# Case Study

# Design Analysis of Scuba Diving Fins with Ansys Discovery

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## Summary

Ansys Discovery serves as a comprehensive simulation-driven design tool, seamlessly integrating instant physics simulation, high-fidelity simulation, and interactive geometry modeling into a user-friendly interface. This integration empowers product designers and simulation engineers to explore a diverse range of concepts across different physics such as structures, fluids, and heat transfer through simulation.

This simulation of scuba diving fins is to investigate the sea water flow patterns around the fins and analyze the resulting forces to calculate drag. The simulation aims to provide insights into the optimal fin design for efficient underwater propulsion, considering the effect of factors such as blade shape. The study seeks to enhance our understanding of design requirements of scuba diving fins and contribute to the design refinement for improved performance and diver's experience.

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## 1. Introduction

Scuba diving as a sport is when a person dives underwater to explore nature with Self-Contained Underwater Breathing Apparatus (SCUBA). The typical basic SCUBA setup [1] includes a wetsuit or drysuit[1], gas tank, dive mask, regulator, Buoyancy Control Device (BCD), dive computer, and fins [2].

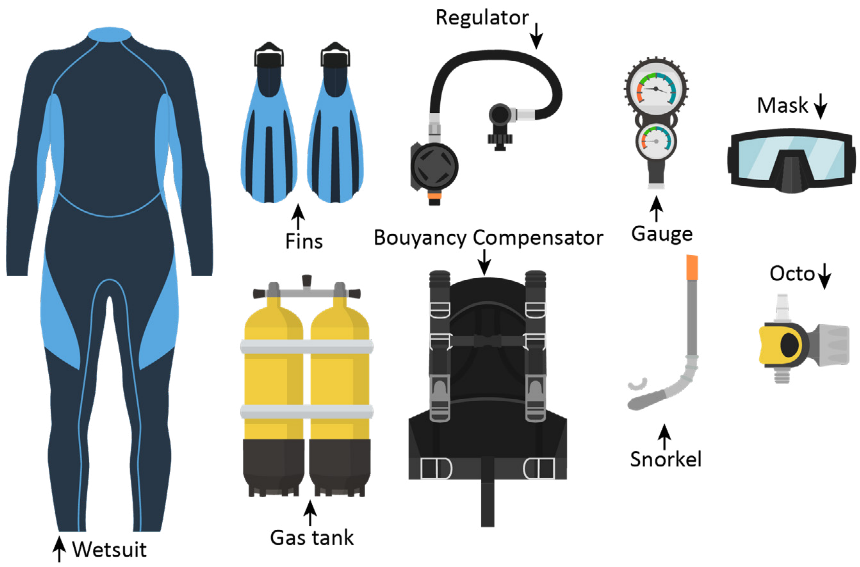


Figure 1: A typical basic SCUBA setup, including wetsuit, fins, snorkel, gas tank, and more

Years before SCUBA was invented, free divers and underwater hunters used fins with mask and snorkel to get down to depth quickly and provide bursts of speed as needed. Fins were created after observing the water-propulsion effectiveness of web-footed animals, such as ducks and frogs. Fins make swimming with foot-propulsion easier, more effective, and considerably more enjoyable.

Scuba divers have several needs when it comes to fins. Overall, scuba diving fins need to provide a balance of thrust, maneuverability, comfort, durability, and buoyancy in the right size to meet the specific needs of the individual diver and the conditions they are diving in. Here are some of the most important requirements:

- Propulsion: Scuba diving fins need to provide enough propulsion to move the diver through the water efficiently. This means they need to be able to generate a significant amount of thrust with each kick which requires stiffness.
- Comfort: Scuba diving fins need to be comfortable to wear which means they should fit well. They should avoid causing any chafing or discomfort while at the same time, fins that are too small or too large can negatively impact performance. To some extent, the flexibility and stiffness matter here as well.
- Durability and mechanical integrity: Scuba diving fins need to be able to withstand the stresses of regular use, including exposure to salt water and repeated impacts with rocks or other objects. Strength will be one of the crucial parameters in the sense that sports equipment must be strong enough to be safe for divers.

1 Wetsuits are skin-tight and used in other sports such as surfing. This suit keeps the wearer warm by heating up the layer of water in between the body and the suit. For extreme cold temperatures, a drysuit is needed. These are completely waterproof and have an air layer for additional thermal insulation.

- Buoyancy: The fins should not be too heavy, as this can negatively impact a diver's buoyancy control – this is governed by the materials density in relation to water.
- Maneuverability: Divers also need to be able to maneuver easily underwater, especially in tight spaces or strong currents. This requires fins with optimal stiffness that are responsive and easy to control, as well as precision in movements, which is important for divers who plan on diving in tight spaces or navigating through underwater obstacles.

To fulfill most (if not all) the requirements mentioned, designing scuba diving fins also requires careful consideration of the shape of the blades, the kicking force and resistance under water, as well as the materials that they are made from. Design requirements and design parameters can be explored via both material selection and simulation with Ansys software products. This content will be covered across two separate case studies; a breakdown of which requirements will be addressed in each document can be found in the table below.

Table 1 Breakdown of design requirements of the scuba diving fins using both material selection and simulation.

| **Ansys Tools Used** | **Design Requirements** |
|---|---|
| Ansys Discovery | Shape of the blades, the kicking force and resistance under water: Propulsion, maneuverability, and size |
| Ansys Granta EduPack* | Maneuverability, comfort and size, durability, and buoyancy |

**Covered in Exploration of Materials for Scuba Fin Design using Ansys Granta EduPack*

## 2. Scuba diving fin design simulation background

Simulating scuba diving fins involves consideration of the interaction between the fins and water. The physics behind simulating scuba diving fins can be broadly categorized into principles related to hydrodynamics and propulsion.

Here are some key aspects:

- Fluid Flow and Drag - When a diver kicks or moves their legs with scuba diving fins, they initiate a fluid flow around the fins. The fins are designed to channel and direct the water in a specific way as the diver moves through it. Drag, on the other hand, is the resistance encountered by the fins as they move through the water. The shape, surface texture, and overall design of the fins impact the drag force. Streamlining the fins helps minimize drag, allowing for smoother and more efficient movement underwater.
- Lift and Propulsion - Similar to the lift generated by an aircraft wing, scuba diving fins generate lift in the water. This lift is a result of the shape of the fins and the angle of attack. As water flows over the curved surface of the fins, a pressure difference is created, lifting the diver in the opposite direction of the flow. Understanding the angle of attack is crucial for maximizing lift and propulsion.
- Pressure Distribution - The pressure distribution across the surface of the fins during different phases of the kicking motion is critical. This information helps refine the design to ensure a balanced and effective distribution of pressure for optimal performance.
- Material Properties - Different materials have different buoyancies, flexibilities, and resistance to fatigue. Therefore, we will bring the materials candidates suggested from the first part of this case study: Exploration of Materials for Scuba Fin Design using Ansys Granta EduPack into discussion: Polymers such as Polyethylene (PE) and Polypropylene (PP), natural rubber and Ethylene vinyl

acetate (EVA), glass fiber reinforced (GFRP), and carbon fiber reinforced epoxy (CFRP) composites.

- Interaction with Diver's Movement - The fins are designed to respond to the diver's leg movements. As the diver kicks, the fins generate lift and propulsion. The interaction involves understanding how the fins accommodate changes in leg orientation, speed, and direction, allowing for underwater agility and control .

In summary, the design of scuba diving fins is a delicate balance of shaping the fins to generate lift and minimize drag, optimizing the angle of attack for efficient propulsion, and ensuring that the fins respond effectively to the diver's movements. Through careful consideration of these factors, divers can achieve improved maneuverability and reduced effort when using scuba diving fins. With Ansys Discovery, we will gain insights on the early-stage design considerations of fluid flow and pressure distribution, leading to drag. Materials are considered in Exploration of Materials for Scuba Fin Design using Ansys Granta EduPack. A full design cycle would also need to consider the interaction with the diver's movement, including fluid-structure interaction between the fins and the water, but we will not progress to these topics in this study.

## 3. Analysis of Scuba Diving Fin Design using Ansys Discovery

For this simulation, we will be using Ansys Discovery due to its easy to navigate interface and built-in geometry modeling capabilities[2]. , is available for those seeking further details. In this case study, this software has been used to model the sea water flow over one scuba diving fin, with Figure 2 outlining the steps followed to solve this problem [3].

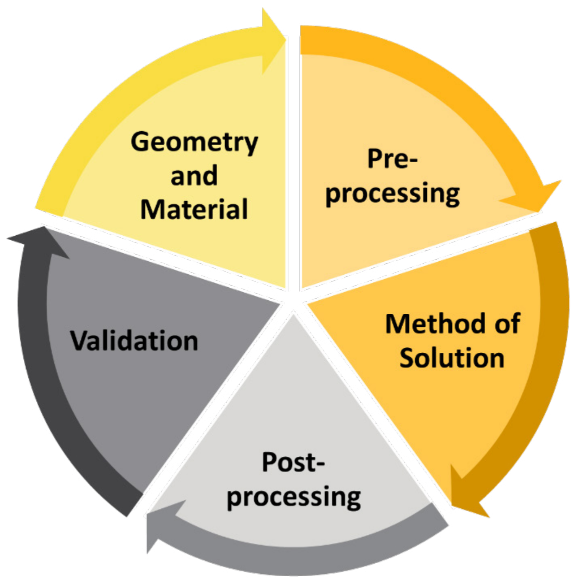


Figure 2 The product design cycle: we will be using Discovery as our Method of Solution.

To analyze the design of the scuba diving fins with Discovery, we will simplify the use case of the scuba diving fins in structural and fluids simulation, respectively. We will be exploring and discussing how materials and fin blade shapes affect Displacement, Von Mises Stress and, the Factor of Safety to see why there are so many different designs in structural simulation and modeling the propulsion in fluids simulation to provide some additional evidence along. We will also include some discussion on mass properties so that we will be able to have a very quick comparison on cost and carbon footprint of different materials.

2 Additional information on Ansys Discovery can be found here: Ansys Discovery Student Version and here: Ansys Discovery 3D Design webpage

## 3.1 Fin Blade Simulation Setup

The popularity of different fins can vary among divers based on personal preferences, diving style, and flow conditions. There are several types of scuba diving fins, each designed for specific purpose and preference. Here are some common types:

- Paddle fins – the most common type of fins and are characterized by a wide, flat blade shown in Figure 3 (a).
- Jet Fins – Jet fins have a shorter, stiffer blade compared to paddle fins. Jet fins are known for their durability and are often used by technical divers and military personnel, shown in Figure 3 (b).
- Long Blade Fins – These fins have a longer blade compared to traditional paddle fins, providing more surface area for a powerful kick. They are often preferred by divers who want maximum propulsion, shown in Figure 3 (c).
- Split Fins – Split fins have a split down the middle of the blade. This design is intended to reduce resistance and make kicking more efficient, but opinions on their effectiveness vary among divers, shown in Figure 3 (d).
- Hinged Fins – Some fins have a hinge mechanism that allows the blade to pivot. This design aims to reduce strain on the ankles and leg muscles, shown in Figure 3 (e).
- Channel Fins – These fins have channels or grooves on the blade surface. The channels are designed to direct water flow, increasing the efficiency of each kick, shown in Figure 3 (f).

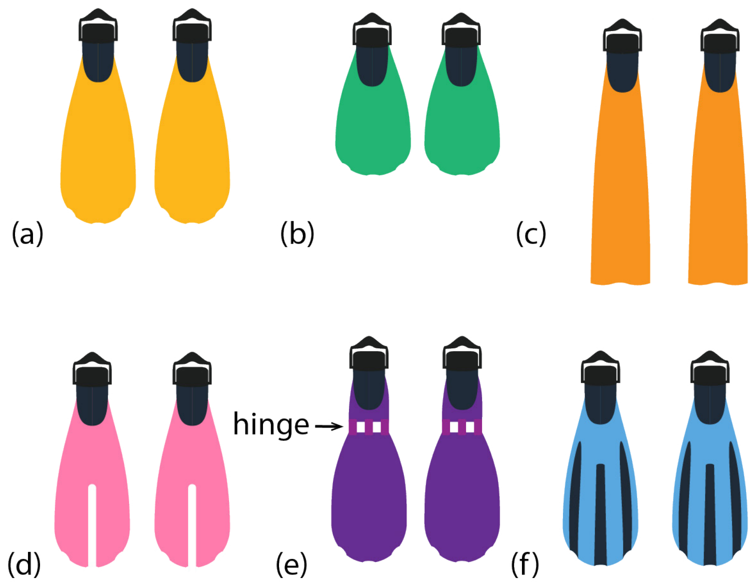


Figure 3 Popular types of scuba diving fins in the market: (a) paddle fins; (b) jet fins; (c) long blade fins; (d) split fins; (e) hinged fins; (f) channel fins.

This is too many fin options for this particular case study, so we will narrow our focus to fins most commonly used by common scuba diver. Therefore, jet and long blade fins will be removed from consideration. We will also remove channel fins, as they dramatically increase the complexity of our simulation.. This case study will compare the paddle fins and split fins, with the following models (Figure 4) based on the size of typical fin designs from Mares, a popular fin manufacturer [4]. A blade length of 380mm and width of 210mm (derived and rounded up based on blade thrust area of around 78000mm$^2$) with a thickness of 5mm, shown in Figure 4 (a) and (b) in trimetric and bottom views is used for the paddle fin while for the split model, we have cut the paddle fins to form a slit with the dimensions of 150mm×16mm×5mm, shown in Figure 4 (c) and (d).

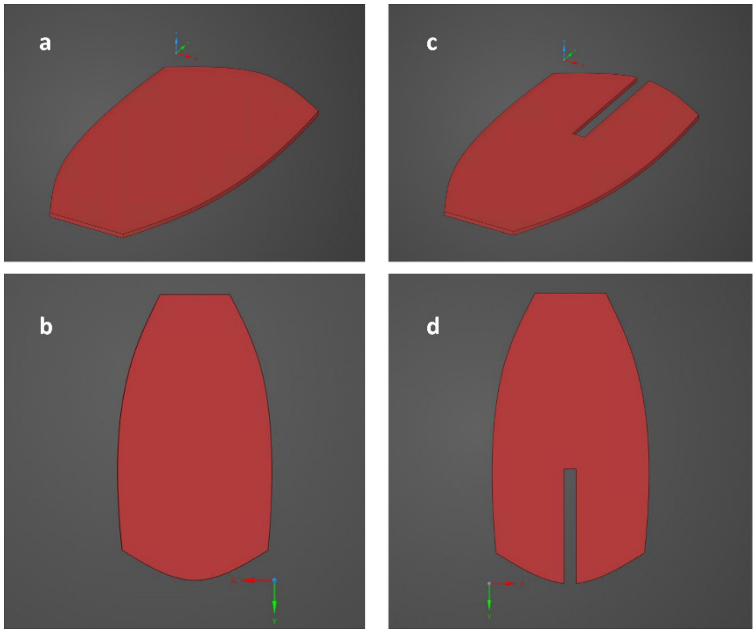


Figure 4 Scuba diving fin blade models applied in this case study: (a) and (b) trimetric and bottom views for a paddle fin blade; (c) and (d) trimetric and bottom views for a split fin blade.

As mentioned previously, this case study was split into two parts. The top material candidates identified in Part 1 are Polyethylene (PE), Polypropylene (PP) (similar as PE), natural rubber and Ethylene vinyl acetate (EVA), glass fiber reinforced (GFRP) and carbon fiber reinforced epoxy (CFRP) composites. For the simulation analysis, we will focus on comparing two quite different materials, PP and CFRP composites for each design.

## 3.2 Structural Analysis of Scuba Diving Fin Design in Discovery

We have narrowed down to a list of material candidates in the first part of this case study in Exploration of Materials for Scuba Fin Design using Ansys Granta EduPack, which includes Polyethylene (PE), Polypropylene (PP) (similar as PE), natural rubber and Ethylene vinyl acetate (EVA), glass fiber reinforced (GFRP) and carbon fiber reinforced epoxy (CFRP) composites[3]. From this list, for our simulation analysis, we will focus on comparing PP and CFRP composites.

To mimic the use case of the scuba diving fins, we will be fixing our blade at the edge and we have chosen a force of 50N to mimic kicking in the water (as shown in Figure 5) for both paddle fin and split fin blades.

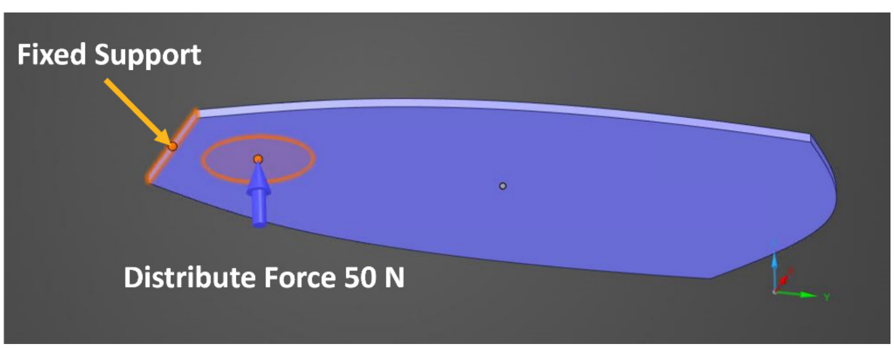


Figure 5 Structural analysis boundary conditions for the blade of a scuba diving fin

3 Note that Ansys Discovery only allows for isotropic material properties, which is a limitation when simulating composite materials, which are often orthotropic in nature.

As a next step, we can run a simple static structural simulation with the boundary conditions shown in Figure 5 on scuba diving paddle and split fin blades made from PP and CFRP with a thickness of 5 mm under the Refine mode in Discovery, and the following results are gained in Table 2 and Figure 6 respectively.

Table 2 Simulation resutls of scuba diving paddle and split fin blades made from PP and CFRP with a thickness of 5 mm.

| **Parameters** | **PP (Paddle)** | **PP (Split)** | **CFRP (Paddle)** | **CFRP (Split)** |
|---|---|---|---|---|
| Thickness/mm | 5 | 5 | 5 | 5 |
| Weight/kg | 0.299 | 0.288 | 0.518 | 0.499 |
| Factor of Safety (FoS) | 10.7 | 10.7 | 177 | 175 |
| Maximum Displacement/mm | 10.9 | 11.4 | 0.333 | 0.342 |
| Maximum Von Mises Stress/ MPa | 3.19 | 3.17 | 3.77 | 3.81 |
| Cost*/USD | 0.52 | 0.50 | 20.78 | 20.00 |
| Carbon Footprint*/kg | 0.86 | 0.82 | 26.3 | 25.3 |

**With price and carbon footprint information retrieved from Granta EduPack*

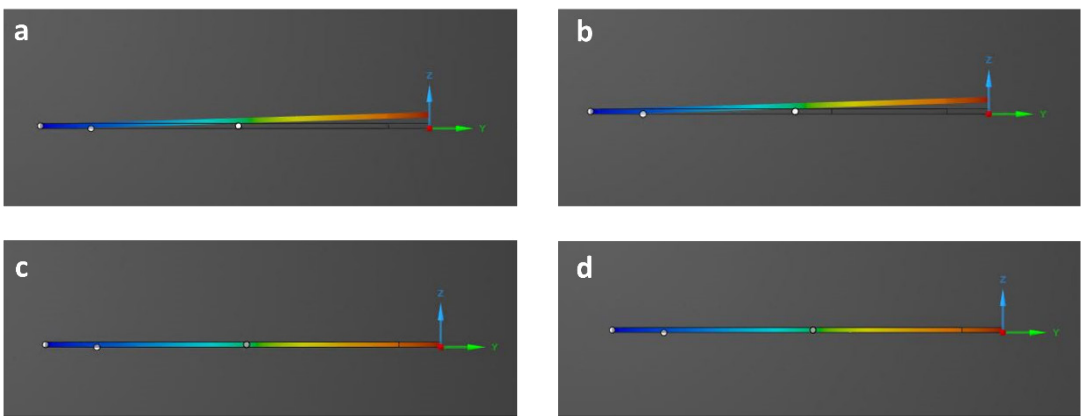


Figure 6 Maximum deflection for scuba diving fins blades made from: (a) PP paddle blade; (b) PP split blade; (c) CFRP paddle blade and (d) CFRP split blade with a thickness of 5 mm.

It can be seen that the choice of whether to split the blade does not lead to large differences in our structural analysis in Discovery, but here we can explore how different materials affect the Factor of Safety, Maximum Displacement and Maximum von Mises Stress. PP, as a lighter materials option, has an adequate Factor of Safety for scuba diving fins, with a lower cost and a lower carbon footprint compared with CFRP. However, if we are looking at the maximum deflection of the blades made from both materials, though both of the materials are showing moderate deflection, we could see from Figure 6 that CFRP blade deflects less than the PP blade when comparing the same designs under same boundaries conditions, showing PP could be a more flexible for scuba diving fin option for divers.

The high Factor of Safety[4] with 5mm thick CFRP fins suggests there is room for design thickness optimization. Therefore, considering the manufacturing capabilities, we will reduce the thickness of the CFRP blade to 1mm to reflect the reality since this is the thinnest typical CFRP blades available to buy. Results of the simulations are summarized in Table 3 and Figure 7 comparing with the PP blades.

4 Factor of Safety was calculated using the equation FoS=yield strength/maximum part stress

Due to the reduction of the thickness, we see the expected increased deflections in Figure 7 together with corresponding decrease of weights and therefore costs and carbon footprint as well. Note the Factor of Safety is still significantly higher than that of the PP blades, even with this thickness reduction.

Table 3 Simulation results of scuba diving fin paddle and split blades made from PP with a thickness of 5 mm and CFRP with a thickness of 1 mm.

| Parameters | PP (Paddle) | PP (Split) | CFRP (Paddle) | CFRP (Split) |
|---|---|---|---|---|
| Thickness/mm | 5 | 5 | 1 | 1 |
| Factor of Safety | 10.7 | 10.7 | 30.3 | 24.4 |
| Weight/kg | 0.299 | 0.288 | 0.104 | 0.0999 |
| Cost*/USD | 0.52 | 0.50 | 4.1704 | 4.01 |
| Carbon Footprint*/ kg | 0.86 | 0.82 | 5.28 | 5.07 |

**With price and carbon footprint information retrieved from Granta EduPack*

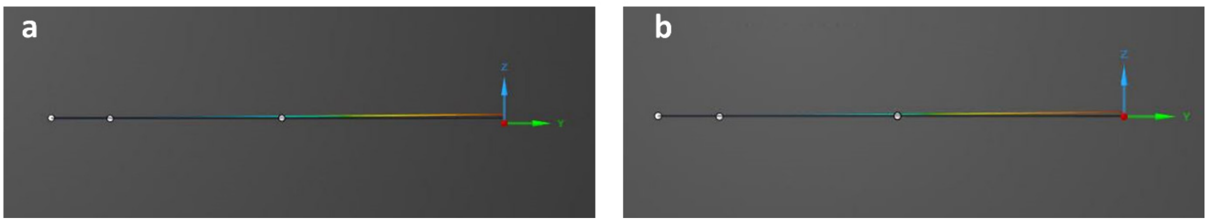


Figure 7 Maximum deflection for scuba diving fins blades made from: (a) CFRP paddle blade and (b) CFRP split blade with a thickness of 1 mm.

## 3.3 Modeling the sea water flow patterns and analyzing the forces around the fins

Moving on, we will check how the sea water will flow around the fins: here, we will start to see how the paddle fins and the split fins are different. We will also look at the forces on the fins from the water. To simplify our simulation, we will look at a static fin at an angle to the flow, rather than a full kicking cycle. To simplify the complexity of the use case of scuba diving fins, we will consider only diving in confined open water. Confined open water is an open water site that offers swimming-pool-like conditions with respect to clarity, calmness, and depth. This simplification allows us to consider the water to be completely calm, with no waves or sea currents. We can consider Bernoulli's principle, which states that as the speed of a fluid increases, its pressure decreases, and vice versa, in steady, incompressible sea water with constant density. In the case of scuba diving fins, as the diver kicks and water flows over the surface of the fins, the velocity of the water increases on the upper surface, leading to lower pressure according to Bernoulli's principle.

The equation for Bernoulli's principle is as follows:

where P is the absolute pressure of the fluid, ρ is the density of the fluid, v is the velocity of the fluid, g

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

is the acceleration due to gravity, and h is the height of the fluid above a reference point.

In the context of swimming horizontally, this equation can be simplified to focus on the relationship between velocity and pressure which is:

$$P + \frac{1}{2}\rho v^2 = \text{constant}$$

For this fluid flow simulation, our diver is moving at a speed of 2 m/s in almost still sea water. It is worth noting that divers do not always swim horizontally. When they are attempting emergency descending or ascending, to rescue another diver for example, they can be almost perpendicular to the surface of the sea water, shown in Figure 8.

Figure 8 Emergency ascending position of a scuba diver, almost perpendicular to the surface of the sea water

However, emergency descending or ascending are rare scenarios for recreational diving. Most commonly, divers will be swimming horizontally, also known as the trim position. They will still be nearly-horizontal even when descending or ascending in a standard dive as shown in Figure 9, mostly to reduce the resistance from any sea currents, which usually flow horizontally, and to reduce risks from quick ascension/descension. For these reasons, vertical positions such as shown in Figure 8 are only common in emergency ascent or descent situations..

Figure 9 Underwater trim position for a scuba diver

When we are looking at the fin blades, the ideal situation is to reduce the resistance/drag from sea water as much as possible while minimizing the force perpendicular to the flow direction to maintain the same depth, since frequent depth changes will not only cause higher gas consumption, but pressure difference at different depths will bring higher risks to divers. We will be looking at the highest kicking point, with an angle of about 30 degrees to the horizontal for the discussions on velocity and static pressure fields. For the discussion on the forces on the fin blades, we will be introducing another kicking point with a horizontal angle of 10 degrees to show how the fins are moving under water at these two different positions. In summary, we will be comparing the paddle and split scuba diving fins made from CFRP with a thickness of 5mm with boundary conditions indicated in Figure 10.

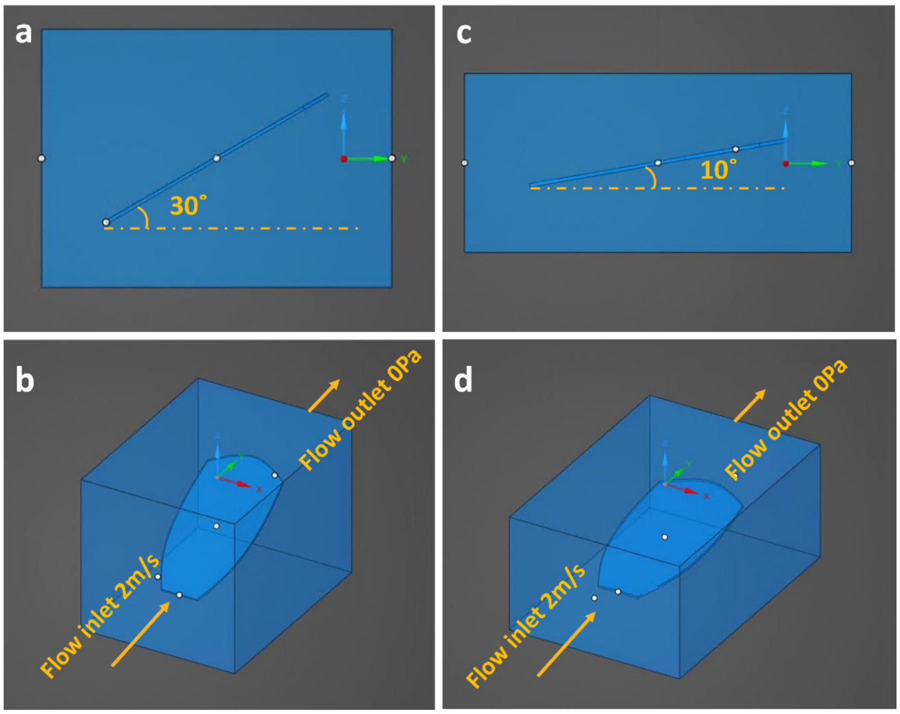


Figure 10 Fluid Flow simulation setting up with boundary conditions for blades with angles of about 30 degrees, (a) and (b) and 10 degrees, (c) and (d) to the horizontal.

Figures 11 to 14 show the following Discovery simulation results using the Refine mode with LiveGX solver, using a Polyhedral mesh, for the 5mm CFRP fin with the two geometry designs at the 30-degree angle:

- Planar views of the velocity fields at the central axis on y-z plane for paddle blade, Figure 11(a) and split blade, Figure 11(b).
- Velocity fields at 5mm away from the corresponding starting point of the spit with streamline emitter along the x-z plane for paddle blade, Figure 12(a) and split blade, Figure 12(b).
- Planar views of the static pressure fields at the central axis on y-z plane for paddle blade, Figure 13(a) and split blade, Figure 13(b).
- Static pressure fields at 5mm away from the corresponding starting point of the spit with streamline emitter along the x-z plane for paddle blade, Figure 14(a) and split blade, Figure 14(b).

The velocity field shows the speed and direction of sea water around the fin blades, which helps us visualize the fluid dynamics. We can see from Figures 11 and 12 that the overall velocity of the flow past the fin is increased due to the position of the split in the fin, i.e. we can see that the flow is not as slowed down by the split fin as by the paddle fin.

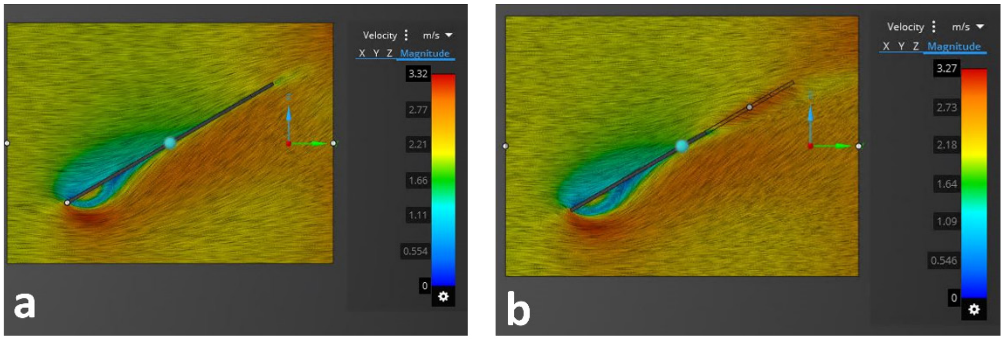


Figure 11 Fluid flow simulation results of planar views of the velocity fields at the central axis on y-z plane for paddle blade(a) and split blade (b).Note the central axis passes through the slit in (b), so there is fluid flow through the paddle.

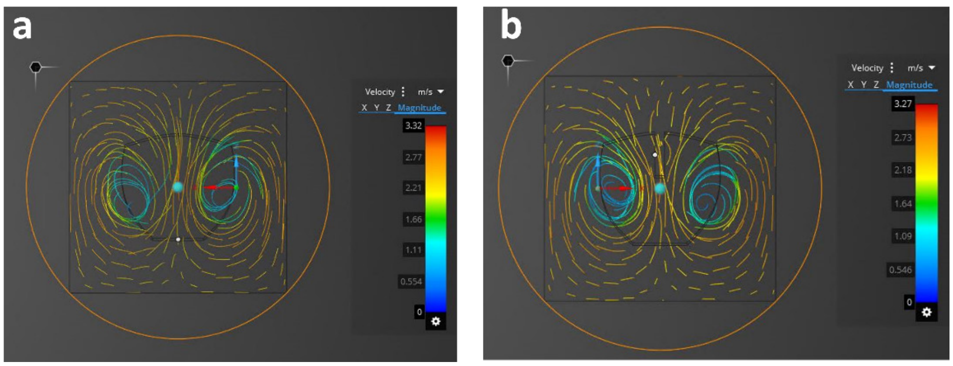


Figure 12 Fluid flow simulation results of velocity fields at 5mm away from the corresponding starting point of the spit with streamline emitter along the x-z plane for paddle blade (a) and split blade (b).

The pressure field, shown in Figures 13 and 14 displays variations in pressure across the fin blades. Looking at these figures in combination with Figures 11 and 12, we can consider whether this problem could have been adequately studied using Bernoulli's equation. The assumptions of Bernoulli's equation are that the flow is inviscid, incompressible, steady and one-dimensional. We have obviously included all three dimensions in our simulation, but this helps us to see:

a) The flow is not one-dimensional: streamlines can be seen spreading sideways across the fin's surface
b) The flow is viscous and unsteady: although we have only taken a snapshot in time, the presence of vortices behind the paddle blade tells us that these assumptions are invalid.

However, studying the simulation results can give us insights into the flow behavior and what the diver will experience. The significant pressure difference between upstream and downstream shows that the diver will experience drag on the fins at a 30-degree angle. The split blade shows slightly less low pressure downstream (looking at the location of minimum pressure), and slightly less high pressure upstream of the slit area, so should have less drag. In contrast to the structural simulations, here we can see a difference between the paddle blade and the split blade, which may be a reason to choose one over the other. We can confirm this by extracting the force on the fin blades from the simulation.

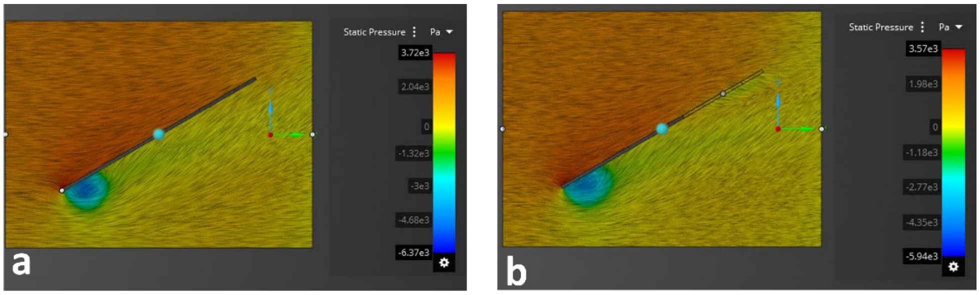


Figure 13 Fluid flow simulation results of planar views of the static pressure fields at the central axis on y-z plane for paddle blade (a) and split blade (b).

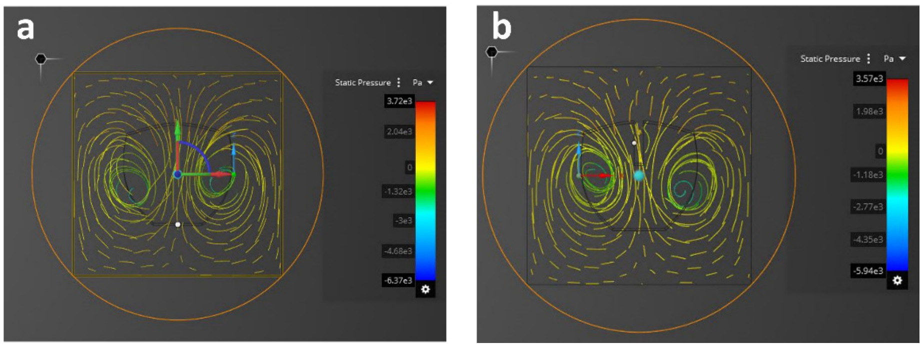


Figure 14 Fluid flow simulation results of static pressure fields at 5mm away from the corresponding starting point of the spit with streamline emitter along the x-z plane for paddle blade (a) and split blade (b).

For the kicking angles of 10 and 30 degrees, we have applied force monitors on the y- and z- directions, respectively and the results are summarized in Table 4 for both blade designs. The forces in the y-direction can be seen as drag/resistance, providing extra evidence to what has been seen from the static pressure fields in Figures 13 and 14. While for force on z-direction, when scuba diving fins are in use, there will not be only one of them in use, they are broadly used symmetrically, therefore the force perpendicular to the flow direction should be balancing out This force may therefore not affect the diver's overall motion, but we could still see that the split fin blade will result in a more stable fluid motion around it and lower forces are being exerted here, which provides more stability when in use.)

Table 4 Summary of forces on y- and z- axes at kicking angles of 10˚ and 30˚ for CFRP paddle and split fin blades.

| Force Direction | Paddle at 10˚ | Split at 10˚ | Paddle at 30˚ | Split at 30˚ |
|---|---|---|---|---|
| y-axis | 8.33N | 7.34N | 115N | 107N |
| z-axis | -48.7N | -42.8N | -203N | -186N |

## 4. Conclusions

In conclusion, this case study has provided a simplified exploration of the design of scuba diving fins, leveraging the capabilities of Ansys Discovery. The analysis includes a structural evaluation of different materials, specifically comparing Polypropylene (PP) and Carbon Fiber Reinforced Epoxy (CFRP) composites. The simulation results include Factor of Safety, Maximum Displacement, Von Mises Stress, with estimations of cost and carbon footprint discussed in detail. By comparing the paddle fins and split fins, we have gained some insights on design choices.

The fluid flow simulation offered a glimpse into the sea water interaction with the scuba diving fin blades. By considering the velocity fields, static pressure fields and forces, the study shed light on how the design of fins influences water flow patterns. The analysis confirmed that split fins, with their unique design, contribute to a more streamlined water flow, reducing drag and potentially enhancing overall efficiency.

While the fluid flow simulation offered a glimpse into the interaction between sea water and scuba diving fin blades, it is important to note that the study's current scope doesn't model the entire kicking cycle of scuba diving fins. To achieve a more comprehensive understanding, advanced structural fluids simulations are needed to accurately reflect the way a real fin blade behave when in use: it's deflection due to the water force will change the flow around it, known as fluid-structure interaction.

This advanced simulation capability will enable a more detailed exploration of the dynamic forces involved in the complete kicking cycle, offering deeper insights into the intricate fluid dynamics of scuba diving fin performance.

## 5. References

[1] PADI (n.d.), about SCUBA gear from: https://www.padi.com/gear?equipment=All
[2] PADI (n.d.), about SCUBA gear, specifically on fins from: https://www.padi.com/gear/fins
[3] M. Saravana Kumar, L. Mohee, Ansys Education Resource – Lecture Unit: Introduction to Fluid Mechanics with Ansys Discovery | Ansys
[4] Mares (n.d.), about Avanti Quattro+ Fins from: https://www.mares.com/en/avanti-quattro-18

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