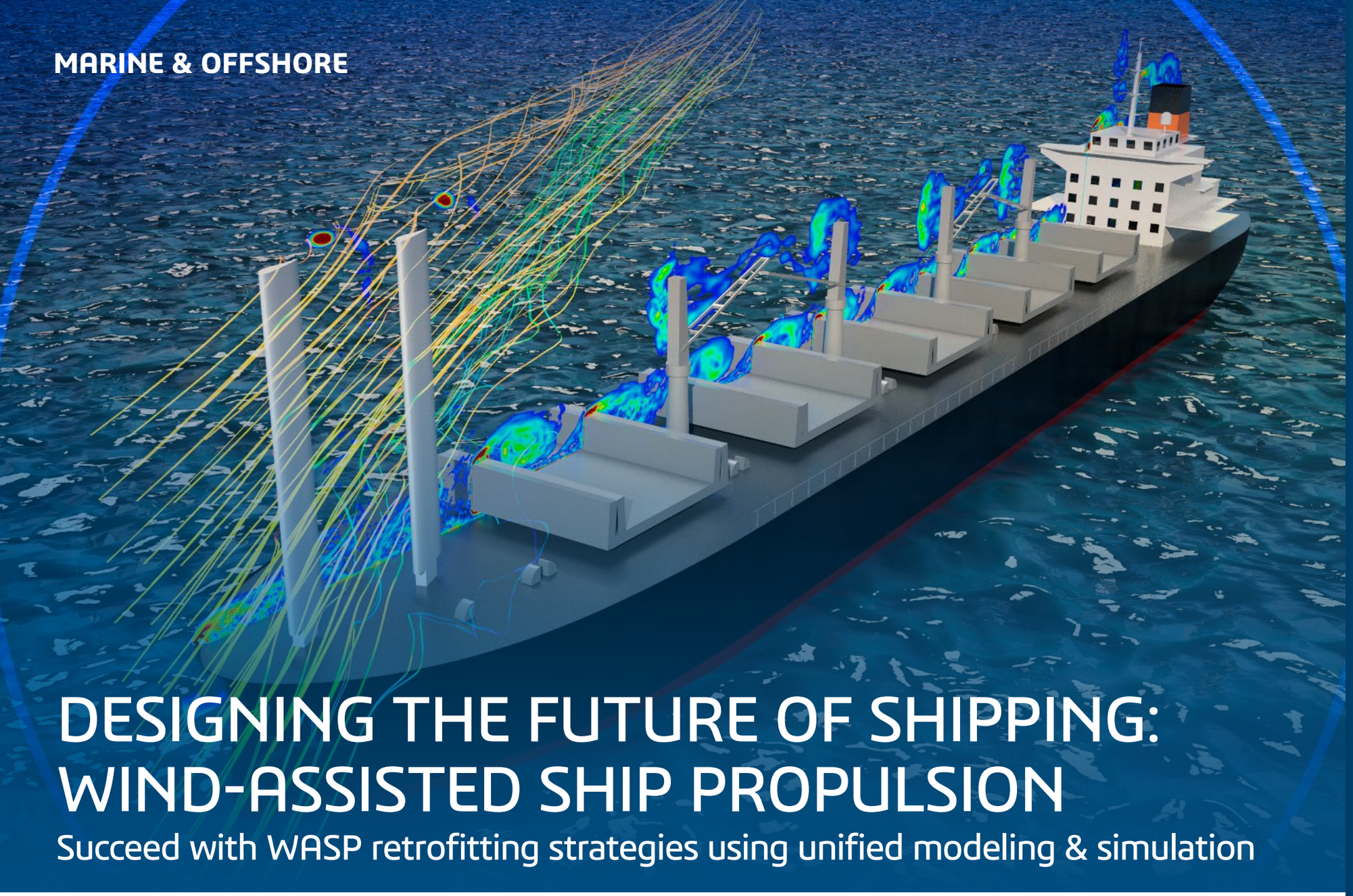
MARINE & OFFSHORE



DESIGNING THE FUTURE OF SHIPPING: WIND-ASSISTED SHIP PROPULSION

Succeed with WASP retrofitting strategies using unified modeling & simulation

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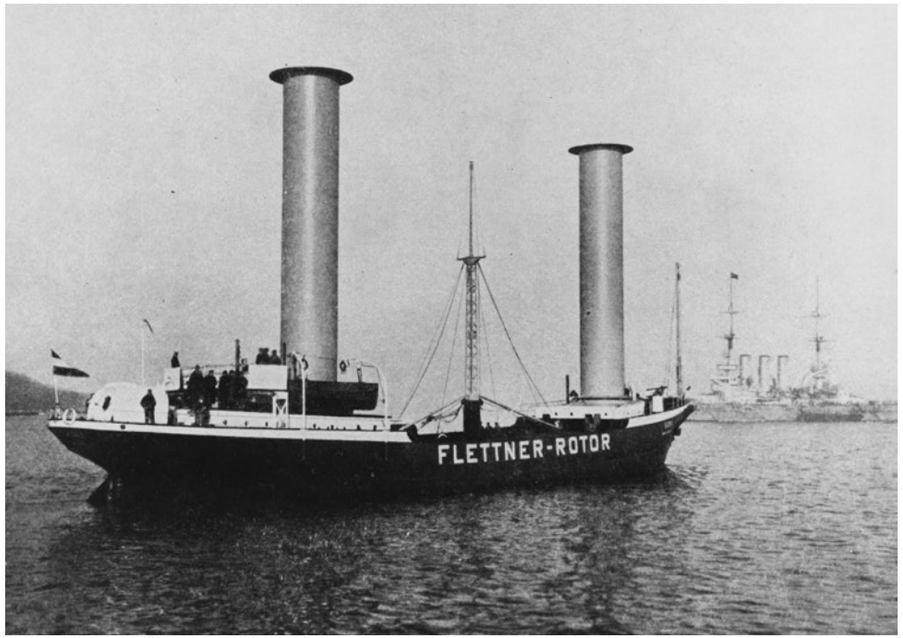
DASSAULT SYSTEMES

INTRODUCTION—WASP IN THE MARINE & OFFSHORE INDUSTRY

Shipping is the most energy-efficient method of long-distance cargo transport, but it remains a very fossil fuel-intensive transport method. Almost all large ships are powered by fuel oil, and especially heavy fuel oil (HFO), which produces considerable particulate emissions and sulfur pollution when burned. 3% of all CO_2 emissions produced worldwide come from shipping, giving it a similar carbon footprint to many countries. The marine and offshore industry is looking for alternative energy sources that will help shipping to meet sustainability goals while keeping costs low, and wind-assisted ship propulsion (WASP) is one promising technology.

WASP uses wind power to drive the ship in addition to its engines, using sails, fan propellers and airfoils. WASP is intended to be used to supplement the ship's engines rather than replace them entirely, reducing fuel consumption. Real-world trials have shown a reduction in fuel consumption of 5-9%. Retrofitted ships can achieve potential savings of 25%, and custom ships may realize even greater reductions.[1]

Retrofitted WASP is ideal as a transitional solution for HFO-burning ships while greener fuels such as methanol, ammonia and hydrogen are developed. Modern WASP systems are automated, requiring little intervention from the crew and none of the labor-intensive work associated with traditional sail systems.



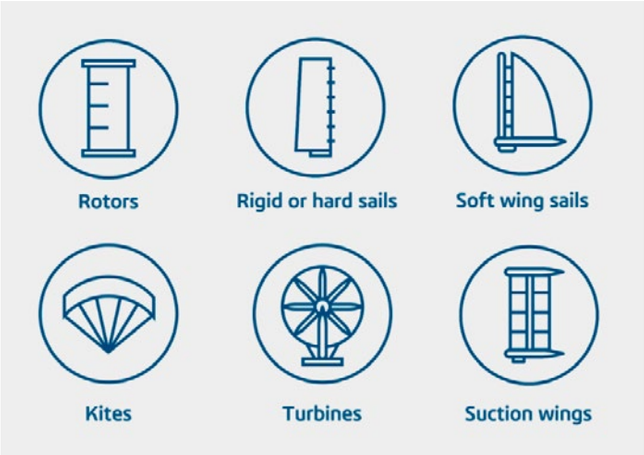
The Buckau, the Flettner Rotor Ship, photographed in 1924. Library of Congress, Prints & Photographs Division, [ggbain 37764]

[1] DNV, Wind-assisted propulsion system in a nutshell, https://www.dnv.com/maritime/insights/topics/waps-wind-assisted-propulsion-systems/

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THE CHALLENGE OF WASP SYSTEM DEVELOPMENT

Installing WASP on an existing ship poses many challenges. From the drawing board to the shipyard, engineers need to understand new physical phenomena and complex interactions between the sail and the rest of the ship. Simulation is already used in many areas of the marine & offshore industry (see box) to develop ships and marine infrastructure, and it can also be used to design, analyze and optimize WASP.



Types of WASP systems.

In this e-book, we will show how modeling and simulation (MODSIM) is helping designers and system integrators to develop WASP systems and integrate them on real ships. With MODSIM, engineers can design and analyze WASP systems faster and understand performance before prototypes and sea trials begin. Designs can be optimized at the concept stage and potential issues identified early, speeding the ship's progress through retrofitting and re-certification. **MODSIM for WASP reduces development time, costs and risk**.

How does the marine & offshore industry use simulation?

Ships are complex systems including mechanical, fluidic and electronic sub-systems, which must operate safely, reliably and efficiently even in the roughest sea conditions. Simulation models the real-world performance of a component, device or system virtually, allowing it to be analyzed without the need for a physical prototype.

Common applications of simulation in shipbuilding include:

- Hull bending and structural integrity
- Hydrostatics and seakeeping
- Fatigue analysis of welds and joints
- Propeller design
- Engine and transmission design
- Pump and pipe analysis
- Antenna and radar placement
- Noise and vibration
- Degaussing

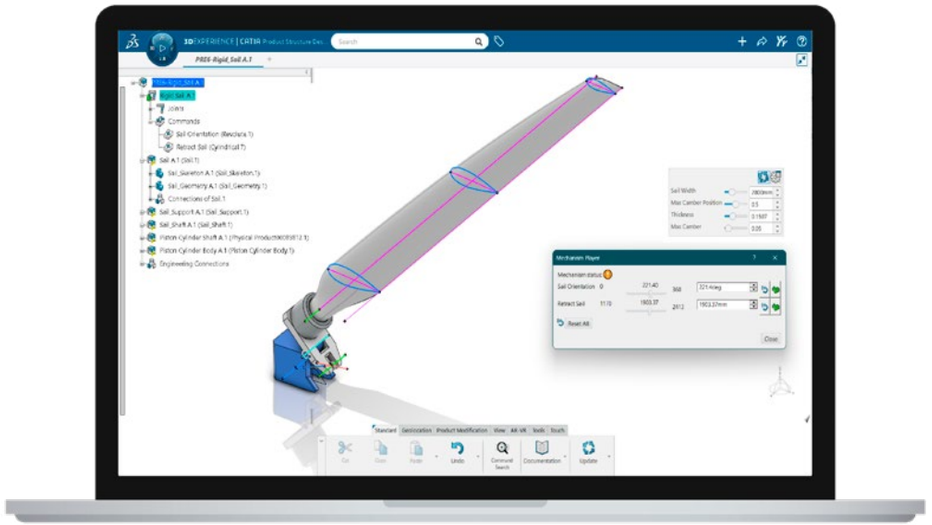
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WASP COMPONENT DESIGN

WASP DESIGN: FROM COMPONENT...

The development of a WASP system begins with the **sail element, in particular the airfoil shape**. In this section of the e-book, we discuss the design and optimization of the sail itself, in isolation from the rest of the ship.



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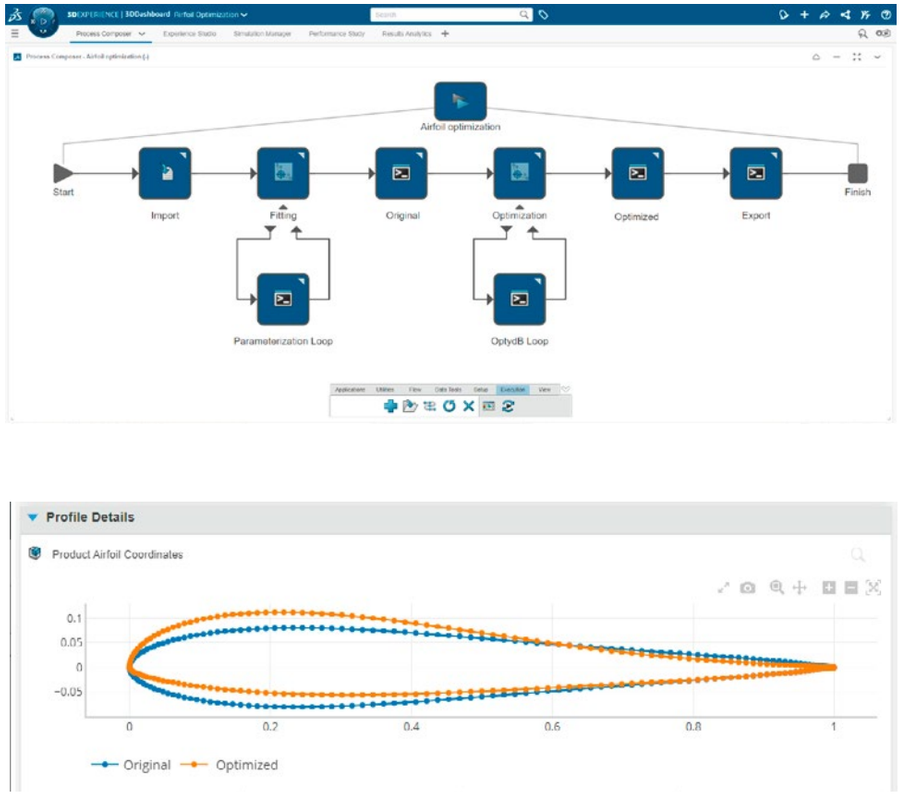
CONCEPTUAL DESIGN OF THE AIRFOIL

The first stage involves designing the airfoil shape. The objective is to create a 2D design optimized for the operating conditions and design requirements such as lift, drag and, potentially, noise. For this example, we have generated a sail for a bulk carrier and have run it over a range of different wind speeds to find the best trade-off across a range of wind conditions.

The process starts with a basic airfoil outline, parameterized so that its shape can be automatically adjusted by the optimizer. A 2D viscous panel method tool, which is connected to the **3DEXPERIENCE®** platform by means of the Process Composer app, quickly optimizes the airfoil outline to maximize the lift-to-drag ratio.

In the demonstrated airfoil, the lift-to-drag ratio has increased by more than 50%, while the predicted noise emission remains constant, as determined by our built-in panel method. The airfoil shape has changed significantly, resulting in a flatter pressure side and a more cambered suction side.

Read more about the Process Composer.



2D viscous panel method tool, connected to the 3DEXPERIENCE platform through Process Composer, optimizing the airfoil's shape.

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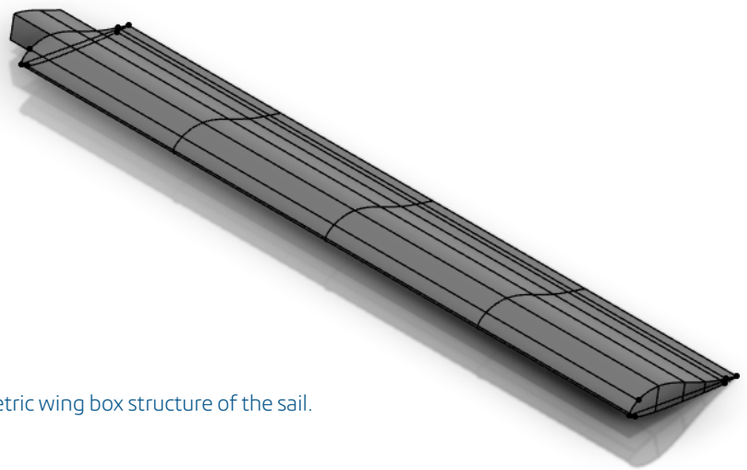
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MODELING ASPECT OF THE SAILS

Once the airfoil shape is optimized, the outline is extruded in 3D to create a CAD model ready for further analysis. No (re-)import or export is needed; the 3D model is linked directly to the outline and a change to the parameters can automatically be reflected in the 3D model.

This process applies to both single-element sails and multi-element wings. Operators often seek designs that achieve high lift-to-drag ratios. As a result, both passive and active high-lift devices—such as multi-element wings—along with techniques like suction and blowing, are increasingly being considered.

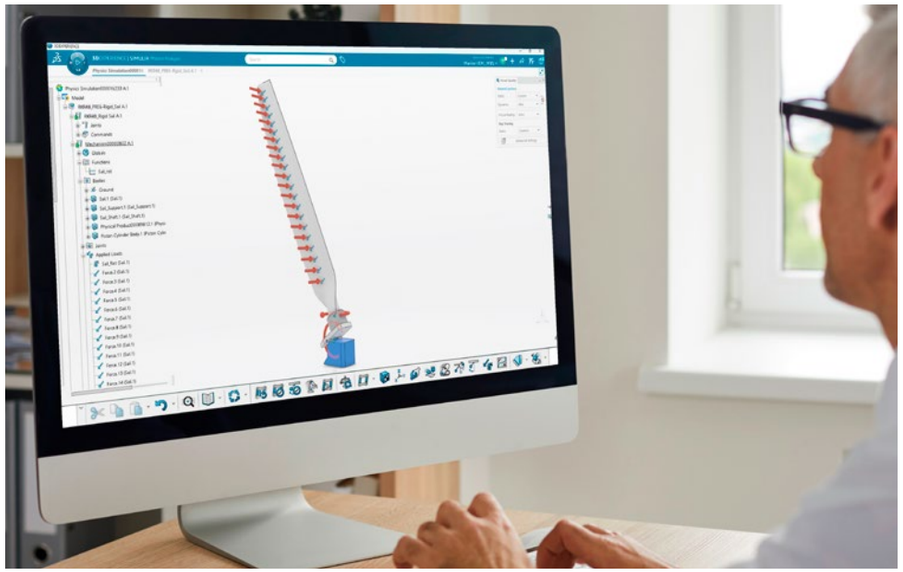
The design also specifies the internal structure and material properties of the sail. These can be parameterized to connect them to act as variables for a design optimization. In the example here, variables include the skin, spar, rib and attachment locations and thicknesses. The design includes the root mechanism, which is needed to control the movement (pitch and optionally lifting).



Parametric wing box structure of the sail.

There is no need to build a separate simulation model – the mesh is automatically generated from the CAD model. This unified modeling and simulation (MODSIM) approach speeds up analysis and means designers without in-depth simulation expertise can get started faster. (See page 15 for more about MODSIM).

The designer can perform quick simulations at this stage to sanity check the geometry. Important tests include modeling kinematics with regard to motion/movement to check for proper behavior and potential collisions, as well as secondary checks of loading using Simpack Motion roles. Using simulation early in the design process identifies potential issues early and helps to identify root causes, allowing them to be fixed quickly.



Forces and moment due to retraction of sail mechanism.

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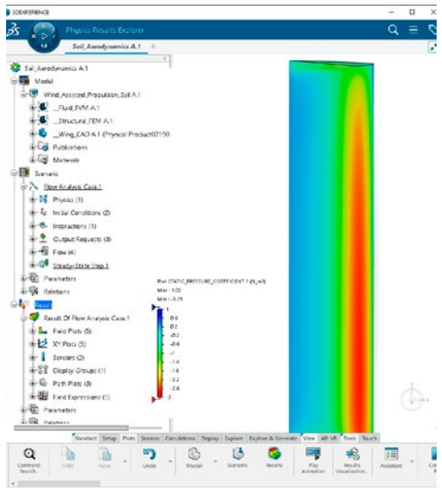
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SEQUENTIAL FLUID-STRUCTURE INTERACTION OF THE SAIL

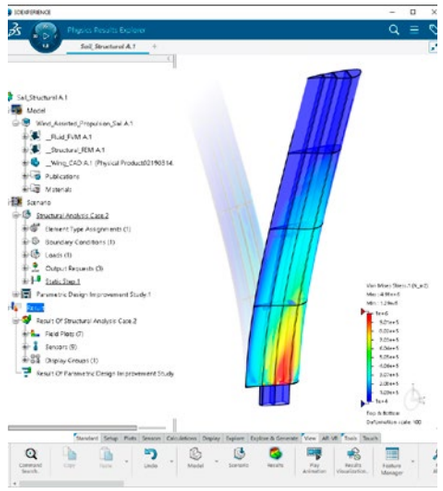
The interaction of moving air with the sail puts it under strain, causing it to bend. This bending can compromise the integrity of the structure. To analyze this effect, a sequential fluid-structure interaction (FSI) simulation is carried out. In an FSI simulation, first, the fluid flow around the airfoil is calculated using computational fluid dynamics (CFD) methods. The resulting forces are then automatically extracted and used as the basis of a structural mechanical finite element method (FEM) simulation in Abaqus.

This sequentially coupled procedure allows the easy setup of an optimization scenario. The parametric design improvement study app can then reveal e.g., the relationship between component thickness and deformation. From the results, the engineer can select the design that uses the least material and has the least weight while keeping displacement within the required tolerance.

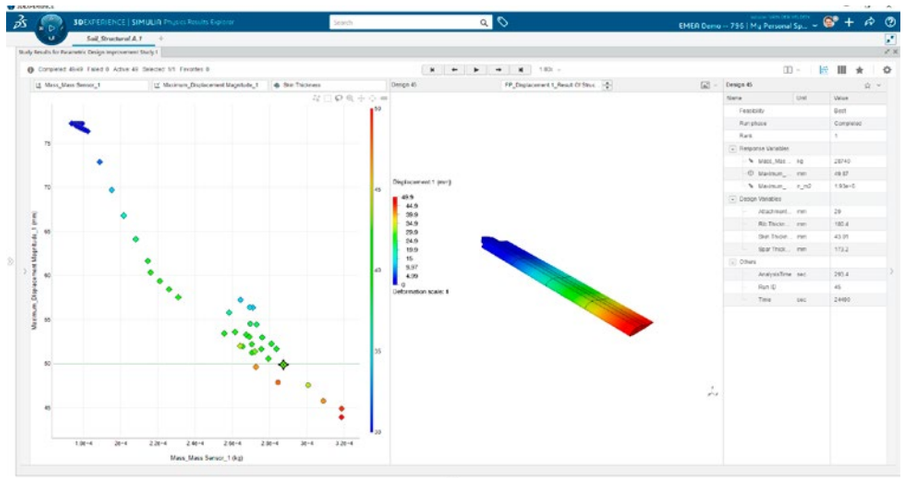
Read more about sequential fluid-structure interaction.



Pressure loading on sail from CFD simulation.



Deformation from FEA simulation.



Guided ML Parametric Design Study to isolate optimal design.

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Images courtesy of Computed Wing Sail (CWS).

CUSTOMER STORY—CWS

Computed Wing Sail (CWS) is charting a course for a greener future in maritime transport. Handling production from its factory in Saint-Nazaire, France, the company's innovative wing sail technology is designed and virtually tested using Dassault Systèmes solutions.

CWS's propulsion has been designed with versatility in mind. It's suited for any type of vessel that would benefit from a hybrid propulsion system – from oil tankers to container ships – and can be installed on new ships or retrofitted on existing ones. This offers a cost-effective solution for operators aiming to reduce their carbon emissions and cut their fuel consumption. The sail's lightweight design, compact footprint and folding mechanism means it takes up minimal deck space.

Achieving the perfect balance between lightweight design and durability is crucial. Every part undergoes rigorous virtual and physical testing to make sure it can withstand the harsh conditions of the open sea, yet be as light as possible. With Dassault Systèmes simulation solution from SIMULIA, CWS can test the loads on both the main metal beam and the composite parts that form the shape of the wing. By reducing weight wherever feasible, CWS is able to enhance performance and efficiency. The testing also involves evaluating numerous points and interfaces between subsystems to make sure everything integrates seamlessly and functions as intended.

> "We thoroughly test each component to ensure the structure can withstand the expected loads. By analyzing stress data from simulations and comparing it to material properties, we can continually improve the model. Our goal is to create a structure that is both lightweight and strong enough to withstand the demands it will face at sea.
>
> Nicolas Baldacci, composites engineer at CWS

Read the full story on our website.

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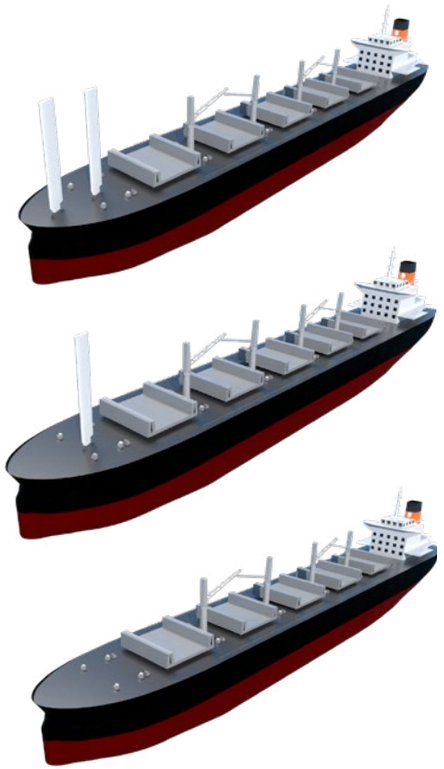
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WASP SYSTEM DESIGN

WASP system engineering doesn't end once the sail is designed. The sails need to be installed on a ship. Regardless of whether this is a newly-built vessel or a retrofit, WASP system integrators have to ensure that the sails will be able to coexist with the other systems on the ship, such as radar, lighting and any superstructure on the deck.

Engineers can analyze ship performance at the system level by building a virtual twin of the ship. A virtual twin is a digital model of the system that contains all performance-relevant data, such as requirements, geometry, subsystem placement and multiphysics simulation results. In this section, we explore the role of simulation and the virtual twin in placing sails on a ship, covering a range of multiphysics interactions.



Various WASP configurations.

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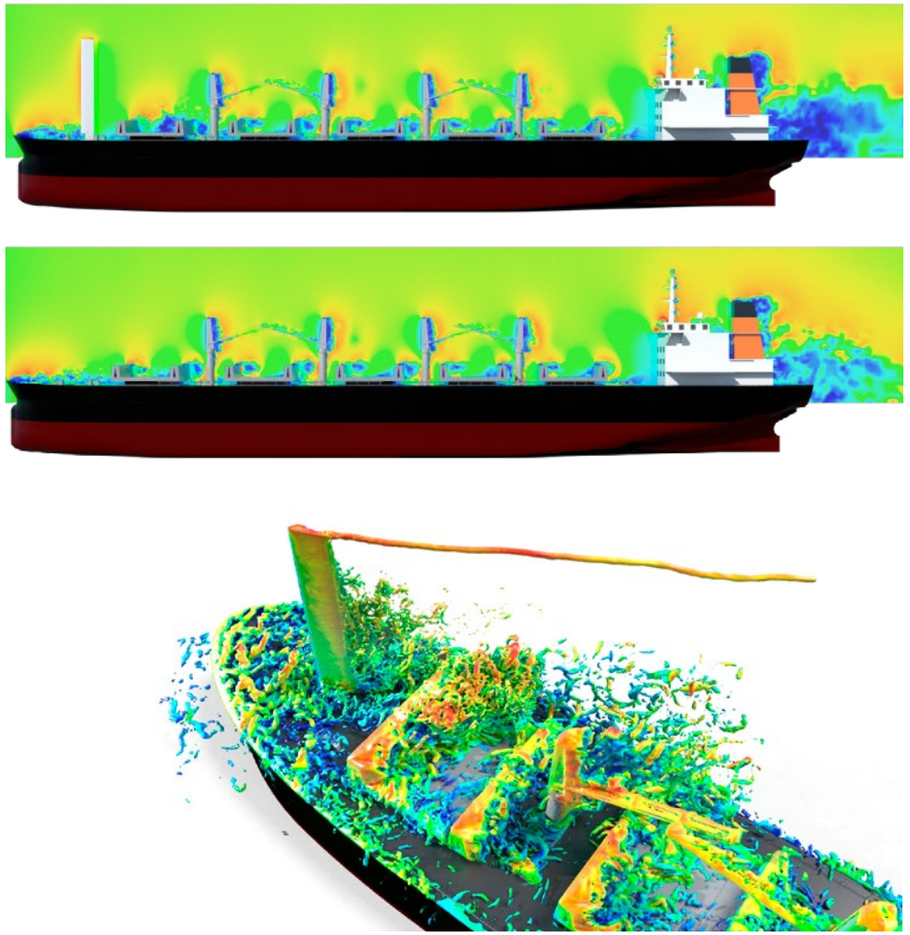
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SAIL PLACEMENT AND AERODYNAMIC INTERACTION STUDY

Retrofitted WASP poses a significant additional challenge: the superstructure of the ship is already in place and the sail placement must work around this. Large structures such as the bridge, funnels, cranes and stacked containers can all interfere with airflow and reduce the effectiveness of WASP. Turbulence from the interaction of sails and other structures also poses safety risks to the crew working on deck. A windage analysis reveals the aerodynamic interaction of the ship's superstructure with the sail and helps engineers optimize placement as well as improve crew safety.

A full-scale ship is very large, typically hundreds of meters in length, yet the geometric details that affect airflow can be very small. This results in a very dense mesh for simulation. PowerFLOW is able to simulate very large, detailed geometry like this efficiently with the Lattice Boltzmann Method (LBM) using the Very Large Eddy Simulation (VLES) approach. PowerFLOW's automatic meshing and parallel processing capabilities streamline the simulation process, reducing computation time and boosting productivity.

PowerFLOW technology not only handles complex geometries but also provides significant advantages for simulating aerodynamic performance. It delivers higher accuracy and efficiency when modeling high-lift devices in complex, dynamic, unsteady flows. Because turbulence is largely resolved rather than modeled, PowerFLOW can effectively reproduce the effects of the atmospheric boundary layer (ABL), which is crucial for understanding the real-world behavior of lifting surfaces. By simulating accurate and detailed geometries without simplification, it captures all aerodynamic influences with greater fidelity. These strengths have been demonstrated in benchmark studies, such as the High-Lift Prediction Workshops, where PowerFLOW produced results that closely matched experimental data.



Deck windage simulation with PowerFLOW

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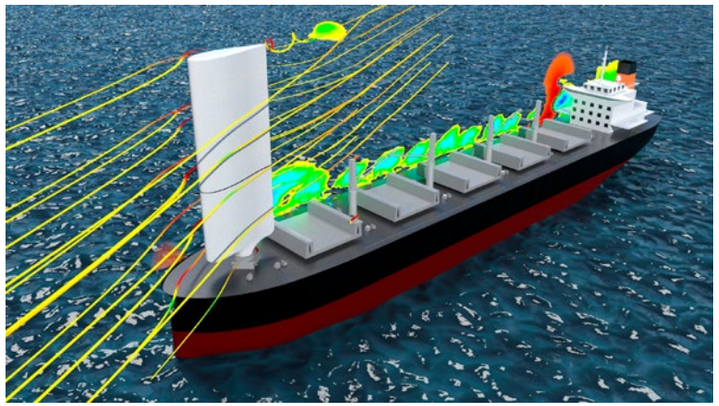
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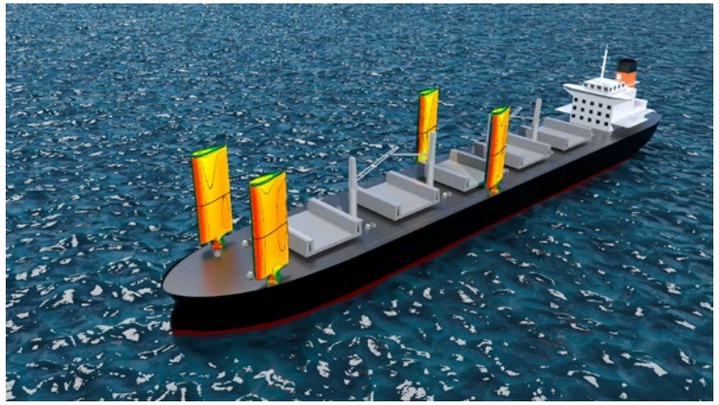
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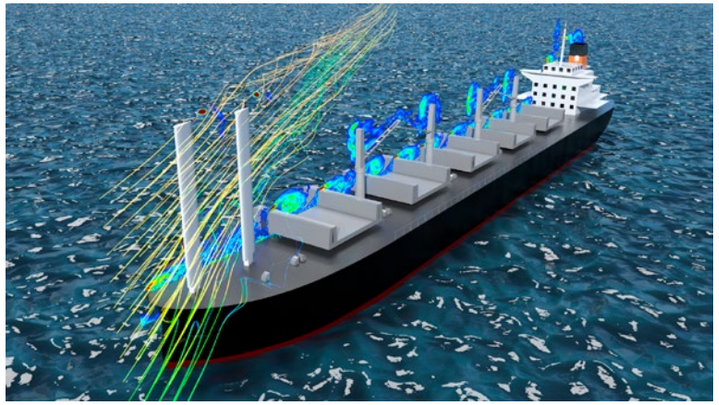
SAIL PLACEMENT AND AERODYNAMIC INTERACTION STUDY

Multiple studies can be performed for different wind speeds and directions, replicating the full range of expected real-world weather conditions. For example, comparing the effectiveness of one big sail compared to two small sails. For a two-sail configuration, the second sail has reduced aerodynamic performance due to the interaction with the wake from the leading sail. Both sails cause additional wind turbulence at the deck level, but at a level comparable to other ship structures. This information helps engineers to decide whether a second sail is worth the additional weight and cost.









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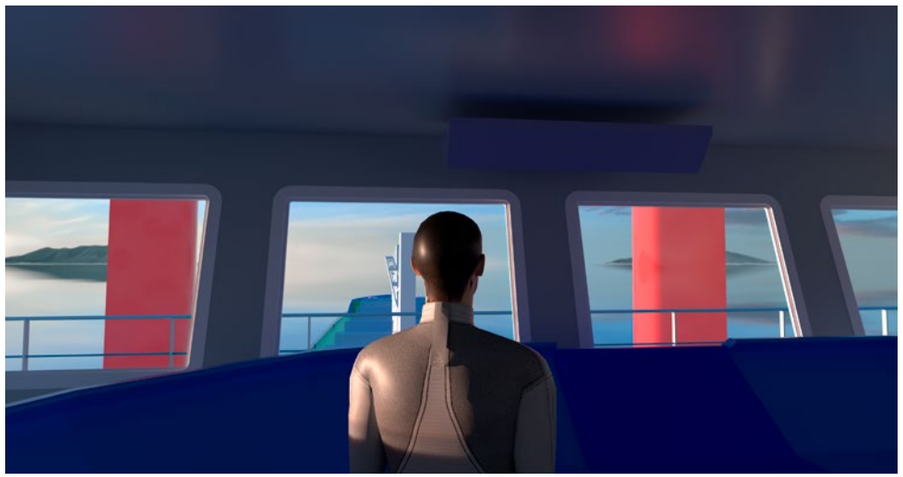
SAIL PLACEMENT—BRIDGE VISIBILITY AND NAVIGATION LIGHTS

Although ships are equipped with a wide range of navigation equipment, visibility remains crucial to navigation and maneuvering. Sails potentially block visibility from the windows of the bridge, and prevent navigation lights from being seen by other ships. To comply with the rules set by the classification agencies, the designer should take these items into consideration when placing the sails on the ship.

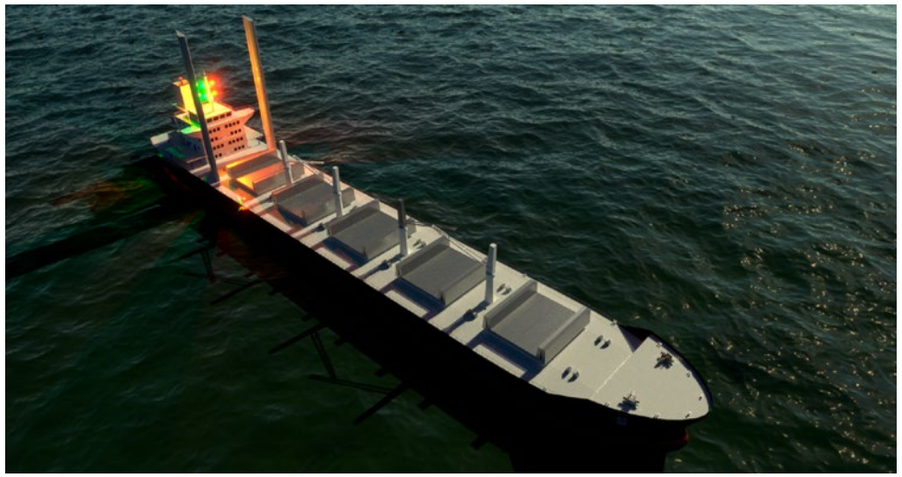
With the virtual twin in place, critical sanity checks—such as component clearance, placement accuracy and spatial integration—can be performed instantly. 3DEXCITE provides precise sight line analysis from multiple virtual camera positions, enabling visibility assessments from key viewpoints such as the bridge or deck, under realistic operational conditions.

High-fidelity renderings convert design data into photorealistic visuals using advanced ray-tracing and global illumination, enabling accurate evaluations of form, finish and spatial perception. Physical light sources can be virtually placed and configured to replicate real-world lighting characteristics, intensity, temperature and direction, supporting the simulation of varied environmental conditions.

This is particularly valuable in WASP systems, where elements such as the rotor sails must be evaluated not only for performance but also for their impact on visibility, safety and crew operations. Accurate lighting and shading renderings help capture reflections and shadows on deck and superstructure, ensuring regulatory compliance and optimal situational awareness at sea.



Bridge visibility study performed using 3DEXCITE Deltagen.



Navigation light assessment to ensure clear visibility at sea.

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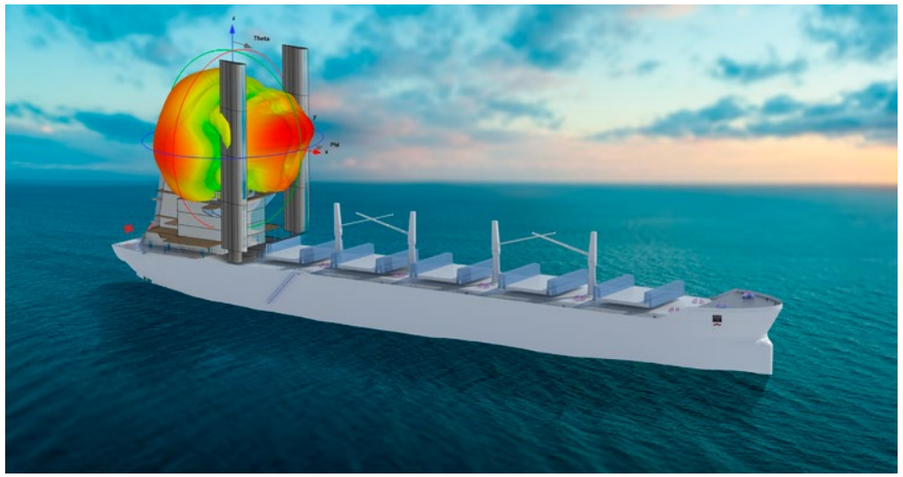
ANTENNA INTERFERENCE AND RADAR BLIND SECTORS

In addition to interrupting visible sightlines, the sails of WASP systems can also block, reflect, absorb or refract signals from antenna systems. This can interfere with communication and positioning systems and cause blind sectors for radar systems.

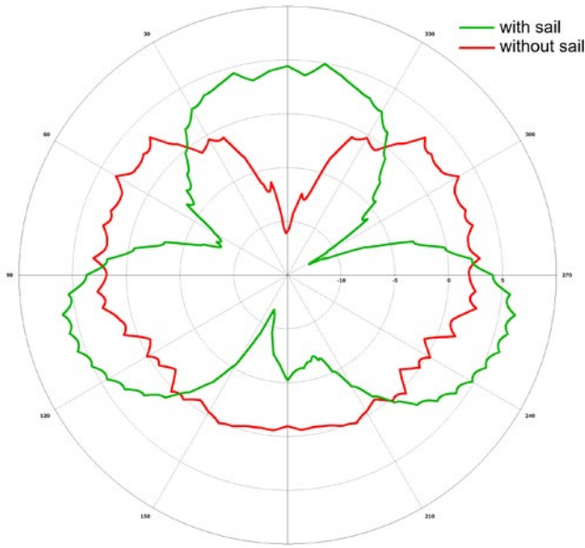
Antenna placement and coverage can be effectively modeled in CST Studio Suite. For very large platforms such as a ship, CST Studio Suite offers the Asymptotic Solver, which uses ray tracing methods to efficiently calculate field propagation from the antennas.

Antenna installed performance often differs significantly from its free space performance measured in isolation, due to the metallic structure of the ship platform on which it is installed. Simulation can calculate both the nearfield around the antenna and its farfield performance or radiation pattern. This shows the impact of the sails and other superstructure elements on antenna performance and clearly illustrates blind sectors where farfield performance is reduced.

In some cases, fields radiated by one antenna may be reflected off a sail and be received by another antenna on the same ship. This causes co-site interference between radio systems. CST Studio Suite can calculate the interference between different antenna systems, taking into account their different frequency bands. It highlights interference risks, enabling engineers to mitigate them through changes to antenna placement or filtering.



3D farfield plot of installed antenna.



Radiation pattern of installed antenna on a ship, with (green) and without (red) sails.

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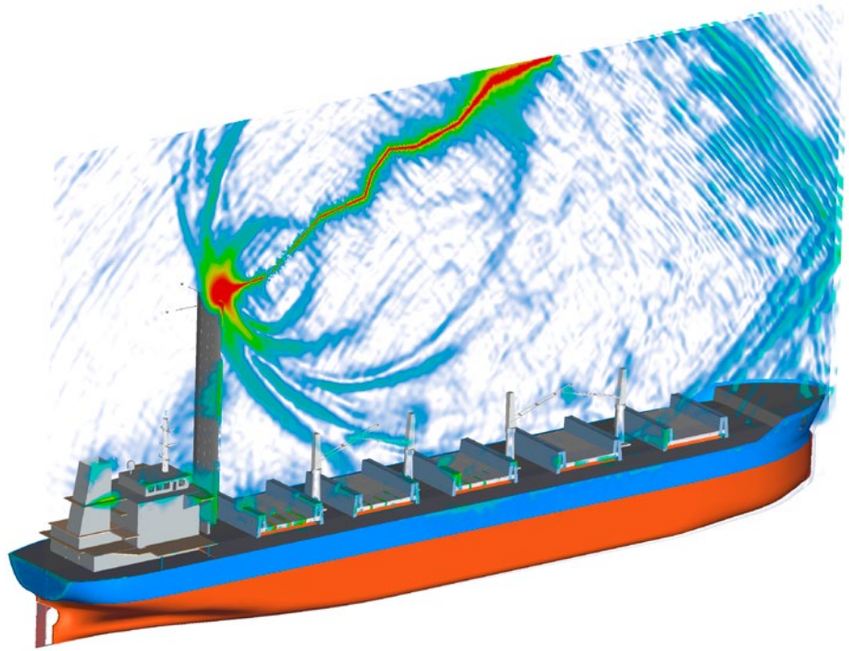
LIGHTNING STRIKE AND ENVIRONMENTAL ELECTROMAGNETIC EFFECTS (E3)

The sail of a ship on the open sea equipped with WASP is likely to be the highest object for many miles. As a result, the sail may attract a considerable number of lightning strikes during storms. Lightning can damage the sail by generating heat and it can also cause power surges and electromagnetic interference in nearby cables. The sail will need to be able to conduct the lightning currents safely to the electrical earth.

Simulation can be used to model the propagation of lightning strike pulses through the sail. An initial electrostatic simulation quickly calculates the electric field around the ship during a lightning storm. Points of high field strength are the most likely attachment sites. These are often on sharp corners and edges where the field is concentrated and can potentially be mitigated by rounding the sail endplates at key points.

Once an attachment site has been identified, a transient simulation then models the propagation of the lightning strike in the time domain. Engineers can examine both the currents inside materials and the electric fields and induced currents in neighboring cables.

Other environmental electromagnetic effects (E3), such as high-intensity radiated fields (HIRF) and electromagnetic pulse (EMP), can also be analyzed using the same methods to ensure that WASP system motors and electronics operate reliably under interference.



Lightning strike on the sail of a bulk carrier, visualized using the CST Studio Suite TLM solver.

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THE ADVANTAGES OF UNIFIED MODELING AND SIMULATION (MODSIM)

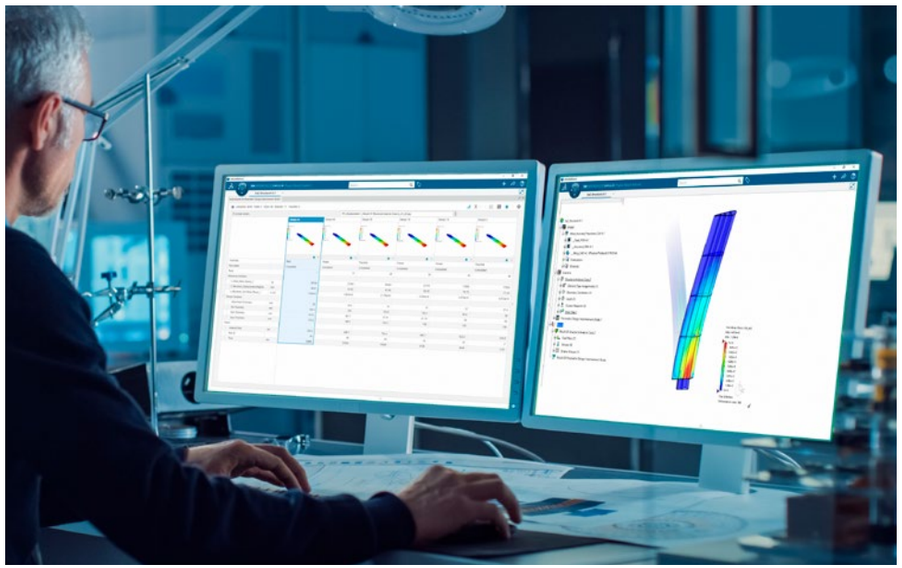
Modeling (computer-aided design or CAD) and simulation (computer-aided engineering or CAE) are often considered completely separate disciplines and siloed off. The modeling is done by the designer, who builds a 3D geometry but has little experience with testing and simulation. The simulation, meanwhile, is done by a simulation analyst who understands the technical details of simulation but is not involved in the design.

Unified modeling and simulation (MODSIM) bridges the gap between these two disciplines. In a MODSIM-powered design process, the designer has access to simulation during the modeling process, allowing them to quickly analyze the performance at any stage of development. They can compare the performance of design variants before handing the design over for testing.

The simulation analyst now has the power to perform simulations directly on the design geometry. They can adapt and modify the design using parametric and non-parametric optimization tools powered by simulation. These automatically adapt the geometry to find optimal design trade-offs, and with MODSIM, the optimal geometry is automatically passed back to the designers.

In WASP development, MODSIM brings the designers and engineers together in a common working environment. The designer can quickly find an optimal airfoil design (see page 4) before any wind tunnel testing, while the analyst can use the WASP sail design in their analysis without the additional work of rebuilding simulation models and pass optimized designs straight back to the designer.

MODSIM is enabled by the Dassault Systèmes **3DEXPERIENCE** platform, which brings together design and simulation tools in a common environment and provides a data platform that acts as a single source of truth for all stakeholders. MODSIM on **3DEXPERIENCE** helps accelerate WASP system development by reducing modeling work and testing, and reduces costs and design risk by increasing the communication between designers and analysts.



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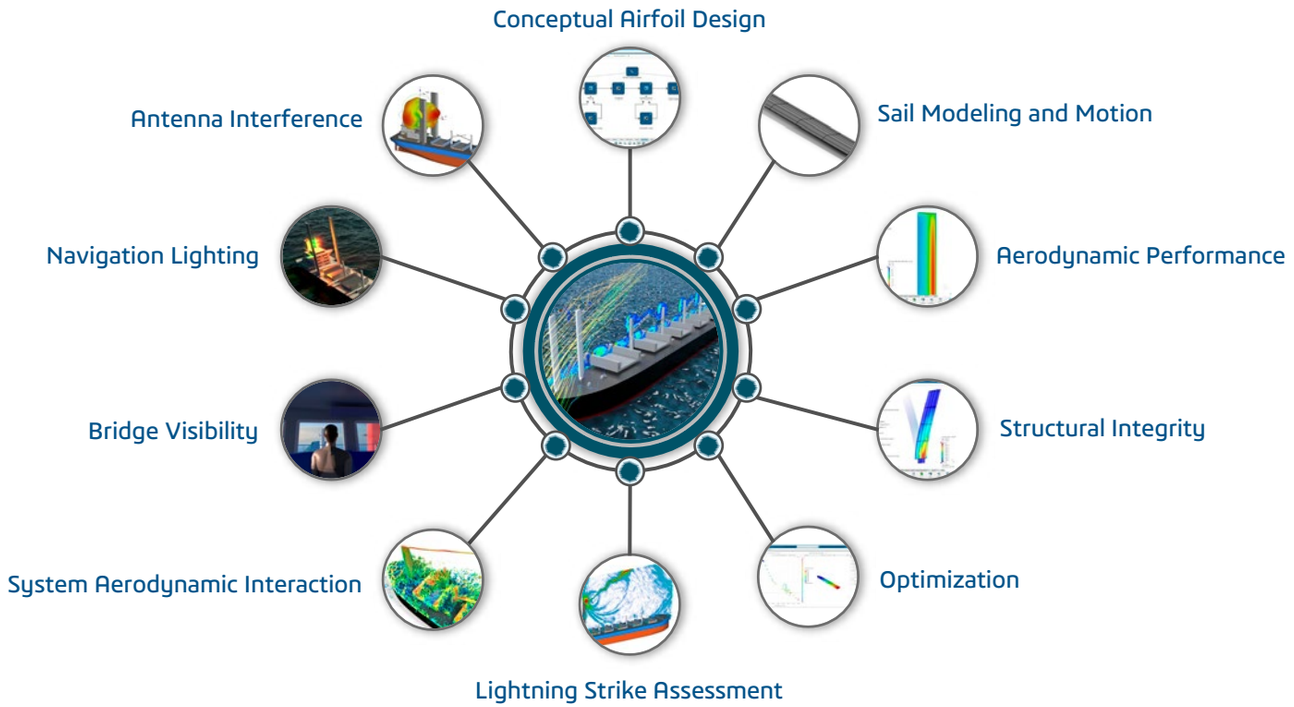
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A MULTIPHYSICS, MULTISCALE SIMULATION SOLUTION

As shown throughout this e-book, WASP engineering is a multidisciplinary challenge. Structural, aerodynamic and electromagnetic factors all need to be considered, with complex trade-offs between them. The sail also needs to be understood at many scales, from cross-sections and individual components up to the full vessel with all sails attached.

The SIMULIA brand of Dassault Systèmes encompasses simulation tools covering all these disciplines of physics, with industry standard tools including Abaqus for structural mechanics, PowerFLOW for computational fluid dynamics (CFD) and CST Studio Suite for electromagnetics. The MODSIM workflow brings all these tools together. Design geometry from CATIA, SolidWORKS or other industry tools can be directly imported into the simulation tools, linked together by the **3DEXPERIENCE** platform. 3DEXCITE supports visualization and rendering.

With MODSIM, all the different types of analysis shown in this e-book can be performed as part of a single unified workflow. Models do not need to be rebuilt for each kind of analysis and all the collected data can be stored and analyzed in a common environment.



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KEY BENEFITS OF MODSIM FOR WASP SYSTEM DESIGN

Using MODSIM for WASP system design brings advantages across the development cycle.

Faster development
Accelerate development and reduce design time.

Cut costs
Reduce rework and the need for physical testing with virtual prototypes.

Reduced risk
Analyze all performance factors of the retrofitted WASP before construction and testing.

Break down silos
Improve collaboration between design and analysis through MODSIM.

Read more about wind-assisted propulsion at sea.

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WASP is a promising technology for reducing fuel consumption and increasing the sustainability of shipping. Retrofitting WASP to an existing vessel can significantly improve efficiency and reduce emissions. However, several challenges must be addressed, including the design of the sails, the overall aerodynamics of the ship, and concerns related to lightning strike and radar interference.

Simulation provides engineers with the tools needed to analyze WASP system performance during the design process, allowing them to address potential issues before the costly stages of prototyping and sea trials. Problems can be identified and resolved earlier and performance can be optimized to get the best efficiency. Projects can be completed faster, with lower costs and risks.

SIMULIA offers a range of multiphysics simulation tools capable of meeting the challenges of WASP system design. WASP manufacturers are already using SIMULIA tools as part of the development process to bring innovative products to market faster.

Unified modeling and simulation (MODSIM) brings simulation into the design process, integrating it into existing CAD workflows. Designers can take advantage of simulation at any stage of development to analyze and optimize designs. MODSIM breaks down the silos between design and analysis and democratizes access to simulation, further accelerating development and cutting risk.

To learn more about how MODSIM on the **3D**EXPERIENCE platform can help achieve successful WASP retrofitting, contact us.

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Virtual Worlds for Real Life

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