Project Report **Membrains**

For the last decades, a dramatic increase of microplastic in the environment has taken place. To find a solution we investigated the suitability of a Manta Ray-inspired, non-clogging water filter to combat the worsening issue of microplastic water pollution. The Manta Ray is a source of inspiration as it can efficiently filter plankton from seawater to feed itself without its gills clogging. We examined the ability of the gills to create the so-called ricochet effect. This effect is created by the anatomy of the gills, which creates turbulent water swirls that make particles bounce off the gills while water can pass in between.

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Preface by the Supervisor

Prof. Dr. Oliver Lieleg

Even though our society has realized that the immense amounts of plastic we produce and dispose of are not sustainable, we are still way behind in creating solutions that might help us to deal with the existing plastic materials and the waste they create. These, however, do not only create severe problems for nature (be it in landfills or in the oceans): when broken down into microplastic particles, such plastic waste can make its way back to us humans via the food chain. Indeed, there is increasing evidence that several medical conditions such as disorders of the gastrointestinal system, cardiovascular problems and neurodegenerative diseases are linked to an exposure to microplastic particles. Thus, this realization should strongly increase our motivation to avoid unsustainable plastic materials in the future, to quickly find solutions to avoid microplastic formation, and to prevent such microplastic from entering our water supplies.

The Membrains team decided to tackle the third item from this urgent to-do list. Inspired by the water filtration system of Manta rays, they designed a filtration unit that – according to the simulations conducted so far – should be very efficient in removing particulate contaminations from water. If experimental verifications of the designed prototype are equally promising as the simulation results obtained by the team, such a device could be extremely helpful in filtering out microplastic particles from processed water generated in industrial or private settings (e.g., after the laundry of clothes made from synthetic fibers).

Supervisor insights

Having met several times with the Membrains team during the last year, it was very interesting to see how a group of students with quite different backgrounds organizes itself to tackle an interdisciplinary problem. The Membrains team soon realized that pursuing their very ambitious plan to design and craft a functional prototype within a year would be more complex and time-consuming than they had initially thought – but this is absolutely normal in the life of a scientist.

What is your research interest or motivation for science?

In my own research, I investigate mucin glycoproteins, which are the key macromolecular components of mucosal systems such as the tear fluid, saliva, or gastrointestinal mucus. Recently, motivated by a touristic visit to India I made in fall 2019, we investigated how particulate air pollutants such as black carbon particles affect the barrier properties of mucosal gels – and we indeed observed significant alterations. Similar to those airborne particles, microplastic particles are also likely to have a negative effect on those mucosal systems. This is troubling as our mucosal layers constitute our body's first line of defense against pathogenic invaders, and messing with this defense line is a very bad idea. We are currently also looking into the question of how problematic microplastic particles are in this context.

What special experience from your studies/career would you like to share with the scholars?

Both in my time as a PhD student and postdoc and now, leading a team of PhD students, the research work I was and am involved in was and is always conducted by people with varied scientific backgrounds. This makes daily research life a bit more challenging since – at least at the beginning of a project – all team members need to find a similar terminology when discussing their ideas. After a while, however, such a mixed team can achieve much more than more homogeneous groups. Looking at a scientific problem from different points of view is, in my experience, always helpful.

Preface by the Supervisor

Gwillem Mosedale

We've all seen a pebble ricocheting across a lake. Each bounce giving rise to concentric ripples that expand and overlap. Eyecatching, but frivolous?

Not so! Ricochet separation is the basis for sophisticated filter designs. It took the manta ray and team Membrains to remind us that biology relies more heavily on filters than we do and that, therefore, it may have a trick or two up its sleeve when it comes to showing us how to remove microplastic from pipes and waterways.

My lasting impression of this group is its demeanor: attentive, gracious, barely flinching when parts of the briefings got shaky because the responsible team member had another engagement. Combine that with an unassuming, calm assurance when meeting us supervisors or TUM's president and you have the Membrains.

My professional perspective is that of propagating a bioinspired approach across an organization, which has been my role at TUM. So, collaborating with TUMJA as part of the call "Learning from nature" was a good fit. Inevitably, I noticed some benefits that learning from nature offers: TUMJA participants cherish the freedom to work on topics of their own choosing. In addition to granting that freedom, the TUMJA leadership would like projects to acquire scientific relevance/publication quality. But unbridled freedom can lead to great projects that remain scientifically superficial. On the other hand, scientific work carries a degree of complexity which implies closer supervision.

Biomimetics, the study and transfer of (technical) solutions from biology to products and processes, satisfies both these aspirations. Teams are guided by natural models and less through external interference. A great way to grant freedom and foster science at the same time. The name is BIOMIMETICS ;-)

My wish for the Membrains: whether you do it quietly or overtly, I hope that you keep setting ambitious goals, always. There is more to be learned and achieved by aiming too high, initially, than the other way around. If biological evolution teaches us one thing, it's that our best chance at disruptive innovation lies in ignoring limitations (real or imagined) when we start out. ■

The mysterious giants of the seas and the lessons they can teach us

In Greek mythology, Nausicaä, daughter of King Alcinous and Queen Arete, is a princess of the Phaeacians, people of sailors. In the sixth book of Homer's Odyssey, Nausicaä and her maids play by the seashore when they meet the shipwrecked Odysseus.

As a symbol of courage, generosity and beauty, Nausicaä has inspired many painters and sculptors throughout the ages, and it is after her that the largest aquarium in Europe has been named.

Today's aquarium with the same name (slightly adapted to Nausicaá) consists of several dozen aquariums and terrariums, with a total of 17 million liters of seawater and around 58 thousand marine animals from all around the world, enabling a breathtaking discovery of marine wildlife. Winding corridors lead visitors into an alien and uncanny world that keeps fascinating with its beauty and diversity. In one tank, delicately shimmering jellyfish float by, while in the next, swarms of sardines dart past. A few meters further, sharks glide gracefully through the water, barely moving their tail, while in an enclosure close by, penguins waddle along.

The most impressive part of the visit, however, is the largest aquarium of Nausicaá, a tank with 10 million liters of water where a complete ecosystem was built, modeled after the island of Malpelo in the Pacific Ocean. Here, hammerhead sharks, tropical fish, and reef fish swim by, and make the visitor feel part of the underwater world. But one sea creature, in particular, stands out with its impressive shape and size: the manta ray. With a wingspan of up to nine meters, these huge animals appear to be flying through the water. They owe their name to their characteristic big fins, which flap like wings. The name manta comes from Spanish and means "blanket."

But not only their appearance makes manta rays spectacular animals. They can leap an incredible two meters out of the water and spin before falling back into the water. Furthermore, manta rays have the largest brain to body size of all fish and a highly developed sensory system. An example of manta rays' cognitive function is their ability to recognize themselves in a mirror. These intelligent beings know how to collaborate and have complex social behavior. When feeding, for example, mantas "stack" on top of each other. The stack leader will eat, then another manta ray will lead, so that each one gets a turn. Additionally, when mantas find nutrient-rich areas, several mantas follow one another in a circle. By doing this, they create a spiral that traps the food allowing them efficient eating. Apart from their impressive intelligence, manta rays, which can live up to 50 years, are very hygienic. They wait up to an hour at certain reef locations to get cleaned by smaller fish.

The mantas' bodies are adapted to serve as a disguise. They are counter-shaded, dark on top, and lighter underneath. If viewed from a predator below, the white belly will camouflage them with light from the sun. On their “heads”, mantas have cephalic fins that unroll when feeding and that look like small horns, giving the manta its nickname: the devil fish. Despite their nickname, mantas are gentle giants and do not represent a threat to humans. Manta rays have a "tooth band," made up of thousands of little teeth, which might seem threatening, but they do not use their teeth to hunt. To eat, they filter plankton, small fish, krill, crustaceans, and other food particles out of the water, using rows of tiny plates in their gills. When they are ready to eat, they unroll the fins by their mouth to help funnel the food into their mouth. They swim with their mouth open and chest cavity extended to allow water and food to flow in. The food gets filtered out of the water by the manta ray's gills allowing him to digest it.

This behavior caught our attention. How can the manta swim with its mouth open for minutes at a time, filtering food out of the water, without its gills getting clogged? This remarkable ability is due to the so-called ricochet effect, which we turned our attention to during our project. We dived deep into the ricochet effect to understand its mechanism and to try to use it as an inspiration to make a non-clogging water filter. Water filters are used in countless applications. They are necessary to preserve water quality and protect rivers and oceans from textile and plastic waste. For the last decades, a dramatic increase of microplastic in the environment has taken place. This microplastic affects humans as well as wildlife and it is of the utmost importance to address this issue. Most

filters used nowadays are filters that clog and need to be manually cleaned or replaced. A non-clogging filter inspired by the manta ray would be a great help to fight plastic and microplastic in our environment.

The manta ray also has special significance at the Nausicaá Aquarium, as the building is shaped like the sea colossus. In the oceans, finding a manta ray is a rare event, even for experienced divers. It therefore feels like an honor to watch this gentle giant from such close distance at the Nausicaá Aquarium. It is even more humbling, as the manta ray is listed as a threatened and vulnerable animal in the IUCN Red List. The threat to the existence of these animals is the rising demand in international trade, fishing, and bycatch. The trade for their gill plates is worth approximately $30 million. Furthermore, branches of Chinese medicine have been increasing the demand for manta rays. The harvest rate is exceeding their reproduction rate, which is a slow process as the gestation period is 13 months and only 1 or 2 pups are born every 2 to 4 years. To address this problem, legislation has been created to protect manta rays. For instance, in Hawaii, criminal penalties and fines have been established for killing and capturing these animals in state waters. Peru has also passed legislation that bans manta fishing and forces fishermen to release any mantas caught as bycatch back into the ocean. While these laws help, manta rays as well as many other marine animals are still threatened by mankind. Walking through Nausicaás' big halls reminds us how small we are, what beauty can be found in the oceans and how crucial it is to preserve the treasures of the sea.

In our project, we tried to learn from the manta ray, hoping it will provide us with new solutions to filter microplastic out of the water. We hope to inspire others to learn from nature as well, in order to build a more sustainable future together.

Assessing the Ricochet Effect as a Non-Clogging Method for Microplastic Filtration

Abstract

This project investigated the suitability of a Manta Ray-inspired, non-clogging water filter to combat the worsening issue of microplastic water pollution. The Manta Ray is a source of inspiration as it can efficiently filter plankton from seawater to feed itself without its gills clogging. We examined the ability of the gills to create the so-called ricochet effect. This effect is created by the anatomy of the gills, which creates turbulent water swirls that make particles bounce off the gills while water can pass in between. In a first attempt to create a filter mimicking the manta ray, we tried to achieve the ricochet effect with a 3D-printed prototype. We were not able to recreate the ricochet effect with this method and, therefore, resolved to use simulations before testing our prototype in real life. The simulations showed that the ricochet effect can indeed be achieved in our prototype and that its effectiveness varies with different flow velocities and shape parameters of the filter. The next step in our project is to print the simulation-tested prototype and validate its effectiveness in real life.

Background

The rising problem of microplastic contamination and pollution has been observed for several years. Already in the 1960s and 1980s, pieces of plastic were being found in the stomachs of several animals (Connors & Smith, 1982; Kenyon & Kridler, 1969).

Today, microplastic contamination and exposure to humans have become an inevitable problem. As reviewed by Marczynski and Lieleg (2021) and Prata et al. (2020), microplastic particles can come into contact with humans through their contamination of water and even air. As described in these reviews, microplastic can be detected in tap water, the air we breathe and products for daily use, such as shower gels, bottled beverages and honey. Another source of microplastic exposure is eatable fish. Considering the fact that up to 102 000 plastic particles per m3 were found in seawater close to a Swedish harbor (Norén, 2007), the contamination of fish is clearly a very urgent theme which needs more attention.

Microplastic particles in general are considered particles smaller than 5mm (Moore, 2008). For ethical reasons, experiments on microplastic effects on human health are problematic, leading to the limitation that evidence for microplastic effects is mainly based on observational studies. Even though also strictly regulated, animal experiments can provide more detailed information about the main mechanisms of these particles. Despite these limitations, several studies show a convincing connection between microplastic particle exposure and pathological conditions (for more details and summary tables see Marczynski and Lieleg (2021)). These pathologies include respiratory, gastrointestinal and neurological diseases, such as COPD, Morbus Crohn, and Alzheimer's. Summarized as inflammatory diseases, this connection to microplastic is consistent with the reported potential reaction of the human body after being exposed to microplastic. As reviewed by Prata et al. (2020), contact with microplastic may lead to chronic inflammation and increased oxidative stress. Given that chronic inflammation diseases reduce healthy life expectancy (Kotas & Medzhitov, 2015; Radak

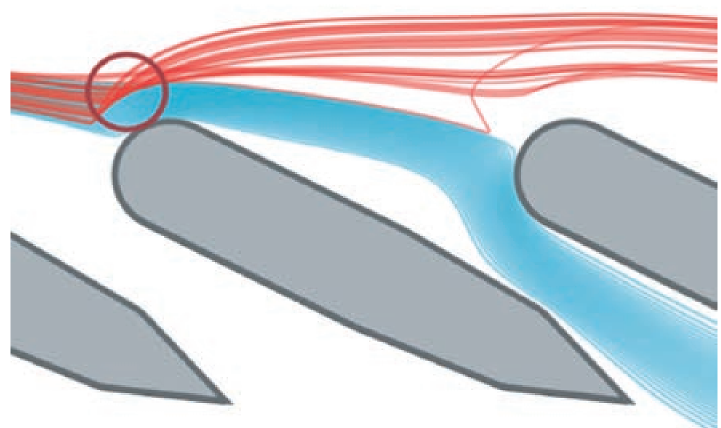

Figure 1: Ricochet effect visualization from (Divi et al., 2018). The blue and red lines show pathlines of water and particles contained in the flow. The grey geometry shows the filter elements.

et al., 2019), we need more focus and research on the effects of microplastic on the human body and how to avoid and reduce microplastic contamination in our products and environment.

This project aims to design a non-clogging microplastic particle filter that can help combat the highlighted issues. Inspired by the manta ray, the underlying mechanism that is used as the basis for this filter is the "Ricochet Effect." It uses the inertial mass of the particles in the fluid to leverage ricochet motion. Figure 1 shows the ricochet effect in motion.

As the particle size is orders of magnitude bigger than the dimensions of water, the system can be viewed as a colloidal suspension, in which the particle is being dragged by the water flow but reacts slowly to changes. When a particle hits one fin, it "bounces" back and due to its inertia doesn't follow the water around the obstacle.

If the distance to the next fin is just right, the same "Ricochet Effect" happens at the next fin resulting in a pile-up of particles above the fins.

If the distance between the fins is too large, the particle would just follow the water. On the other hand, if the distance is too small, the particle could in the best case "bounce" on the second or third next fin or in the worst-case scenario move down the next fin. When building a ricochet effect filter, one's calibration of fin size, the distance between fins, the contact angle, as well as the form of the fin, depends on the nature of the filtered particle, especially on its mass, average velocity suspended in the water, size and mass density.

When looking at the potential efficiency of such a filter, the amount of water that passes through the fins grows linearly with the number of fins; however, the loss of particles to the cleaned flow also grows exponentially. If you then want to reach the desired density of particles in the uncleaned flow, there should exist an optimal filter using the ricochet effect.

Goals and Methods

This project takes off where previous related works on the ricochet effect stopped. In order to develop and commercialize ricochet effect solid-fluid filters, a design needs to be optimized and the effectiveness, when compared to established filters, has to be proven. Furthermore, use cases for the implementation of the filter have to be identified and proven. Therefore, the goal of the project was to develop and optimize a filter design using simulations and tests with 3d-printed prototypes to determine the filter efficiency and other flow properties of different designs and boundary conditions.

The design features to be optimized are the shape of the shell of the filter, the shape of the fins, the angle of the fins with respect to the water flow and the distance between the fins. The flow properties to be optimized are the flow speed and particle size.

The first proposed method was to 3d-print a modular prototype inspired by "Team Bats" in the Bionik Seminar at TUM and to optimize the fin design by replacing the fins and testing each design in a hardware test with a water pump. This first prototype is shown in Figure 2. After the first trial, we realized that hardware tests were extremely time intensive and that the water retention of the modular filter worsened after each reassembly. Therefore we decided to transition completely to fluid simulations instead. Here changing the filter design should be less time intensive and the water-tightness of the filter would no longer be an issue.

Figure 2: First 3D-printed prototype.

Ansys Fluent was used as the simulation software. For more time-intensive simulations, we gained access to the Leibniz Rechenzentrum's Linux Cluster. Simulations were carried out in the following sequence of steps. First, the 2D filter cross-section was modelled in SpaceClaim. Then a mesh of the flow area was generated. Next, the boundary conditions of the water flow were set and the particle injections were defined. At this point, the flow properties to be calculated were selected and then the simulation was carried out. Finally, the flow properties were read off and saved.

The setup is visualized in Figure 2. Here green represents the mesh, the blue arrows represent water flowing into the inlet and the red arrows represent water flowing out of the outlet. The top length is 15 mm, the bottom length is 10.4 mm, the height is 7 mm, the inlet size is 3 mm, the outlet sizes are 2.75 mm and the fins are 2.5 mm long and angled at 45 degrees.

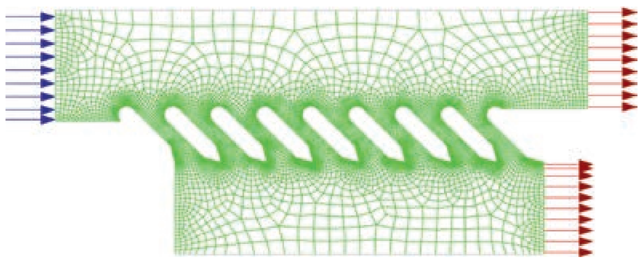

Figure 3: Visualization of the filter setup. The blue arrows indicate water flowing into the filter inlet. The red arrows indicate water flowing out of the two outlets. The top and bottom outlets are the dirty and clean outlets respectively. The green lines represent the discrete 2-dimensional mesh generated for simulations.

Outcome and Discussion

The simulations' results are summarized in Table 1 and the simulation parameters are listed in Table 2.

It can clearly be seen from the results that the percentage of particles filtered increases with the water flow velocity. Beyond an inlet flow velocity of 2 m/s, no particles were recorded exiting through the clean water outlet. A possible explanation would be that at larger flow velocities, the momentum of the water and the contained particles is too great to change direction and pass through the clean outlet. However, the percentage of water flowing through the clean outlet also increases with larger flow velocities, thereby proving that this is not the case. Instead, the ricochet effect seems to be effectively filtering out particles while letting water pass.

Inlet Flow Velocity (m/s)	Particle Mas Flow (kg/s)	% Water	% Particles
0.25	0.0025	18.4	9.44
0.5	0.005	18.5	2.70
1	0.01	22.0	0.0480
2	0.02	27.3	0.00
4	0.04	67.0	0.00
6	0.06	68.5	0.00

Table 1: Percentage of the inflowing water and particles that exit through the clean outlet for the different inlet flow velocities and particle mass flows tried in the simulations.

To validate the effectiveness of the ricochet effect we also analyzed the water velocity contours and visualized the movement of the particles. Figures 4 and 5 show the flow velocity profiles for an inlet flow velocity of 1 and 4 m/s. A strong difference in the two contours can clearly be seen. For the 1 m/s inlet velocity, the velocity profile of the dirty water remains almost unchanged whereas the clean water flow velocity is very close to zero. For the inlet velocity of 4 m/s, the velocity profiles in both the clean and dirty water flow change significantly from inlet to outlet. In the dirty water flow the flow velocity decreases, while it increases for the clean water flow. This reinforces the takeaway that the filter works best for larger flow velocities since a large proportion of clean filtered water is desired.

Figures 6 and 7 show the visualizations of the particle locations for an inlet velocity of 0.25 and 2 m/s. Similarly, to the previous two figures, the difference is very clear. For the lower inlet velocity of 0.25 m/s, the ricochet effect works poorly leading to particles being seemingly randomly dispersed throughout both the clean and dirty water flow. For the flow velocity of 2 m/s, the flow of the particles is very orderly and no particles can be seen in the clean water flow.

The weak effectiveness of the ricochet effect for lower flow velocities can be explained by the fact that it relies on turbulence.

Particle Diameter	Particle Density	Mesh Size	Wall Condition	Reynoldsnumber	Waterviscosity
0.45-0.5 mm	1.3 g/cm^3	0.02-0.2 mm	Noslip	1660-19900	0.001003 kg/ms

Table 2: Simulation parameters

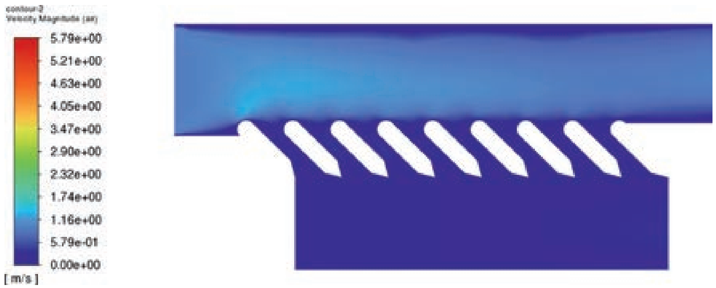

Figure 4: Flow velocity profile for an inlet flow velocity of 1 m/s.

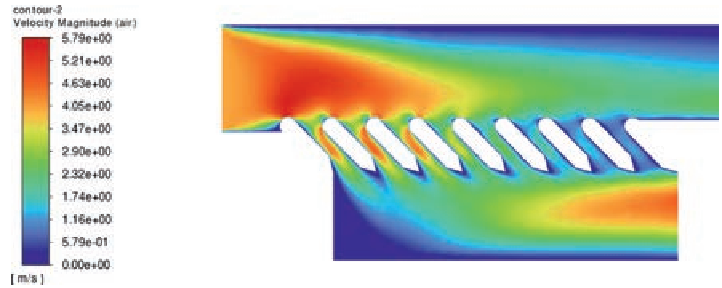

Figure 5: Flow velocity profile for an inlet flow velocity of 4 m/s.

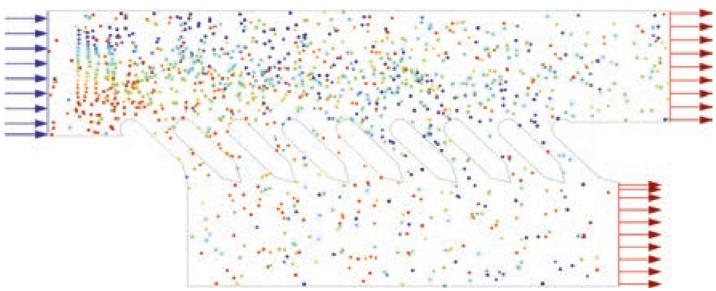

Figure 6: Particle location visualization for an inlet flow velocity of 0.25 m/s.

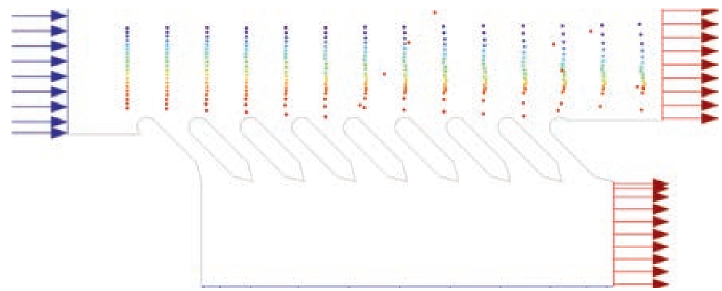

Figure 7: Particle location visualization for an inlet flow velocity of 2 m/s.

At low flow velocities, there is not enough energy in the flow for the necessary turbulences to form. On top of that, gravity exerts a downward force on the plastic particles forcing them downwards. Without the ricochet effect, nothing is stopping them from entering the clean water flow so it becomes contaminated.

Because the manta ray swims at a velocity of about 4 m/s we hypothesized that the effectiveness of the ricochet effect would peak at this velocity. The simulations showed that this hypothesis was false and that instead, the effectiveness continues to increase beyond this velocity. At 6 m/s there are still no particles in the clean water flow but the percentage of the water flowing through the clean outlet is slightly improved from 67 to 68.5 %.

Summary and Future Goals

Our simulations showed that the ricochet effect is indeed a promising approach to building efficient, non-clogging filters. Furthermore, suitable flow velocities for the ricochet effect were identified. The unexpected complexity and time intensity of the simulations in Ansys Fluent prevented the investigation of other parameters within the scope of this project. Further simulations and prototyping would be necessary to confirm the results and to optimize the filter's geometry. Specifically, the project could be continued by:

- performing simulations with different filter designs
- building a prototype and testing the simulation results with a physical model
- identifying and testing suitable real-world applications (e.g. downstream of washing machines)

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Self-reflection

One year and a half seemed like a long time when we started our TUMJA project, but our time at TUMJA is now almost over and we look back at this time, reflecting on our journey and all we have learned.

Our journey started in November 2021 during the first TUMJA weekend, when our interdisciplinary team of 7 was formed, bringing together the fields of study of mechanical engineering, medicine, physics, and business administration. Our original idea was to find inspiration in living membranes to create an efficient filter system. However, we soon decided to take our inspiration from marine wildlife instead and to mimic the gills of the Manta Ray. As we were attached to our team name Membrains, we decided to keep this name nevertheless.

As a team and as individuals, we learned a lot from our project. We learned how to cooperate and work as an interdisciplinary team, manage time and resources, and organize ourselves to maximize the work output. Our supervisors and tutors were of great help, entrusting us with the knowledge, experience, and contacts we lacked.

As time went by, we had to face many challenges of an organizational or technical nature. We all had many projects and obligations in parallel to TUMJA and working on our TUMJA project while also working on Bachelor's theses, Master theses, laboratory work, or being abroad, turned out to be our greatest challenge. Optimized work distribution and regular feedback helped us to overcome these challenges.

TUMJA also proved to be a great opportunity to meet many interesting and diverse people from all sorts of backgrounds and fields of study with many events promoting the exchange between the scholarship holders. We valued these events very much since they had not been able to take place for many months because of the Corona Pandemic and our predecessors had very few opportunities to meet in person. As a team, we got along incredibly well and enjoyed many shared team-building moments, which will remain valuable memories.

Acknowledgments

Foremost, we wish to express our gratitude to our supervisors Prof. Dr Olivier Lieleg and Gwillem Mosedale for their support of our project and the knowledge and insights they shared with us, as well as for regularly challenging us, which helped us improve our project drastically. Their guidance was of great value to us.

Furthermore, we would like to thank our tutor Martin Zirngibl for his help and valuable assistance during our project.

Thank you to Arthur Bucker, Simon Hofmann, Negar Shahmoradi, and Hristiyan Vasilev from Team Bats from the Bionik Seminar at TUM. Their design for a ricochet-effect filter inspired ours and gave us a great starting point for our prototype.

Thank you to Bernardo Miller Naranjo for helping us overcome the software difficulties we faced when running simulations.

We also wish to thank Thomas Fromm for his advice and training for writing the journalistic part of our research report.

Thank you to Misty Paig-Tran for advising us about her research on the Manta Ray's gills and the ricochet effect.

Last but not least, we would like to thank the TUMJA team and Peter Finger for the organization of all the TUMJA events, for his trust in our project, and for supporting all our ideas. Thank you for providing the tools to finish our project and for teaching us valuable skills for our future careers.


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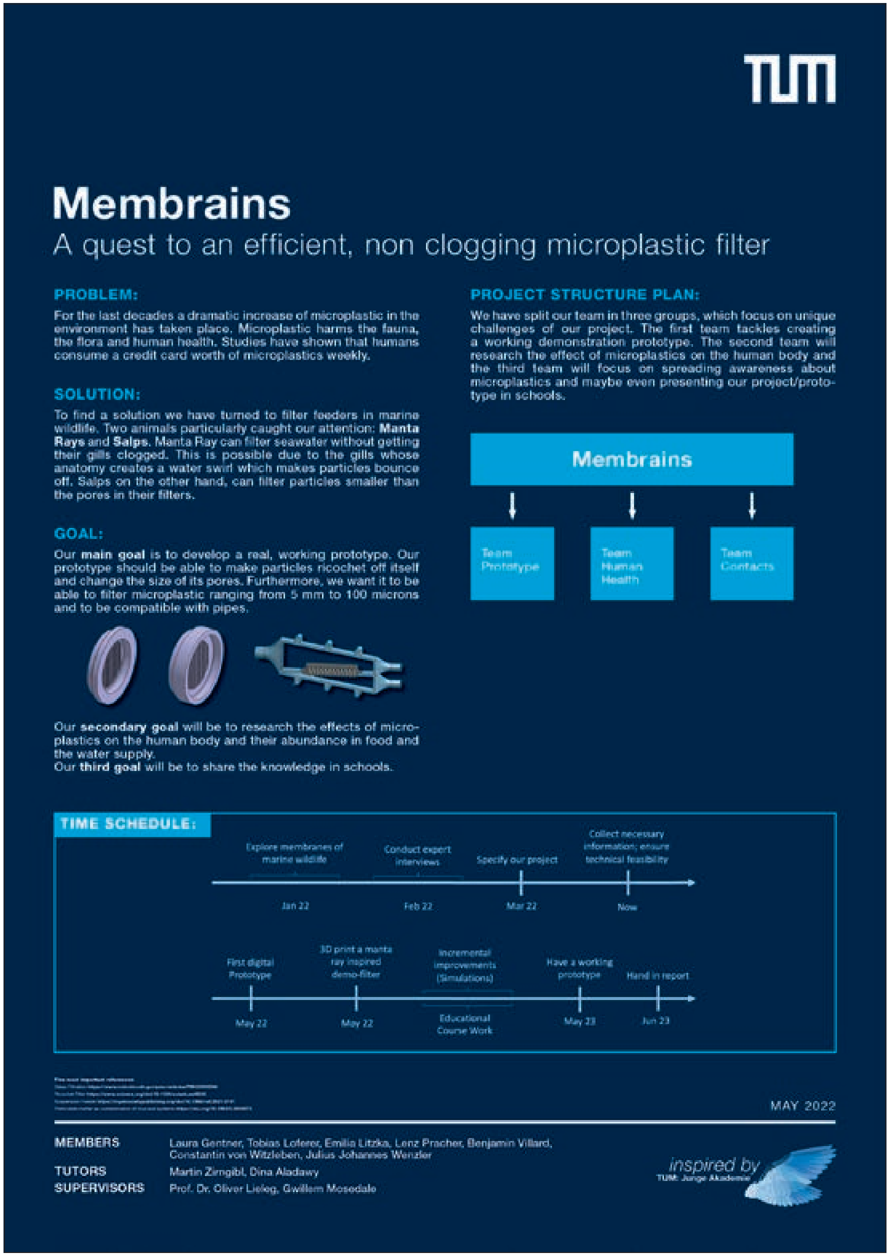
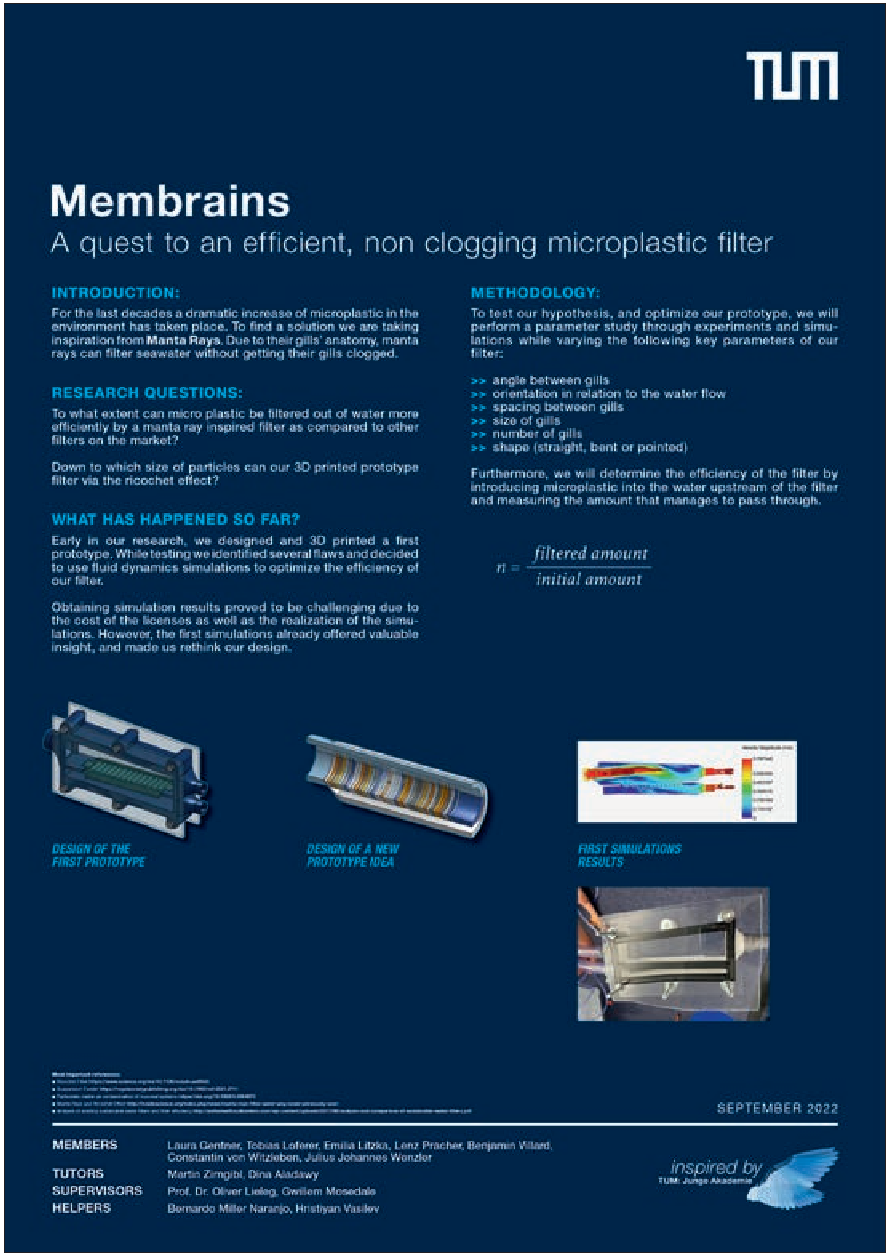
POSTER 1:

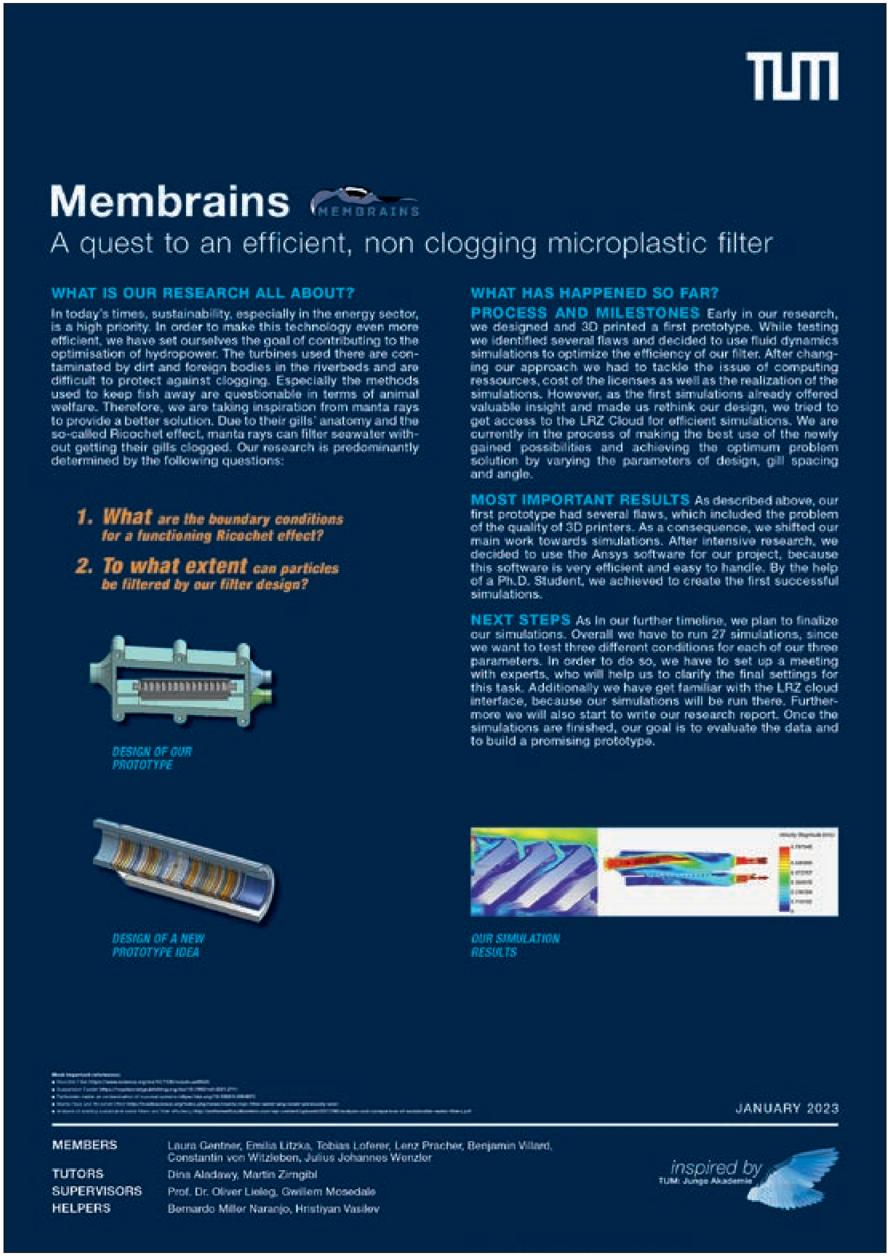


During the first months of our time at TUMJA, we took part in workshops that aimed at helping us define our project. We had decided to focus on the topic of “filters” but still had to narrow this subject down. Our first idea was to take inspiration from membranes to improve facemasks. However, we soon realized that the order of magnitude we would have to look at would be in the nanometer range. We decided that this range was too small for us to work on for the TUMJA project. Therefore, we shifted our attention to marine wildlife and in particular the Manta Rays and Salps. They seemed like a great opportunity to improve water filters. The first poster shows that we focused on defining our subject and covering the basics with a first explanation of the problem faced and the solutions we thought of. We split our team into subteams (Prototype, Human Health, and Contacts) and defined our goal. Furthermore, a first schedule was set for all the subtasks.



POSTER 2:

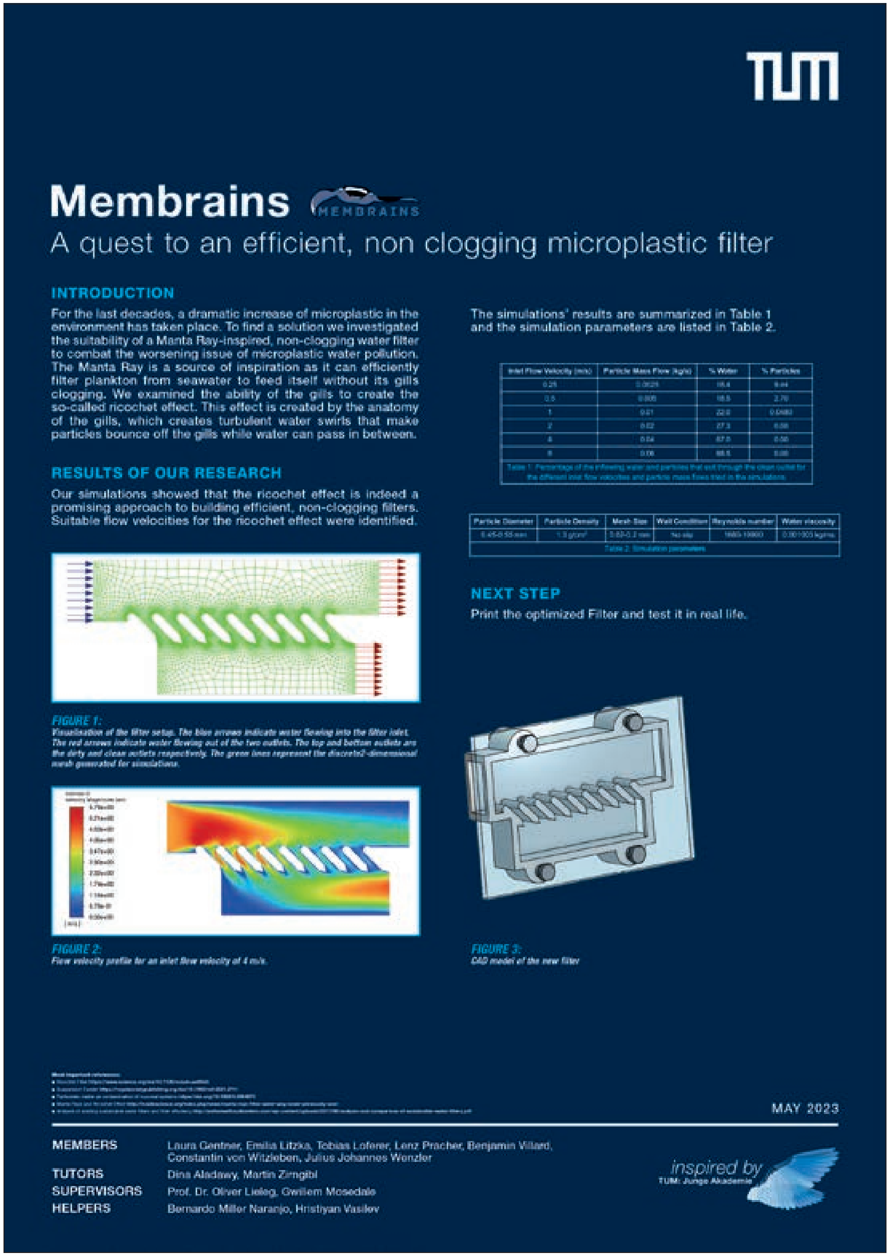
During the following months, we continued working on our project. With the help of many constructive comments and workshops, we realized our goal was still too broad and would likely be hard for us to achieve. Once again, we narrowed down our goal, removing the Salps and the educational course from our focus. Furthermore, during a workshop weekend focused on project management, best practices, and core problem definition, we defined our research question. We also worked on the methodology, as can be seen on the poster. We explored several prototype designs and printed one. We changed the division of the team with the dissolution of the Human Health team and the creation of the team Simulations. ■



POSTER 3:

After printing our first prototype, we tried to test the ricochet effect using a water pump and our 3D-printed prototype. However, testing turned out to be more challenging than expected, as our prototype was severely leaking and water motion was complicated to see with bare eyes.

We realized that simulations offer a more efficient way to test the parameters and, from that point, we decided to focus on these instead. Once our simulations gave us the optimal parameters for our filter, we planned on printing it once more. We furthermore improved our research questions and created a Logo, representing a Manta Ray, which can be seen at the top of the poster.



POSTER 4:

The last poster shows the final result of the project. Through simulations, we were able to produce a proof of concept for the ricochet effect and show connections between the few defining parameters of the system. We will now print our optimized prototype and test it in real life, using plastic particles. In terms of the three objectives from the first poster, we focused on the main one: to build a water filter inspired by the Manta Ray. We have seen a shift in objectives throughout our project and the timeline was adjusted several times over the course of the project.