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Performance Assessment of Combined Air Lubrification and Suction Sail Systems in Naval Applications

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Abstract. Rigid suction sails represent an innovative technology within the field of naval engineering, integrating aerodynamic principles and airflow dynamics to enhance ship propulsion efficiency. These sails are specifically designed to augment lift force by improving airflow circulation around the aerodynamic profile through controlled boundary-layer suction. This technology constitutes a cutting-edge approach in wind energy harvesting, directly applied to rigid sails aimed at increasing maritime energy efficiency. When combined with air lubrication of the hull, significant improvements in quasi-propulsive efficiency can be achieved, contributing to reduced fossil fuel consumption and, implicitly, decreased environmental pollution.

Keywords: air lubrication; suction sail; pollution;

1. Introduction

Depending on the operating conditions and the efficiency of each technology's implementation, it is possible to achieve a total increase in propulsion efficiency of 20%. Combining new technologies can lead to significant fuel savings and an overall improvement in ship performance. However, it is important to note that these estimates are conditional on specific factors and will vary depending on the type of ship and environment. Further testing and research will help refine these estimates and apply them more broadly to commercial fleets.[1]

The pressure range achieved by the fans used for suction on rigid sails depends on the specific design and purpose of the system. Rigid sails with suction operate by creating a pressure difference between the upper and lower parts of the sails, which helps generate an additional lift force for the hydrodynamic profile. Axial fans play an important role in generating the pressure difference.

Nowadays, shipbuilding already incorporates wind energy in various constructive forms: inflatable sails, kite sails, suction sails, rigid sails, Flettner rotors, etc. As of 2024, there are 38 ships equipped with such applications, with the categories represented in Table 1.[2]

Table 1. Wind energy in various constructive forms in shipping.	
Tehnology uptake by sail type	Number of ships equipped
Inflatable Sail	1
Wind Kite	2
Suction Sail	10

Rigid Sail	8
Fletner Rotors	17

2. Materials and methods

2.1. Suction rigid sails

Although suction rigid sails are still under development for many commercial applications, they have already been tested on various types of ships, including commercial vessels. Moreover, research continues to improve their efficiency and durability. In the future, suction rigid sails could play an important role in the maritime industry by enhancing performance and reducing dependence on fossil fuels. Efficiency improvements are based on two aspects:

- **Aerodynamic principle:** Suction rigid sails are designed to create a pressure differential across their surface. The upper part of the sail has a faster airflow, while the lower part experiences slower airflow. This difference in air velocity creates a lower-pressure zone on the upper side, generating lift force. The suction effect helps maximize the energy captured from the wind, as illustrated in Figure 1.
- **Stability and control:** The suction effect enables more stable navigation because the forces exerted on the ship are more uniform and predictable. These sails can respond more effectively to wind changes and help maintain a constant speed.[3,4]

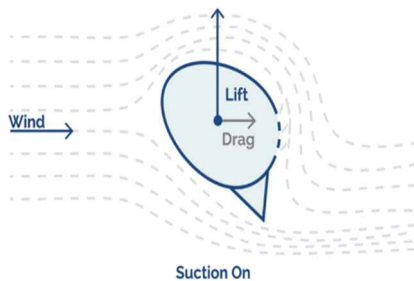


Figure 1. Rigid suction sail



Figure 2. Rigid sail without suction

Compared to classic rigid sails, which can create a certain degree of turbulence and drag (see Fig. 2), the suction system reduces these effects, making suction rigid sails more efficient. They can capture more energy from the wind, with less drag and greater stability.

Advantages of suction rigid sails:

- **Increased energy efficiency:** Reducing drag and maximizing lift force makes ships equipped with such sails more energy-efficient. In some cases, this can significantly reduce fuel consumption.
- **Improved performance:** Ships can reach higher speeds, especially in conditions of weak or variable winds. Additionally, this type of sail can provide better maneuverability in extreme wind conditions.
- **Sustainability:** Being more energy-efficient, suction rigid sails can contribute to reducing CO₂ emissions and minimizing the impact on the marine environment.[5,6]

2.2. Air Lubrication Systems

The injection of exhaust air, already used as suction air for rigid sails, can bring significant benefits for reducing the coefficient of friction between the water and the ship's hull. Thus, the issue arises of the working pressures of axial fans and their use in stages to increase the exhaust pressure, in relation to specific environmental conditions. The factors influencing air pressure depend on:

- Ship type: Larger and faster ships may require more powerful fans capable of creating a greater pressure differential.
- Sail design: Rigid suction sails can vary significantly depending on their design, size, and how they are adjusted.
- Wind speed: Creating higher pressure can be done over a wider range of wind speeds to maximize efficiency in various conditions.
- Fan power: High-capacity fans can generate larger pressure differentials to increase the efficiency of suction sails.

In conclusion, the pressure achieved by fans in a suction sail system can vary significantly, but generally falls within a range from a few Pa up to 200 Pa, depending on the system configuration. The pressure range for lubricating the ship's hull with compressed air (air lubrication systems) depends on the system type and the specific purpose of its use. Generally, these systems are used to reduce friction between the ship's hull and the water by injecting compressed air in the form of fine bubbles into the contact area between the hull and the water, which helps create an air film that reduces hydrodynamic resistance. Typically, the compressed air pressure used in ship hull lubrication systems is relatively low, as very high pressure is not required to inject the air efficiently. The operating pressure of the system can vary between 0.2 and 1 bar (relative pressure), depending on the hull design. The method of distributing compressed air under the ship's hull will be through air injectors (Air Injection System), whereby the compressed air is introduced through injectors located on the ship's hull, usually in areas with the highest friction, such as the bow area, fig. no. 3, and sometimes in the midship section. These injectors are connected to a system of axial or centrifugal compressors that supply the compressed air.

The air is released in the form of fine bubbles (microbubbles) that create an air film between the ship's hull and the water, thereby reducing friction.[7,8,9]

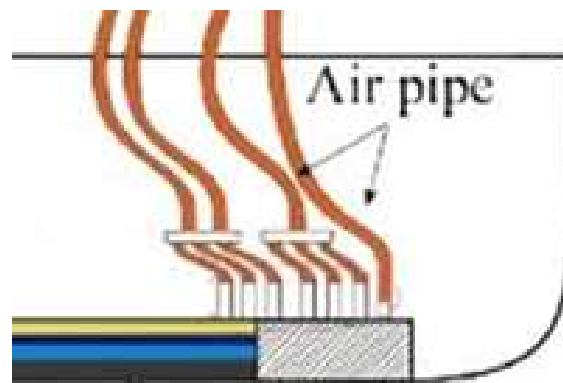


Figure 3. Bow Air Lubrication Systems

The pressure and speed of the injected air are regulated to achieve optimal distribution. Air can be injected at higher pressures in areas where friction is greater and at lower pressures in other areas. Most air lubrication systems are equipped with sensors and controllers that monitor the air flow and pressure, adjusting them according to the ship's operating conditions (speed, flow conditions, etc.) and allowing, in real time, the adjustment of air distribution to maintain optimal ship efficiency.

Benefits of air distribution:

- Friction reduction: The air creates a barrier between the ship's hull and the water, reducing hydrodynamic friction and thus helping to save fuel.
- Performance improvement: Reducing friction improves the ship's performance, allowing it to reach higher speeds with less effort from the propeller.
- Increased energy efficiency: By lowering drag, ships can use less fuel to travel the same distances, which, in the long term, can lead to significant savings.

In conclusion, compressed air is distributed under the ship's hull through a series of injectors or air channels, creating an air film under the hull, reducing friction, and improving the ship's efficiency in motion. This process helps to save fuel and increase the overall performance of the ship.

2.3. Fan pressure range

Fans in suction sail systems are designed to create an airflow that generates negative pressure (i.e., lower pressure on the underside of the sail compared to the top). Generally, the negative pressure can range from -10 to -100 N/m² (Pascals), depending on the size of the sails, the type of ship, and wind conditions. The positive pressure generated by the fans could be lower and may reach up to approximately 100-200 Pa if the fans are used to improve the system's aerodynamics. In some cases, systems can be designed to operate at higher pressures, up to 3 bar (relative pressure) or more, to ensure a constant airflow and uniform distribution of air bubbles over the entire hull of the ship. The exact pressure may depend on the type of ship and operating conditions. [10]

Factors influencing pressure:

- Ship type - large ships traveling at higher speeds may require a more powerful system with higher pressures to achieve a significant reduction in friction.
- Size of the aeration system - a more complex air lubrication system covering a larger area of the ship may require a more powerful compressor system and higher pressure.

The benefits include the reduction of hydrodynamic friction and fuel consumption, as well as improved ship speed and efficiency, especially for ships navigating long routes. In conclusion, for a compressed air lubrication system, the operating pressure is usually between 0.2 and 1 bar, with possible higher pressures (up to 3 bar) depending on the technical specifications of the ship and the system used. The compressed air is distributed under the ship's hull through a specialized system of injectors or distribution channels that allow the creation of an air film between the ship's hull and the water. The purpose of this system is to reduce hydrodynamic friction between the ship and the water, improving propulsion efficiency and reducing fuel consumption. Modern compressed air lubrication systems are designed to inject air efficiently and uniformly over the entire underwater surface of the ship.[11,12]

3. Simulation

The study of airflow dynamics around aerodynamic surfaces is crucial for optimizing performance and efficiency in various engineering applications. A suction sail blade represents an innovative approach to enhancing aerodynamic lift and control through controlled suction mechanisms. ANSYS Fluent, a powerful computational fluid dynamics (CFD) tool, enables detailed analysis of airflow behaviour around such structures, providing valuable insights into pressure distribution, velocity profiles, and turbulence effects.

This simulation outlines the significance of airflow using ANSYS Fluent, highlighting key considerations in setting up the computational domain, selecting appropriate turbulence models, and interpreting simulation results. By understanding the complex interactions between airflow and the suction sail blade, engineers can refine designs for improved aerodynamic performance and energy efficiency.

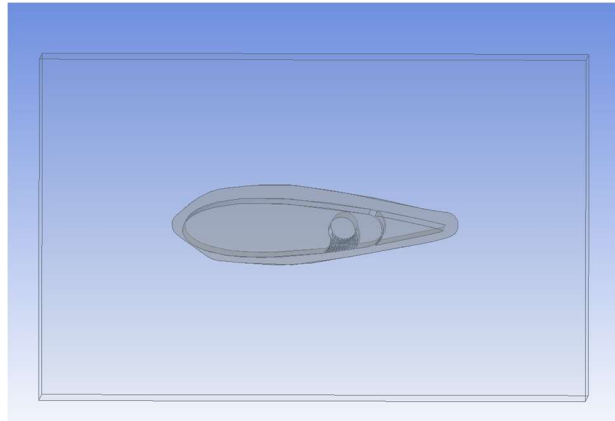


Figure 4. Suction sail geometry

4. Results and discussions

The uploaded CFD simulation images show air pressure distributions around a suction sail blade at different conditions. These visualizations provide additional insights into how air pressure transforms into thrust based on blade angles and airflow characteristics.

Observations from the Pressure Distributions:

- Pressure Gradients Across the Blade Surface
- As the blade angle increases, the pressure distribution shifts, affecting how air moves around the blade.
- Higher pressure regions appear near the leading edge, while lower-pressure zones develop along the trailing edge, indicating areas where aerodynamic forces contribute to thrust.

Comparing Lower vs. Higher Inlet Pressures

- In Figure 8 (10 Pa, 0° suction OFF), the pressure is relatively uniform, leading to weaker airflow control.
- In Figure 9 (60 Pa, 18° suction OFF), there is a significant increase in pressure variations, supporting enhanced thrust potential.

Blade Angle Influence on Thrust

- In Figure 10 & Figure 11 (40 Pa and 20 Pa at 18°), pressure patterns show how adjusting the blade angle strengthens aerodynamic efficiency.
- This suggests that optimized angles, when combined with suction effects, could further refine thrust generation

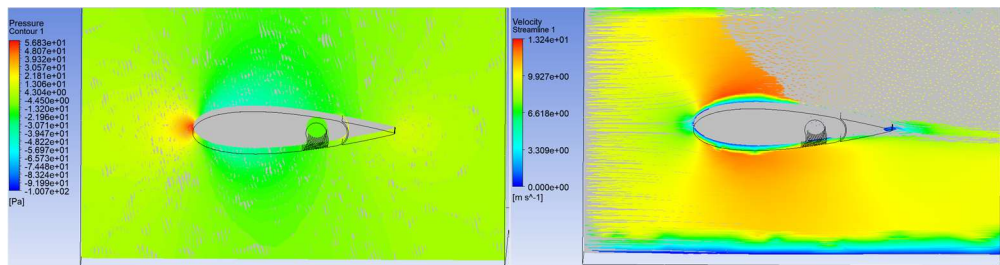


Figure 5. Air pressure 60 [Pa] – blade angle 0, suction OFF

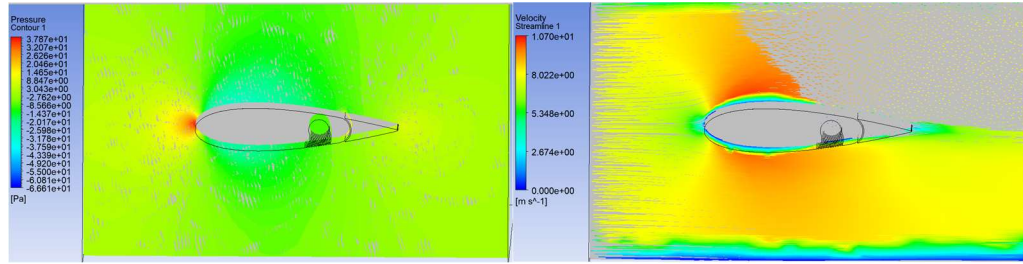


Figure 6. Air pressure 40 [Pa] – blade angle 0, suction OFF

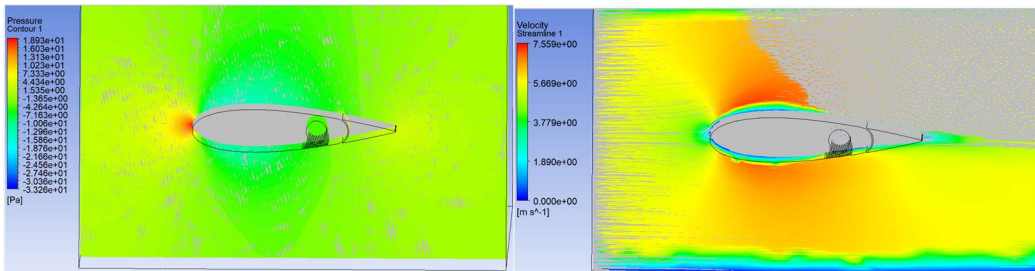


Figure 7. Air pressure 20 [Pa] – blade angle 0, suction OFF

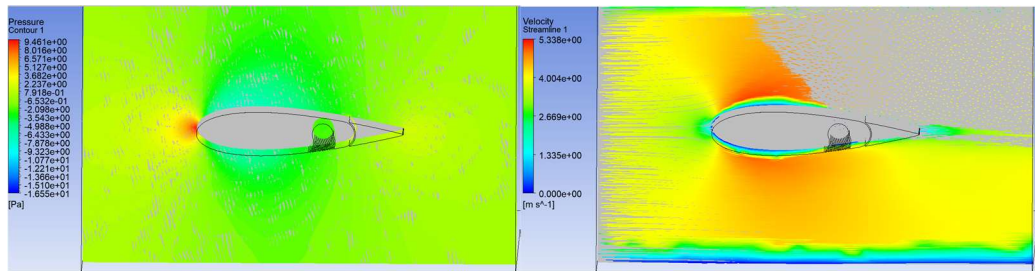


Figure 8. Air pressure 10 [Pa] – blade angle 0, suction OFF

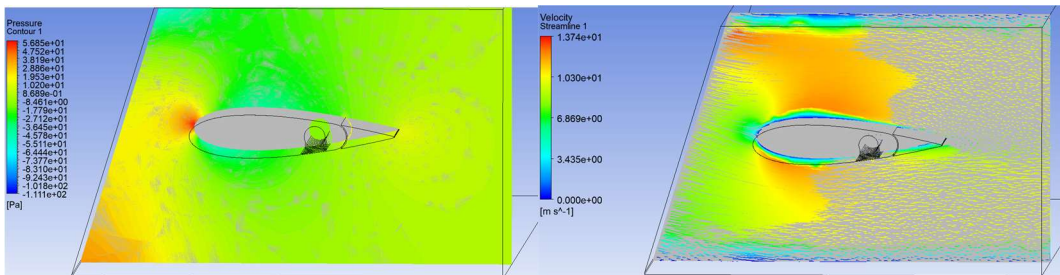


Figure 9. Air pressure 60 [Pa] – blade angle 18, suction OFF

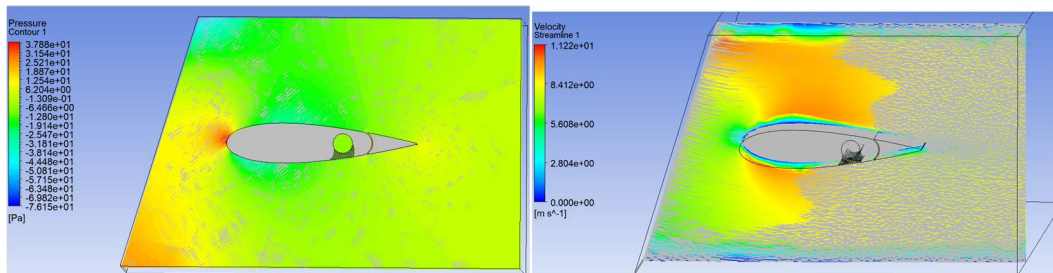


Figure 10. Air pressure 40 [Pa] – blade angle 18, suction OFF

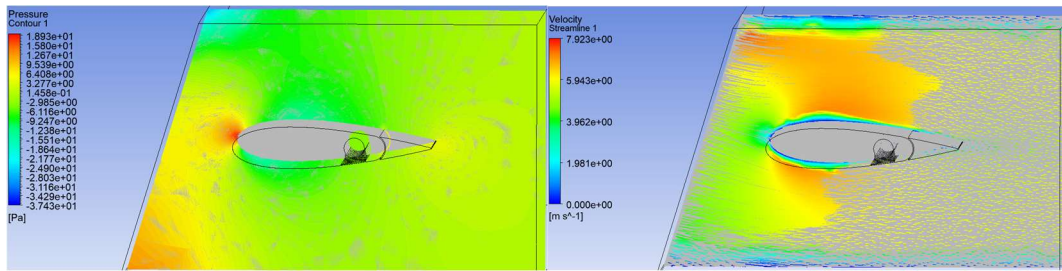


Figure 11. Air pressure 20 [Pa] – blade angle 18, suction OFF

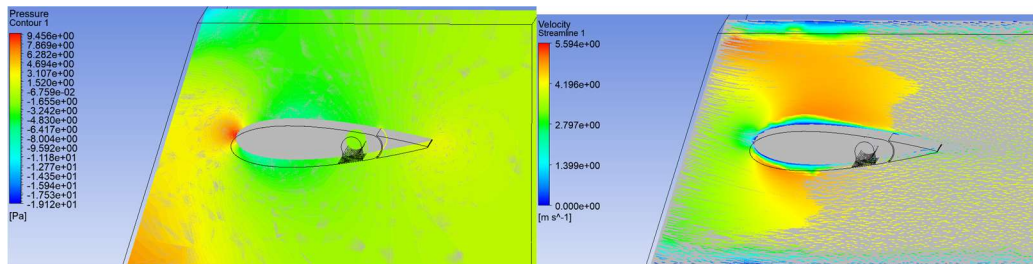


Figure 12. Air pressure 10 [Pa] – blade angle 18, suction OFF

The CFD simulation images showcase air pressure distributions around a suction sail blade at different air pressures (60 Pa, 40 Pa, 20 Pa, and 10 Pa), all with a blade angle of 18° and suction ON. These visualizations allow us to assess how air pressure contributes to thrust generation.

Pressure Distribution Along the Blade Surface

- Higher inlet air pressure (e.g., 60 Pa) results in more distinct pressure gradients, suggesting stronger aerodynamic forces.
- Suction increases localized pressure near the leading edge, influencing airflow direction to enhance thrust.

Impact of Suction on Flow Behavior

- In the 10 Pa case, pressure distribution is more uniform, resulting in lower thrust potential.
- As air pressure increases (e.g., 40 Pa and 60 Pa), suction creates larger pressure differences, leading to stronger air control.
- The lower pressure zones towards the trailing edge indicate efficient airflow redirection, essential for thrust.

Relationship Between Pressure and Air Velocity

- Comparing higher and lower inlet pressures, greater initial pressure leads to better-controlled airflow and higher velocity retention, supporting thrust generation.
- The velocity vector fields confirm that air movement is more directed and structured at increased inlet pressures.

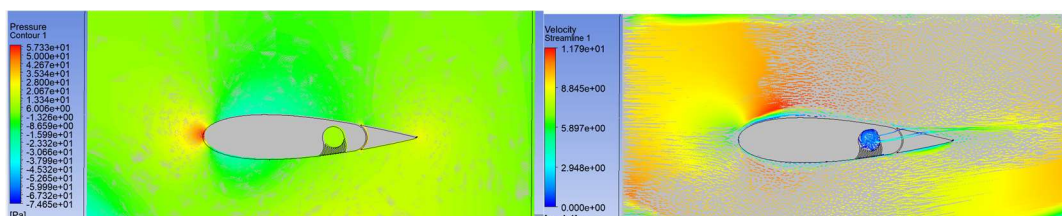


Figure 13. Air pressure 60 [Pa] – blade angle 0, suction ON

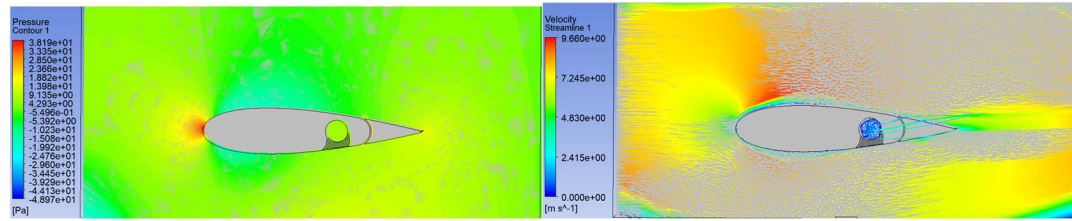


Figure 14. Air pressure 40 [Pa] – blade angle 0, suction ON

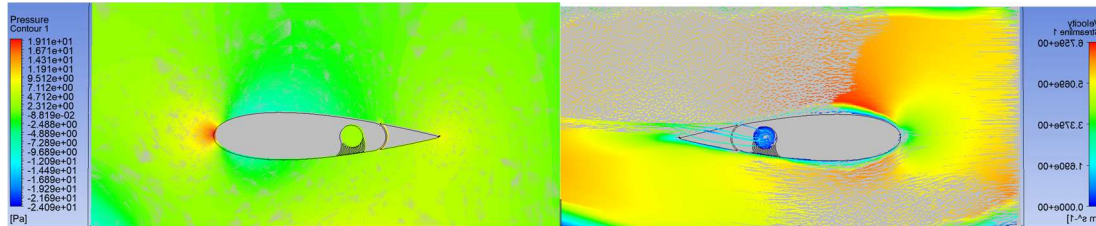


Figure 15. Air pressure 20 [Pa] – blade angle 0, suction ON

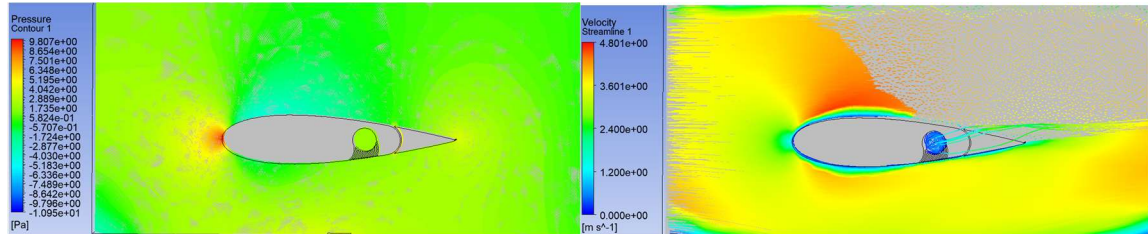


Figure 16. Air pressure 10 [Pa] – blade angle 0, suction ON

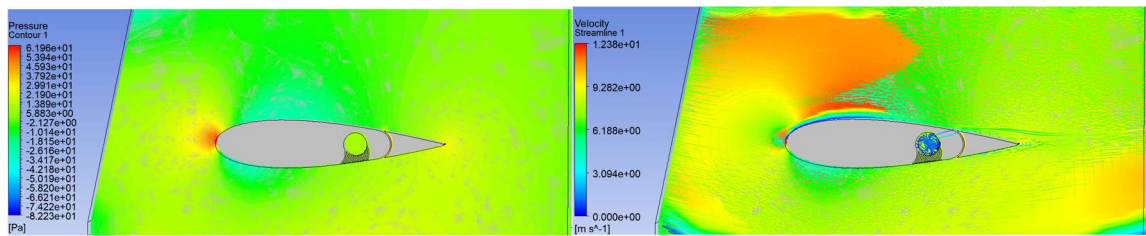


Figure 17. Air pressure 60 [Pa] – blade angle 18, suction ON

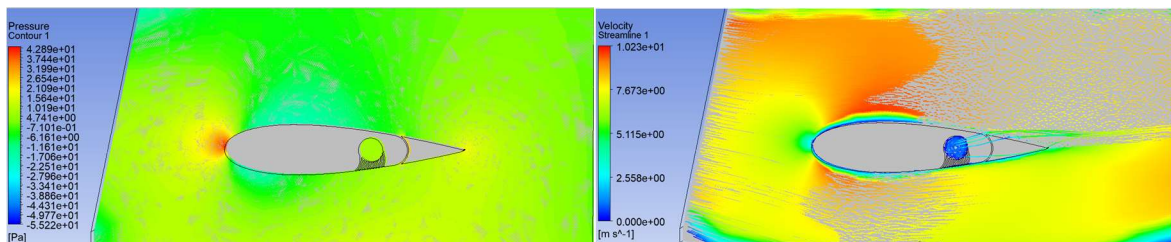


Figure 18. Air pressure 40 [Pa] – blade angle 18, suction ON

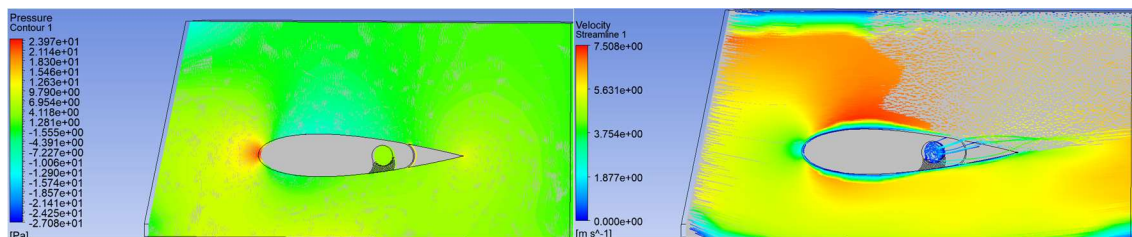


Figure 19. Air pressure 20 [Pa] – blade angle 18, suction ON

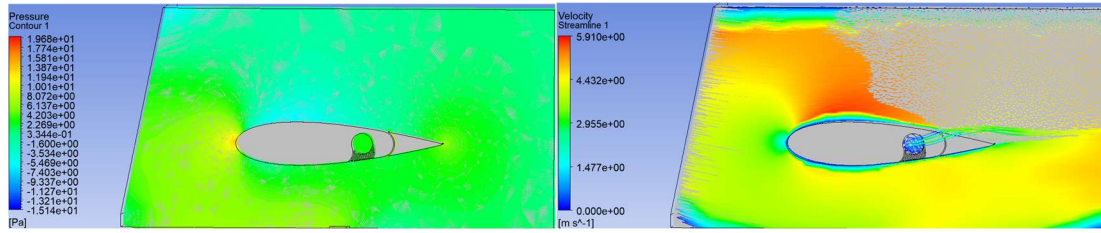


Figure 20. Air pressure 10 [Pa] – blade angle 18, suction ON

Table 2. Simulation results.

Inlet air pressure [Pa]	Blade angle / Air pressure / Air velocity			
	0 deg (suction OFF)	18 deg (suction OFF)	0 deg (suction ON)	18 deg (suction ON)
60	56.83 [Pa] 13.2 [m/s]	56.85 [Pa] 13.7 [m/s]	57.33 [Pa] 11.7 [m/s]	61.96 [Pa] 12.3 [m/s]
40	37.87 [Pa] 10.7 [m/s]	37.88 [Pa] 11.2 [m/s]	38.19 [Pa] 9.66 [m/s]	42.89 [Pa] 10.2 [m/s]
20	18.93 [Pa] 7.55 [m/s]	18.93 [Pa] 7.92 [m/s]	19.11 [Pa] 6.75 [m/s]	23.97 [Pa] 7.5 [m/s]
10	9.46 [Pa] 5.33 [m/s]	9.56 [Pa] 5.59 [m/s]	9.80 [Pa] 4.80 [m/s]	19.68 [Pa] 5.9 [m/s]

The table 2 provides simulated results for airflow over a suction sail blade, comparing cases with and without suction at different inlet air pressures and blade angles. The key observations from the data are:

Effect of Suction on Air Pressure:

- At all inlet pressures, the air pressure increases slightly when suction is activated.
- The most significant increase is observed at higher inlet air pressures (e.g., 60 Pa, where suction ON at 18° results in 61.96 Pa compared to 56.85 Pa without suction).

Effect of Suction on Air Velocity:

- Suction activation generally decreases airflow velocity.
- For instance, at 60 Pa, suction OFF at 0° yields 13.2 m/s, whereas suction ON results in a lower velocity of 11.7 m/s.
- This trend remains consistent across different inlet air pressures, indicating that suction slightly restrains airflow, likely due to increased air adherence to the blade surface.

Impact of Blade Angle on Air Velocity:

- When suction is OFF, increasing blade angle from 0° to 18° leads to a minor increase in velocity (e.g., at 60 Pa, velocity increases from 13.2 m/s to 13.7 m/s).
- This suggests that the tilt helps direct airflow more efficiently, potentially enhancing aerodynamic performance.
- When suction is ON, however, the difference in velocity due to blade angle is less pronounced, showing that suction itself dominates airflow behavior.

Lower Inlet Pressures Show a More Pronounced Effect:

- At lower pressures (e.g., 10 Pa), suction significantly increases the outlet pressure (9.80 Pa vs. 19.68 Pa with suction ON at 18°).
- Similarly, velocity jumps from 4.80 m/s (suction OFF) to 5.9 m/s (suction ON), indicating that suction plays a stronger role in modifying airflow when inlet pressure is minimal.[13]

5. Conclusions

The results suggest that suction leads to an increase in pressure and a decrease in velocity, particularly at higher inlet pressures. The blade angle primarily influences airflow when suction is off, while suction

dominates the effects on airflow dynamics. These findings offer useful insights into optimizing the suction sail design for better aerodynamic efficiency.

Suction Enhances Thrust Efficiency:

- Suction increases pressure gradients, leading to a higher force acting on the blade.
- While suction slightly reduces velocity, this change aids in directing airflow efficiently, improving aerodynamic thrust generation.
- The strongest effects occur at lower inlet pressures, meaning suction sails may be particularly effective in conditions with minimal wind [14]

Coupling these two systems – the fans from the suction sails and the air aspiration for hull lubrication – can bring multiple advantages, including fuel savings, improved performance, reduced system complexity, and a smaller environmental impact. Furthermore, the integration of these systems can lead to more efficient and reliable ship operation, with lower operational costs and greater equipment durability. Reducing fossil fuel consumption by 20% due to the implementation of combined technologies (rigid suction sails and compressed air hull lubrication) could lead to a significant reduction in greenhouse gas (GHG) emissions, but the exact reduction for each emission category depends on the type of fuel used and the ship's characteristics.

Here's how the impact might look in terms of GHG emission reduction:

- Reduction of CO₂ (Carbon Dioxide) emissions. CO₂ emissions are directly related to the amount of fossil fuel burned. Reducing fuel consumption by 20% will typically lead to an approximately 20% reduction in CO₂ emissions. Since CO₂ represents the largest portion of greenhouse gas emissions from ships (especially from the propulsion engine using fossil fuels), a 20% reduction in fuel consumption will result in an approximate 20% reduction in CO₂ emissions.
- Reduction of other GHG emissions (CH₄, N₂O). Methane (CH₄) and nitrous oxide (N₂O) emissions are typically smaller compared to CO₂, but they can significantly contribute to global warming. Although methane and nitrous oxide are not emitted in the same quantities as carbon dioxide, reducing fuel consumption will also affect these gases, as the engine will operate more efficiently, and combustion will be more complete. Estimates suggest that a 20% reduction in fuel consumption can lead to an approximately 10-20% reduction in methane and nitrous oxide emissions, depending on the engine type and fuel.
- Reduction of particulate and SO_x (sulfur dioxide) emissions. Systems that reduce fuel consumption can also contribute to the reduction of fine particulate matter and sulfur dioxide (SO_x) emissions. For example, more efficient engines burn fuel more cleanly, which means less production of particulate matter and sulfur emissions. A 20% reduction in fuel consumption can lead to a proportional reduction in these emissions, i.e., an approximate 20% decrease in particulate and SO_x emissions

Author contributions:

- Conceptualization: I.P.
- Methodology: I.P. and M.C.
- Investigation: I.P. and D.M.
- Writing original draft: D.M.
- Writing review and editing: D.C. and M.C.
- Supervision: I.P. and D.C.

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References

1. Lloyd's Register of Shipping (2019). Marine Technology and Systems Handbook. Lloyd's Register.
2. Hansen, G., & White, R. S. (2009). Introduction to Marine Engineering. Elsevier.
3. Karvonen, T., & Sandblom, T. (2018). Energy Efficiency in Maritime Transport: Application of Alternative Energy Sources. Elsevier.
4. Burelli, A. M., & Vasiliu, L. (2017). Optimization of Ship Propulsion and Auxiliary Systems for Improved Fuel Economy. *Journal of Maritime Science and Technology*, 22(3), 45-59.
5. International Maritime Organization (IMO) (2017). Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP).
6. Kailash, S., & Chavan, M. R. (2021). Innovative Ventilation Systems for Ships to Enhance Fuel Efficiency. *Ship Technology Research*, 68(2), 112-124.
7. Simpson, P. D., & Williams, D. M. (2015). Advanced Compressor Technologies for Marine Applications. *Journal of Ship Research*, 59(1), 22-35.
8. Nielsen, M., & Jensen, M. (2017). Energy Saving in Marine Auxiliary Systems: Ventilation and Air Compressors. *Maritime Economics and Logistics*, 19(1), 50-68.
9. https://mcusercontent.com/9a19186cfd9c5e08aee07a81c/files/7a10343f-57b4-cbcc-0de9-d8d03a368fac/b4b_webinar_Oceanking_DNV_MARTECMA_regulations_may_2024_FINAL_VERSION_WEBINAR.pdf
10. Bakker, W., & Kooi, S. (2014). Integrated Systems for Maritime Fuel Efficiency. *International Journal of Shipping and Transport Logistics*, 6(2), 100-115.
11. "Impact of Wind-Assisted Propulsion on Fuel Savings and Propeller Efficiency: A Case Study" de A. Čalić, Z. Jurić și M. Katalinić, publicat în *Journal of Marine Science and Engineering*, 2024.
12. "Multi-Objective Optimization of Ship Design for the Effect of Wind-Assisted Propulsion Systems" de A. Čalić, Z. Jurić și M. Katalinić, publicat în *Journal of Marine Science and Engineering*, 2025.
13. <https://bound4blue.com/how-suction-sails-work-to-empower-sustainability/>
14. O. N. Volintiru, T. M. Stefanescu, E. Dragomir and A. Pruiu, Scientific Bulletin of Naval Academy, Contributions to the study of functional parameters in exploitation of the heat, ventilation and air conditioning system for special ships , Vol. XXI 2018, pg. 256-261, Volume XXI 2018 ISSUE no.1 MBNA Publishing House Constanta 2018, ISSN: 2392-8956; ISSN-L: 1454-864X, https://www.anmb.ro/buletinstiintific/buletine/2018_Issue1/02_EEA/86.pdf
15. O. N. Volintiru, I. C. Scurtu, T. M. Stefanescu, Modeling and optimization of HVAC system for special ships, RESORT Conference 2018, Resort–International Conference on Sustainable Future and Technology Development, Volume 1122, 15 October 2018, Bucharest, Romania DOI 10.1088/1742-6596/1122/1/012004, <http://iopscience.iop.org/article/10.1088/1742-6596/1122/1/012004>.