Project ID: E-project-042821-163108

Design of An Improved Leg Band for the Common Loon

A Major Qualifying Project Report submitted to the faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the degree of Bachelor of Science

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May 5, 2021

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Abstract

Commercially used plastic bird identification bands present challenges when used in studies related to the Common Loon. The loon's highly specialized leg bone structure and shape, which has evolved to give the species optimal swimming ability, requires correspondingly optimized band shape and size. Existing bands lack matched capability which could jeopardize the loon's physical fitness and survival. This project quantified the theoretical physical energy costs of existing bands using 3D CAD models and fluid flow simulations to determine drag forces and coefficients. Using our novel and improved leg band design, the drag coefficient was compared to existing bands and the results showed that a specialized leg band for the Common Loon could reduce drag by at least 21 percent.

Acknowledgements

We would like to acknowledge Worcester Polytechnic Institute for the funding and resources for this project. We would like to express our gratitude to our project advisors, Professor Ambady and Professor Sabuncu, and loon experts Professor Mark Pokras and Biologist Vincent Spagnuolo for their valuable field and research expertise as well as providing various resources, data, and information regarding loon studies and banding. We would like to thank Lisa Wall, Robert Kirch, Professor David Olinger, and Dr. Erica Stults for their assistance during our prototyping and testing process. We would also like to thank James Mancuso for his hard work before departing from the project team. And lastly, we would like to acknowledge the loons who donated their legs to our study for the betterment of the Common loon species.

Authorship

The members of our team, Talya Goldman, Siyuan Li, and Vincent Tanguilig, worked on each of the sections of the report in an equal capacity. The editing of the report occurred both individually and as a team by each member.

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Chapter 1: Introduction

Common Loons are water birds that have evolved to be highly efficient swimmers and divers. A loon's leg is shaped like a hydrofoil, and placed far back on their skeleton, which aids in their aquatic maneuvers but makes them unable to walk on land. Loons swim by synchronously paddling their feet, and use several different methods to swim including extending a wing or slowing down a leg to act as a rudder. In captivity a loon was measured to swim at the average velocity of 0.86m/s with their legs reaching up to 1.06m/s [1]. While there are very few studies on the swimming of loons, it is suggested that loons and other foot-based swimming birds generate lift forces for propulsion while swimming [2].

Birds of all types are banded to help keep track of population sizes, and are often a good marker for the overall health of an environment. Birds are banded with standard metal federal bands, with an identifying number on it to help track them when they are recaptured. Loons have these federal bands, but are also banded with colored, plastic, commercially used bands to help identify them from a distance, so that recapture of the bird is not required every time. A banded loon could have up to four bands total, two on each leg. The federal bands that are used must be bent from their standard cylinder shape to an oval to fit the unique shape of the loon's leg. Researchers also must shape the commercial bands to correctly fit the loon's leg, but often do not achieve an appropriate shape for the loon’s specialized leg.

The goal of our project was to design a new leg band for loons, as well as to use fluid flow simulations to determine the drag coefficients on the loon leg as well as various bands. To determine the best method of identifying loons, the team analyzed various bird identification methods, with a set of objectives in mind. The team decided to design a new band, as to not be invasive, not require recapture of the loons, and to ensure that the loons are identifiable from a distance. To develop new bands for the Common Loon, our team worked with fields experts to establish the following objectives:

- **The band does not interfere with loon survival or fitness.**
- **The band is long-lasting.**
- **The band is easily applied.**
- **The band has a reasonable price point.**
- **The band should not increase chances of entanglement.**
- **The band should have a high energy efficiency.**
- **The band should be adjustable for application to different sized loons.**

We designed multiple bands, each to address different problems that are present with currently used bands. To determine the impact of these bands on the loons, we also created 3D models of the leg and bands and performed fluid flow simulations on the leg model and bands on the leg model. This provided valuable data regarding the impact of bands on loon swimming.

Chapter 2: Literature Review

In order to obtain deeper knowledge about the subject of loons and bird banding, our team delved into some research about the topic. In this section, we introduce the species of interest, the Common Loon, discuss the physiology and fluid mechanics related to its swimming and flying techniques, and observe the types and impacts of different identification methods on loons and other species.

2.1 The Common Loon

Loons are migratory, aquatic birds, and highly specialized for deep diving. They are able to dive to depths of 200 ft and can be found all over North America [3]. A map of Common Loon migration can be seen in Figure 1. The full list of species of loons include the Red-Throated, Pacific, Yellow-Billed, Black-Throated, and Common Loons.

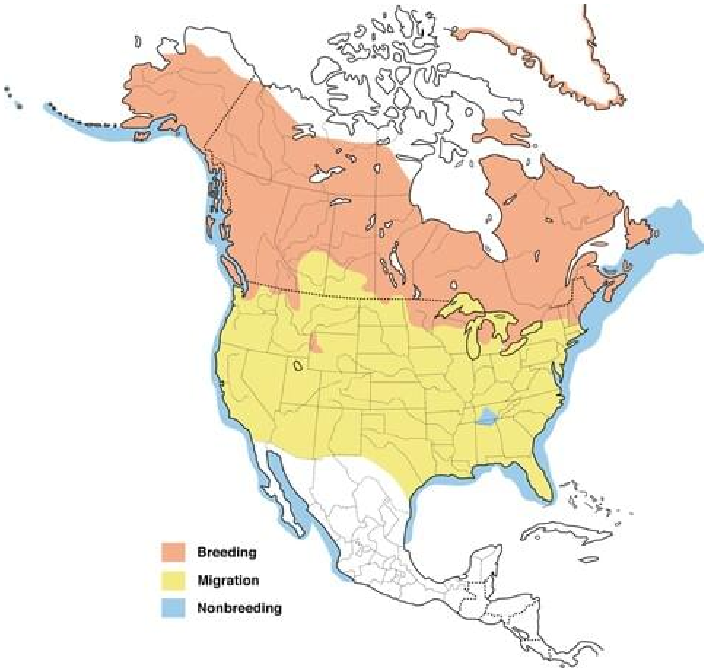


Figure 1. Common Loon breeding, migration, and non-breeding nesting grounds [3]

The Common Loon is a rarely talked about bird with few scientific studies looking into its behavior, anatomy, and influence on its environment. Common Loons take on a bright shiny pattern of black and white feathers shown in Figure 2 below. Each loon's pattern is specific to that individual, so it is likely that loons use this to help identify others. One way they communicate is by letting out loud eerie calls. These calls are most often heard in the summer months when loons are more active in order to elicit responses from neighboring birds. The phrase "crazy as a loon" may be linked to the vocal nature of the Common Loon and its ability to let out these calls, sometimes described similarly to the laugh of a person who is not in their right mind.

Figure 2. Two Common Loons with a chick [4]

Loons are aquatic birds and only go onto land to build nests, breed, and incubate their eggs. Loons are very territorial birds, able to almost recognize their mating partner instantly versus an intruding bird. A loon's territory averages 26.2 hectares in size and contains various nests and nurseries [5]. McIntyre (1983) describes an "excellent" nest to be completely hidden from over-head and straight on views from a boat. Nests must also feature a steep drop into the water to help hide the nests' location. The nest must also have a view of the nursery area. Nurseries are said to occupy around 15% of the total territory space, however, researchers have noted that calm bays or other major physiographic landmarks can play a role in the formation of more nurseries. Common Loon nurseries are often built on soft mud as opposed to rock or gravel-like nesting sites. They also often feature shallower slopes into the water and more aquatic vegetation that draw in small fish that can be fed to the loon chicks [5]. Figure 3 illustrates the physical differences between nests and nurseries.

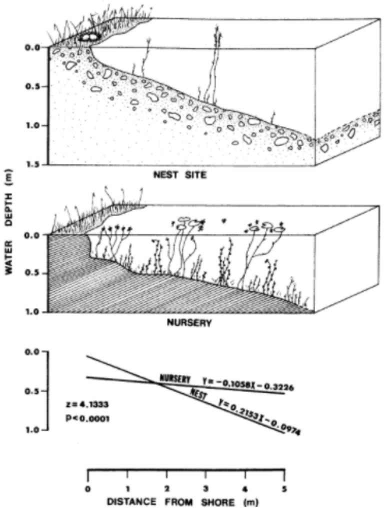


Figure 3. Difference in nesting and nursery sites for Common Loons [5]

Researchers estimate that two adult loon parents with two chicks can eat over a half-ton of fish over a fifteen-week period. Once chicks have outgrown their nurseries, they depart with their parents for their first long swim to the nest. This first swim is believed to majorly imprint on the young birds and can be as long as half a kilometer. Researchers also believe that creating artificial islands can improve nesting locations and reproductive success, however, care needs to be taken to also improve nursery sites, or there will be little effect on hatching success [5].

Juvenile loons are on their own after around twelve weeks. At this time, they travel to coastal waters for roughly two years before returning inland. It is around the time they return that they begin to breed; however, some researchers believe breeding is more common when loons reach six years of age. Loons can sometimes remember where they were fed by their parents as infants and return to similar locations [5].

In winter months, Common Loons molt their feathers and become a simple gray and white. During this time, the loon is flightless until its feathers grow back a few weeks later. Researchers have measured loons to fly at top speeds close to 70 mph. To be able to take off, loons need thirty yards or up to a quarter mile of open water to gain enough speed for lift-off. A loon taking off for flight can be seen in Figure 4 below. Migrating loons can sometimes accidentally land on wet strips of road, mistaking them for waterways. This leaves the loon stranded without enough water to take off. The loon's leg anatomy plays a major role in why the loon is unable to gain enough speed on land [3].

Figure 4. A loon taking off for flight on water [6]

2.2 Physiology

To understand how a band might fit to the loon's leg, we researched the loons anatomy and swimming mechanics. In this section, we first focused on the special anatomy of the loon leg to obtain the structure of the banding location. We then looked into loon swimming, including a loon's leg movements and swimming speed.

2.2.1 Leg Anatomy

Many lineages of birds have evolved to become more aquatic and to swim specifically with their feet. Five such lineages independently reached high levels of specialization. The first of these is called *Hesperornithiformes*, an extinct bird species that was the largest of the lineages and was highly specialized for swimming and diving. However, this bird's large size and inability to walk on land likely contributed to its extinction [7]. The other four are still alive today: ducks, grebes, cormorants, and loons.

The loon's ability to have such a powerful swimming stroke is due to its leg placement and musculature. Loons have two fewer pelvic muscles than found in most birds. The first leg joint, the intertarsal, is able to swing freely along an almost horizontal plane parallel to the loon's body, explaining their affinity for water-living. In addition, the femur and tibiotarsus are only able to move along this horizontal plane which is optimized for aquatic movement. Figure 5 shows a view of the lower leg and the flexible leg joint [8].

Figure 5. Front and side views of the specialized loon leg specimen

The loon's legs are also positioned far back on its body. Figure 6 compares the webbing and location of the four major foot-based swimming aquatic birds. The loon's legs are so far back that they have almost completely lost their ability to walk on land. For this reason, they only go on land during breeding season to nest and lay eggs. They can propel themselves along small distances of land by laying forward on their breasts and paddling their legs exactly as if they were swimming as seen below in Figure 7.

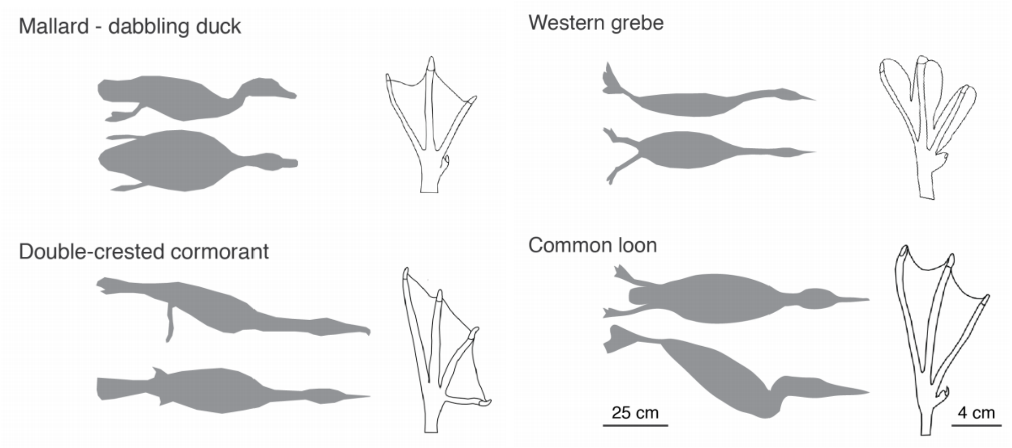


Figure 6. Comparative views of the four major foot-based swimming aquatic birds [9]

Figure 7. A loon unable to walk on land [10]

2.2.2 Loon Swimming

Loons are one of the most agile foot-based swimming birds. As mentioned before, they are built for swimming and diving to the point that due to their anatomy they are unable to walk or even stand on land. Loons are very skilled divers, with records showing their ability to dive to depths of 70 meters and last underwater for durations of up to 2 minutes. They have been recorded swimming at speeds of 0.86 m/s in captivity [9]. Loons have similar swimming styles to grebes and cormorants, where they synchronously paddle their feet laterally to their body. This makes studies on grebes and cormorants effective at filling in the gaps where research on loons is lacking. Below in Figure 8 shows this lateral leg movement.

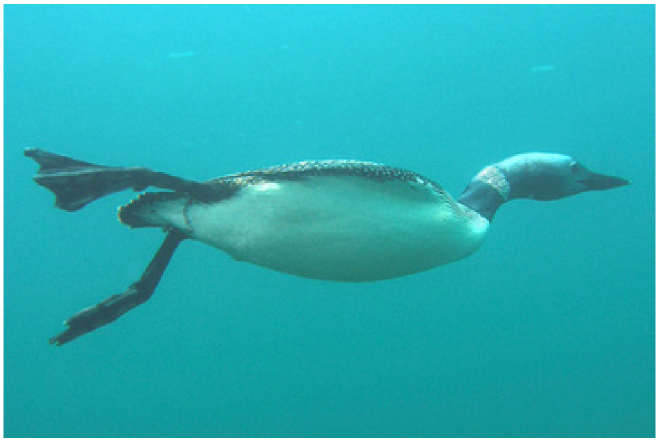


Figure 8. Lateral leg movements during loon swimming [11]

While swimming straight, loons synchronously paddle their feet, which can be seen in Figure 9 where the black lines represent the loon paddling their feet at the same time. Swimming strides are made up of a combination of power strokes and recovery strokes. The power stroke is the period where the bird accelerates during a complete stroke. Loons are able to modulate their speed by adjusting the length of the power stroke. The average power stroke for a loon is 56% of the stride, which lasts an average of 0.26 seconds [9]. The loon's foot starts the power stroke lateral and ventral to the abdomen, then during the stroke, it arcs down caudally, dorsally, and medially. The foot ends the power stroke behind the body with the feet facing medially. During this process, the intertarsal ankle joints are extended, which allows the loons to get the motion that they need to perform the power stroke. The digits abduct at the metatarsophalangeal (MTP) joints, and then at the end of the power stroke the ankle flexes, which brings the MTP joint forward and allows the digits to collapse. Then, the recovery stroke is when the foot and leg swing back to where the next power stroke is going to start. During this process, the MTP travels in an arc cranial, medial, and lateral relative to the body, while the folded digits move behind the tarsometatarsus [9].

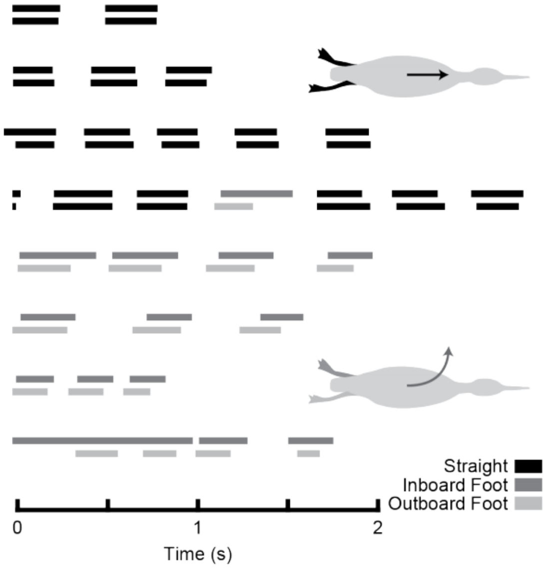


Figure 9. Power stroke timing of a loon's feet during straight swimming and turns [1]

Loons have several different methods of turning while swimming, including meticulous alterations of the positions of their body, wings, and feet at specific times. Their average angular velocity was measured to be about 92.4 deg/s while their average stride centripetal acceleration was measured to be 0.8 m/s^2 [1]. In most turns that were observed, loons moved their bodies out of turn, slightly extended their outer wing during tight turns, and depressed their tails. The important part of turning comes down to what they do with their feet, which includes paddling their inboard and outboard feet at different times. During a turn, a loon will paddle their outboard foot 0.05-0.1 seconds before their inboard foot, making up most of the power stroke for the turn. This difference in time that their feet paddle can be seen above in Figure 9, where the gray lines for the inboard and outboard feet do not start at the same time. During some turns, loons appear to use their inboard foot as a rudder by extending the toes on that foot [1].

Head bobbing is another important part of loon swimming. Head bobbing can be seen in other birds on land and in the water, so it is not uncommon. It is thought that loons bob their heads to help improve their vision underwater. During the recovery stroke of their stride, loons retract their necks and slow the velocity of their heads relative to the water. During the power strokes, they extend their necks, making their heads accelerate faster than their bodies relative to the water. In research trials, the loon's head reached a maximum speed of 1.13 m/s and an acceleration of 7.96 m/s^2 [1]. The little grebe has been studied more when it comes to head bobbing while swimming, and a study showed that head and neck movement does influence diving behavior [12].

It has also been suggested that loons generate lift forces for propulsion while swimming. When looking at the way that loons, cormorants, and grebes swim, there tends to be no motion of the feet in the opposite direction the bird is traveling relative to the surrounding water. This means that there are no large amounts of water being pushed in the opposite direction the birds are traveling. Thus, propulsion likely depends on the generation of greater lift forces than drag forces. Drag, however, is still likely generated to help overcome buoyancy to allow for more efficient diving. In lift-based swimming, the force that is generated is tied to the birds swimming speed, and the forward swimming velocity and velocity of the foot do not cancel each other out like they do in drag-based swimming. The study showed that the stroke of the grebe is about perpendicular to the direction of motion of the bird. This shows that grebe propulsion generates more lift than drag. Figure 10 demonstrates this point, showing that there are large displacements in the z-direction and the y-direction, and very little displacement in the x-direction [2]. The same trend could be followed for loon propulsion.

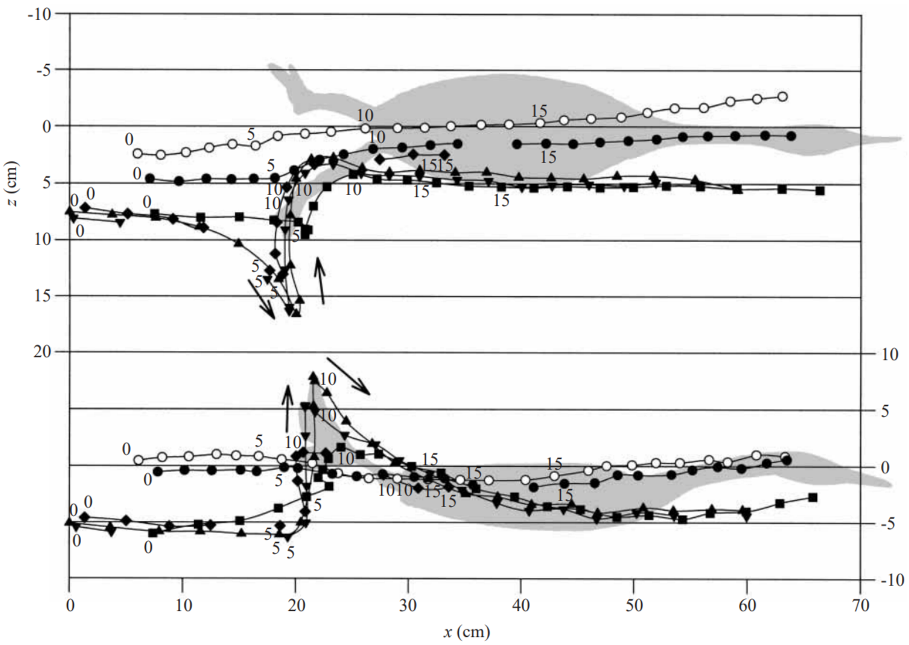


Figure 10. Lateral and dorsal view of one dive sequence for a grebe in water [2]

2.3 Impacts of Identification

Bird identification has a long history and its impacts are also well established. In this section, we analyzed the different impacts of bird identification, especially the environment cost and energy costs. By evaluating the historical impacts of bird banding and the impact of other animal identification, we are able to apply the understanding to evaluate our design, extend the beneficial environmental impacts, and limit the energy cost for loons.

2.3.1 History of Banding

The banding of birds dates back as early as 218-201 BC, when swallows were banded using rope, thread, or paint in order to send longer distance messages more quickly [13]. Records show the reasoning to be communications between officers during the Punic Wars of the Middle Ages. This differs from the current use for banding, which is tracking migrations and survival, but ideas concerning bird identification had originated then. Sending messages continued until the first documented use of a metal bird band was recorded in the 1500s. Primary uses at this time were either communication or as a sign of ownership. However, birds that belonged to certain people sometimes flew away and were returned, providing information as to how far their birds had flown and in which direction. Heading into the seventeenth century, an observation of "a bluebird that was so marked as to be known, built its nest for ten successive years" revealed that people were starting to notice bird behavior. Thus, these types of reports comprised the first records of monitoring bird migration and long-term patterns [13].

The first bird studies are most often credited to John James Audubon, who in the early 1800s, used silver thread to identify several juvenile eastern phoebes in Pennsylvania. He then was able to put together that the same birds had returned the next year, leading him to pursue further scientific studies [13]. Systematic bird studies using scientific methods, however, were officially defined by Leon J. Cole in 1901 when he compared the efforts of the United States Fish Commission having tagged fish and then released them to a potential new system for following the movements of birds [14]. Cole also stated in a paper that bird migration was mysterious, but only in the sense that there was currently no information or studies available to turn the mystery into admiration of this natural phenomenon [14]. This was the beginning of scientific bird banding studies. In the years after this, the development of bird banding evolved into the organizational level, with organizations including the American Ornithologists' Union (who would go on to found the American Bird Banding Association), the Linnaean Society, the New England Bird Banding Association, the Inland Bird Banding Association, and the Eastern and Western Bird Banding Associations, among others [13]. The Biological Survey took charge of much of the bird-banding activity in the year 1920, which merged with the Bureau of Fisheries in 1940 to form the Department of the Interior Fish and Wildlife Service. In 1944, the Fish and Wildlife Service was able to account for over 162,000 banded birds in 349 different species [13].

2.3.2 Environmental Costs

The tracking of animals, specifically birds, has been used by researchers for decades in order to learn more about the species as well as how human activity impacts these animals. Loon tracking can help researchers understand more about loons such as their lifespan, where they travel during different times of year to breed, and other factors. Researchers can then connect this with other data for other individual loons to make greater conclusions about the population as a whole. These conclusions can lead biologists to better understand how human activity impacts the Common Loon. Human activity impacts can involve how pathogens and pollutants bioaccumulate, increase in concentration in animals over time, and biomagnify, defined as an increase in concentrations as they move up the food web. Common Loons are considered to be an indicator species as they are high up along the food web and sensitive to things like climate and pollution. Specifically, loon biologists have seen how lead poisoning and fishing line entanglement greatly impact loon mortality, leading to fishing being banned within loon sanctuaries [15]. An example of the entanglement that can occur is shown in Figure 11 below.

Figure 11. A banded loon with entangled fishing line

Studying human impacts on birds has also led to a better understanding of climate change. Animals react to climate change by moving, adapting, or dying. Researchers analyzed changes in patterns in distribution such as expansions and shifts within the bird data, noting the time period and then compared temperature changes within that time period. Measurable changes in bird migration are indicative of climate change as are higher rates of mortality when coupled with temperature changes [15].

Animals are able to adapt to climate change through phenotypic plasticity and evolutionary changes. Phenotypic plasticity is defined as changes in the animal's physiology and behavior whereas evolutionary changes can be in terms of microevolution as well as major genetic changes over generations. Common adaptations involve the inheritance of new traits through selection or major time changes of seasonal events such as earlier migration or later breeding. Overall, this information is crucial for understanding the world we live in, the wildlife that is a part of it, and how we as humans are affecting it [15].

2.3.3 Animal Identification and Energy Costs

Many studies have been done to determine the impacts of various tracking and tagging techniques on animals. These studies include looking at behavioral differences, and energetic costs caused by the different tracking methods. Most of the studies below are on the short-term impacts of these tracking methods on animals, opening the fact that long term impacts still need to be researched.

A short-term study on the effects of attaching global locations sensors (GLS) to great cormorants' legs was conducted. During the study, the GLS were used to detect the number, duration, and depth of dives that each cormorant performed. This data was used with the assumption that it would hold a relationship with the level of discomfort or invasiveness that each cormorant felt toward the tracking device. No significant difference was found between birds with or without the GLS bands. Each cormorant in the study was also marked with a data-recording tail tag, but the researchers caution using this research as a reference for other birds, since the study was short term, and since the study was done in a period where there was an abundance of prey, making it only representative of a short period of time [16].

A short-term study on the effects of flipper tagging of little penguins found that there was a difference between tagged and untagged groups in terms of diving, over the period of two foraging trips. The penguins were split into three groups, the unbanded group, a control group that had been banned for many years, and a group of unbanded birds that were then banded for one foraging trip. Each bird had a data logger attached to their back to monitor diving depth and temperature. The penguins were monitored for two foraging trips, with the third group getting their bands between trips. It was found that there were short term effects from the banding, with banded birds showing a lower descent rate during dives than unbanded birds. Penguins depend on hydrodynamic drag to dive, and it is also the cause of the largest energy cost for the birds while they are swimming. The long-term cost of banding is unknown and hard to study since birds who do not adjust well to their bands might not survive to older age. There is also the chance that the flapper tag might cause some maneuverability issues with the penguins, which might lead to an increase in flipper strokes which then leads to higher energy costs. Most of the actual long-term costs are still unknown with flapper tags and little penguins [17].

A short-term study done monitoring wing-clipped black ducks involved equipping the birds with FM heart rate transmitters to determine the energy costs of activities including feeding, swimming, and preening. The ducks were observed for 3 to 11 days and the heart rate and behavior of the ducks were monitored for the study. There was a noticeable difference in the behavior of the ducks with monitoring backpacks, showing that they spent less time eating and swimming. Most of their time was spent preening, resting, and alert. It was noted that the ducks with packs noticeably avoided water. The ducks were generally uncomfortable with the packs, which was determined when ducks were seen preening around the backpack and harness [18].

2.4 Fluid Dynamics

When trying to calculate the physical energy costs of identification devices on loons, the most relevant equations would include the drag force equation and the equation for the Reynolds number. Drag is a force that acts in the opposite direction to the relative motion of an object. Devices that cause a higher drag force or have a higher drag coefficient will likely be seen as more invasive and translate into a larger hassle for the bird. The equation for drag force takes into account several factors, including an object's specific drag coefficient. In addition, drag force in fluids depends highly on relative velocity of the object [19]. The drag force equation is shown below.

$$F_D = C_D A \frac{\rho v^2}{2} \qquad \text{Eq. 1}$$

where: F_D is the drag force
C_D is the drag coefficient
A is reference area
ρ is fluid density
v is flow velocity relative to object

When working with loon swimming and diving in water, it was important to specify either laminar or turbulent flow conditions. Out in the wild, with random water and flow movements, it is likely that it would perform turbulent flow, but with the use of virtual flow simulations, we used the equation for the Reynolds number to identify a flow type. In the case of external flow, a Reynolds number of greater than 5×10^5 would translate to laminar flow, instead of the typical threshold for pipe flow [20]. The following describes the equation for Reynolds number.

$$Re = \frac{\rho v L}{\mu} \qquad \text{Eq. 2}$$

where: Re is the Reynolds number
ρ is fluid density
v is flow velocity
L is the relevant length
μ is fluid dynamic viscosity

Another form of the equation uses kinematic viscosity, which is equal to dynamic viscosity divided by density. The equation then becomes velocity multiplied by length, divided by kinematic viscosity.

2.5 Leg Bands

Banding birds was one of the first methods to identify birds. As early as 1595, people used metal bird bands for identification [21]. Compared with different types of bird identification methods, leg bands are inexpensive, nontoxic, noninvasive, lightweight, long-lasting, and easy to assemble. Thus, banding is also one of the most used identification methods.

Figure 12. Aluminum and plastic leg bands: a) butt-end federal band, b) lock-on band, c) rivet band, d) colored band [22][23]

2.5.1 Federal Bands

Federal bands are made of an aluminum alloy and have unique numbers engraved. The butt-end bands are commonly used for loons, as shown in the top left of Figure 12. Depending on the size, an aluminum band can weigh about ten grams and has six to eight years longevity for waterfowls. After eight years, these bands are usually illegible, and therefore, require replacement. Lock-on bands provide a strong attachment to the ends; rivet bands are even more substantial than the lock-on bands [24]. The rivet bands have two extended flanges on the ends and are locked by a rivet. These bands are designed for bald eagles, vultures, raptors, turkeys, and other prey birds [24].

2.5.2 Colored Bands

Colored plastic leg bands are also widely used. Compared to the federal bands, the plastic bands are lighter and have a shorter lifespan than federal bands. The most commonly used material for color bands, especially for the commercial band, is plastics such as PVC, as shown in Figure 12 [23]. Plastics are lighter, easier to color code, and less likely to erode in the ocean than aluminum, but also more brittle than aluminum and difficult to bend into different sized bird bands. With shape arrangements, further issues can be caused for loons. If it is too tight, it will cause inflammation or block blood circulation [25].

2.6 Other Bird Identifiers

Identifying birds in a study involves weighing the pros and cons of each method in order to determine the best option in each instance. The category of bird identification includes various other options besides the main leg banding current standard. These include several electronic devices that use radio (bio-)telemetry as well as alternative physical identification methods.

2.6.1 Electronic Trackers

Many electronic trackers use biotelemetry as a means for transmitting information from the implanted device. One of these devices is a microchip, also referred to as a subcutaneous implant. These are implanted under the skin at the base of the bird's neck or alternatively on the back of the bird [26]. The figure below shows a typical subcutaneous implant, manufactured by Advanced Telemetry Systems.

Figure 13. ATS Series A2800 Avian Glue-on/Subcue [26]

The longest-lasting battery model of the device weighs 11 grams and can last up to 495 days. Devices should not be any more than 3% of the subject's weight. Knowing that the average Common Loon weighs around 3000 to 5000 grams, that would put the maximum weight of a device or implant at 90-150 grams, depending on the specific loon's weight, which places the subcutaneous implant well within the weight limit [26]. A potential advantage of the microchip is negligible interference with the bird's wings, legs, or body, since it is inserted into the outer tissue of the bird. However, this does mean that it takes surgery to insert the device, requiring extensive handling as well as a high degree of surgical skill. In addition, there is the possibility of infection at the site of insertion or rejection of the device by the loon's immune system.

A less invasive electronic option is the Dwyer backpack. The Dwyer backpack is most often used on ducks for longer-term studies [26]. The backpack is placed in the center of the duck's back, strapped around the bird's wings using PVC tubing, and fixed in place with solvent cement. The following figure shows a typical Dwyer backpack.

Figure 14. ATS A1800 Avian Dwyer Backpack [26]

The device with the longest-lasting battery life of 535 days weighs 25 grams. The backpack contains electrical resin and is waterproof. The Dwyer backpack likely has an impact on a bird's wing movement, on top of weighing a hefty amount. One study that used the Dwyer backpack attached it to blue-winged teals and reported that birds with the backpack spent less time in the water, more time preening, and decreased in weight in comparison to unmarked birds [27].

2.6.2 Alternative Physical Trackers

Physical trackers, as opposed to electronic trackers, means that the identification method does not use electrical tracking, but rather tracking by sight and physical labeling, which includes any type of bands, dyes, or other topical substances. A common alternative to the leg band for banding birds is the wing band also called patagial tags [28]. The wing band, in the past made of plasticized nylon but more recently aluminum, is attached to the dorsal surface of the wing, pushed through the webbing of the wing, and fastened. During application, it is important to avoid puncturing flesh or tendons as this would cause pain and/or injury to the bird [28]. Like leg bands, they are often marked with an identification code or even a laser-etched barcode, so that the bird can be scanned and recorded when recaptured. Since the wing band could potentially raise concerns about interference with flight, it is often used on flightless birds so that these concerns can be avoided. Figure 15 shows several shapes and sizes of wing bands.

Figure 15. Tab end wing bands - Style 898 [29]

2.6.3 Feather Dyeing

Short term identification bird dyeing is also widely used as alternatives to long-term devices. The feather dyes can help the birdwatcher identify the banded individuals in a long-distance and quickly apply. The pigments are non-toxic for birds, usually obvious to view birds, and used as an extra identification as other long-term devices [30]. Figure 16 shows the process of applying feather dye.

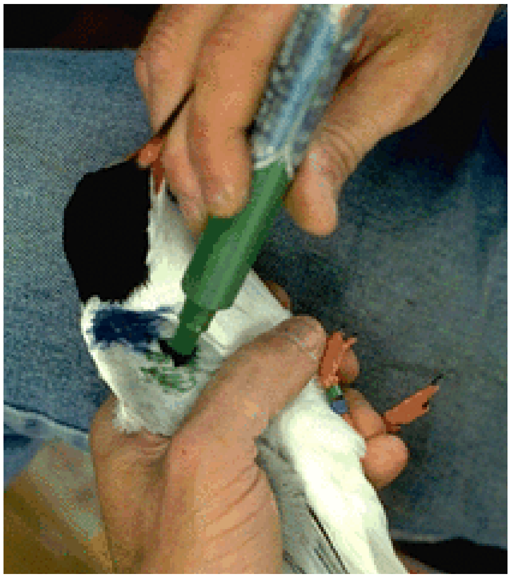


Figure 16. Applying dye on a tern wing, picture adopted from USGS [22]

Chapter 3: Project Strategy

3.1 Initial Client Statement

The scope of our project originated based on the initial client statement we received from our client, Dr. Mark Pokras, of the Tufts Cummings School of Veterinary Medicine. The following shows the initial client statement.

1. Develop a model for the loon leg to analyze the biomechanics of loon swimming and diving using fluid dynamic techniques (*and/or in silico*) to better understand the possible energetic costs of leg banding.
2. Design a better leg band that will improve loon survival in the wild by not interfering with the ability of birds to swim and forage.

3.2 Design Requirements

Based on these objectives, our team analyzed the client statement, attempting to identify the most important details and specifics related to the project. The resulting revisions took the form of the following three objectives. In the first objective, we further clarified our objectives related to analyzing identification of loons and its effect on the loon lifestyle. In the second objective, interference with loon survival was changed to reflect that there is no existing data to support that current bands decrease a loon's chances of survival.

1. Build a CAD model of the loon leg to analyze the biomechanics of loon swimming, diving, and flying using fluid dynamic techniques to better understand the possible energetic costs of leg banding.
2. Research and evaluate the most appropriate identification method (leg band, wing band, etc.) that will least interfere with loon survival in the wild and the bird's ability to swim, dive, forage, and fly.
3. Develop and test a prototype for loon identification based on the team's research.

3.3 Revised Client Statement

Our needs statement is meant to isolate the core problem that drives the project, while identifying the affected population and the potential outcome for this population associated with solving the problem. With this in mind, the following statement represents the specific need of our project.

> There is a need to quantify the immediate and long-term physical energy costs associated with current leg bands so that researchers can gather data on their impact on loon survival and fitness and make improvements to better the technology.

Chapter 4: Design Process

This chapter highlights the steps we took to establish a dependable and capable loon leg band. We started our design process by classifying the client needs and evaluated the commercially available products as inspirations of our own design. Based on these assessments, our design process went through the steps of conceptual designs, enhanced designs, and final design evaluation.

4.1 Needs Analysis

A device that meets the following criteria would be most effective as an identification device. The device must not cause any damage or trauma to the bird and have a negligible effect on their survival. This is most important because it is essential for researchers to prevent interference with the bird's natural life. The device should also be convenient for identifying the bird for the researcher and the public eye. The researcher needs to be able to easily identify the bird in order to gather information about bird health and location. It is also an advantage for the public to be able to locate the bird, in the case that the bird has died and must be recorded as such. A device that does not require recapturing the bird would be the most convenient. The device should be comfortable and form-fitting for the bird, not restricting blood flow or getting caught on outside objects. It should also be easy to put on the bird for both the researcher and the bird. The device should last for as long as possible without needing replacing or tweaking. Finally, the device should be at a reasonable price so that researchers can justify using the device for each bird subject. These criteria can be visualized in Figure 17 below, grouped by whether the criteria is more important for a loon researcher or for the loon itself.

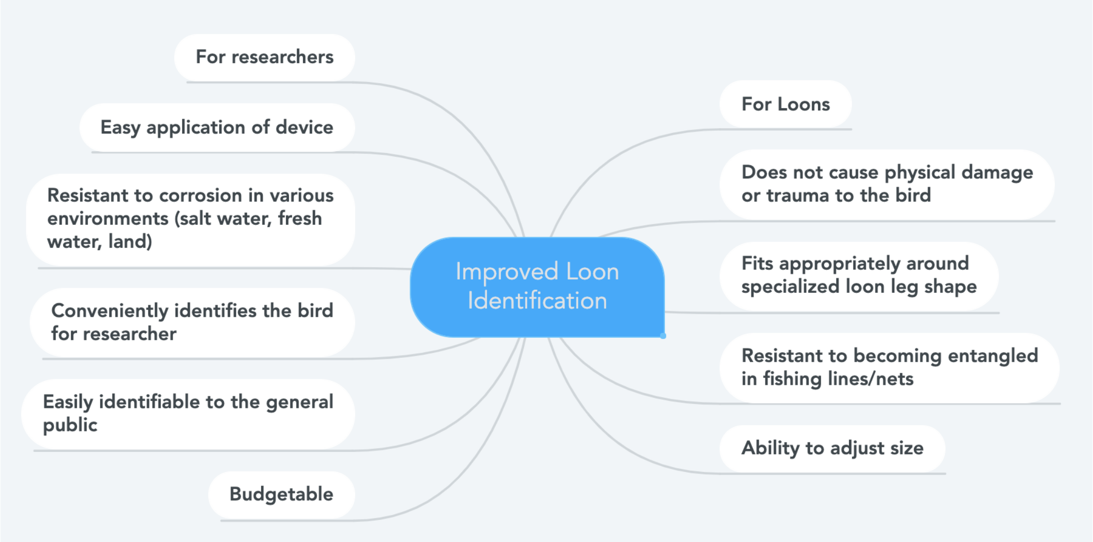


Figure 17. Initial identification device criteria

Using the initial criteria as a guide, the group researched more specific requirements for leg bands when used on loons. We generated performance and functional specifications that needed to be met by any new design, seen in Table 1. The performance specifications indicate quantitative variables that should be met and the functional specifications list all the qualitative factors considered. Although there was not enough reliable quantitative research on bird leg band, an interview with field experts Mark Pokras and Vincent Spagnuolo helped identify desirable values and success thresholds.

Table 1. Performance and Functional Specifications

Performance Specifications	**Functional Specifications**
(Values based on interview with field experts) ● Longevity: over 20 years ● Assembling time: < 15 mins ● Cross-sectional fill ratio: > 80% ● Impact swimming speed: <10%	● Long-lasting ● Good fit for loon leg shape ● Adjusts size as loon grows ● Low impact on energy cost ● Makes loon easy to identify ● Resistant to damage ● Resistant to entanglement ● Adjustable for application ● Minimizes recapture ● Not toxic to the environment ● Low cost

4.2 Concept Maps

Based on the functional specifications, we used concept mapping, shown in Figure 18, to further identify details related to the generation of an ideal design. Each specification was broken down and analyzed for optimal characteristics. Similarly, to the initial device criteria, the specifications were categorized by importance for researchers (blue) vs importance for loons (green).

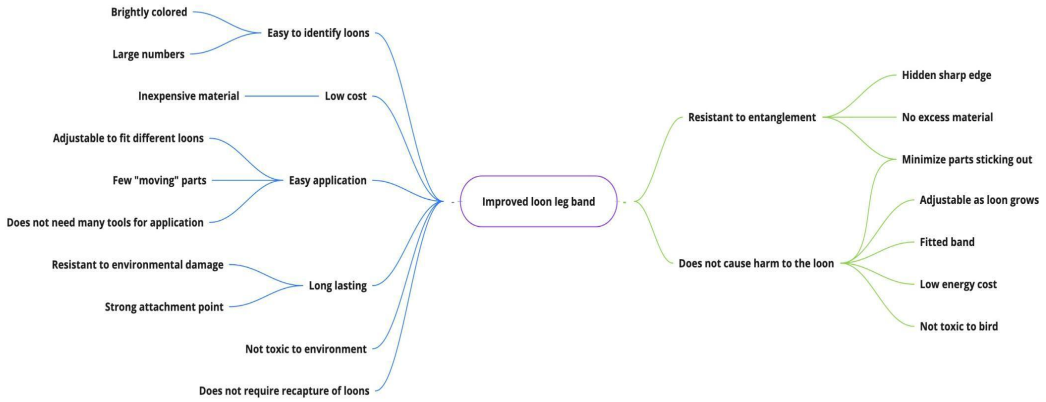


Figure 18. Concept map breakdown of functional specifications

In the following selection matrix, Table 2, we combined these criteria into several main objectives in order to test the viability of each type of device for our purpose. Each objective was given a weight (out of 5) based on our judge of importance as a viable solution. Each option then scored a -1, 0, or 1: -1 for its inability to meet the criterion, 0 as neutral or cannot confirm nor deny, and 1 for exceeding in the category. This score was then multiplied by the weight of the objective and added to return a final score for each device. We evaluated five major groups of bird identification devices that are currently used on various bird species, including leg bands, wing tags, microchips, backpacks, and feather dyeing.

Table 2. Preliminary Device Selection Matrix

Objective	**Weight**	**Leg Band**	**Wing Tag**	**Microchip**	**Backpack**	**Feather Dyeing**
The device does not interfere with loon survival or fitness	5	0	-1	1	-1	0
The device provides convenient identification	4	1	1	0	1	1
The device is long-lasting	4	1	0	1	0	-1
The device does not require recapture	3	1	1	-1	1	1
The device is easily applied	3	0	0	-1	0	1
The device has a reasonable price point	3	1	1	0	-1	1
Rank Score		14	5	3	-1	9

After completing this selection matrix, it was clear that the leg band would be the only device to pursue, considering specific Common Loon needs.

4.3 Conceptual Designs

We brainstormed and designed various ideas as follows, that aim to meet some or all our specifications. The concepts include several band attachment methods, adjustability designs, potential alternatives to bands, and additional features that might add functionality to an existing band.

Design Concept #1

This design resembles the shape of a hair clip, with overlapping tabs to keep the band on the loon's leg, shown in Figure 19. However, the mechanism works more like a reverse hair clip as it is the overlapping tabs that are movable. The rest of the band is rounded and uniformly fit closely to the shape of the loon's leg. Using this idea, the researcher would be able to adjust the size of the band for each bird. Part of the concept behind this design would be to make it easy for researchers to either have a way to bend or break the tabs down to keep from entanglement.

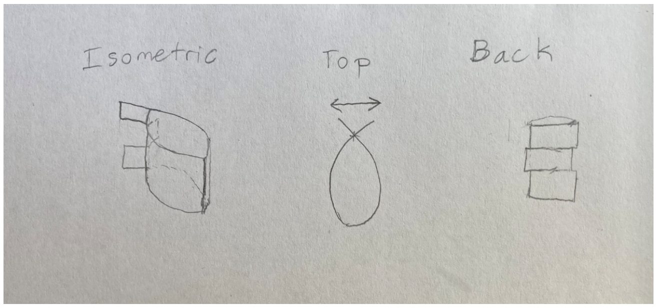


Figure 19. The isometric, top, and back view of the hair clip design

Design Concept #2

This concept in Figure 20 is derived from a zip-tie, which would allow for easy application. The material used would need to be more pliable or thin to allow for movement and application. The extra tab would be bent or broken off to keep the band from getting entangled.

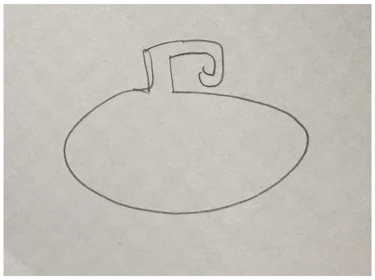


Figure 20. Drawing of the zip-tie design

Design Concept #3

This idea shown in Figure 21 is a way to make sure the band stays on, and it would be to design the band in the style of a concert band. This would use a rivet to ensure that the band is the right size and would make the band adjustable for when the researchers put it on the loons. Problems with this idea include requiring extra material that could get entangled or cause an energy cost in the loons.

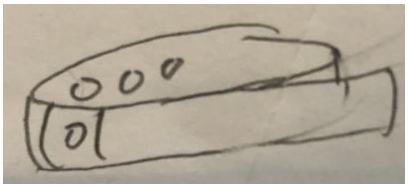


Figure 21. Drawing of the rivet design concept

Design Concept #4

This design is a basic streamlined band, resembling the structure and functionality of existing commercial field bands, thus keeping the simplicity of those existing options. As shown in Figure 22, the difference with this band is that it is specially shaped to the loon's leg biology to offer superior maneuverability for the loon, and thus can be referred to as bioinspired. This design represents the most basic band that meets all the criteria of our clients. It would be built with similar plastics as the existing bands and use the same glue as existing bands to stay together.

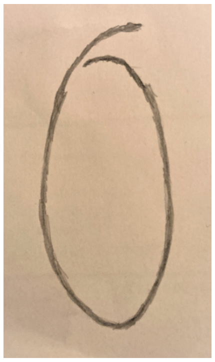


Figure 22. Top view of Design Concept #4

Design Concept #5

Figure 23 shows a reverse ratcheting device that would allow for the pressure from the leg to expand the band as a bird grows. Concerns with this device include the leg not being able to exert enough pressure on the band for it to expand, and if the band gets entangled it might be able to pull the band off.

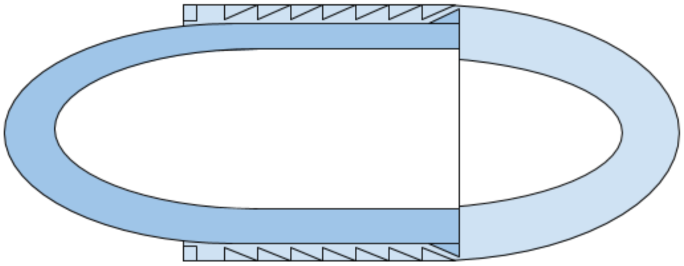


Figure 23. Closed top view of design concept 5, the reverse ratchet

Design Concept #6

This concept would use a stent pattern, shown in Figure 24, to help with expansion over time. With the right materials this would allow the band to expand to fit the shape of the bird with growth. A few concerns include entanglement, and the design might not be strong enough to hold up to environmental damage.

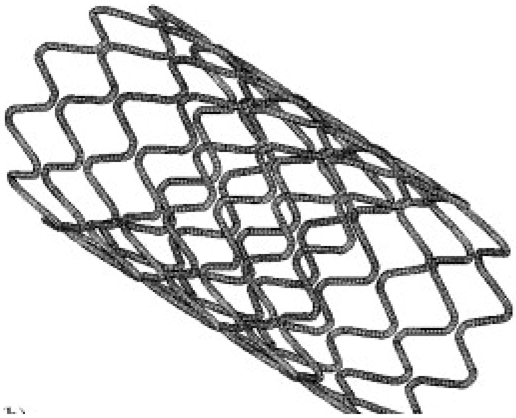


Figure 24. Example of stent pattern [31]

Design Concept #7

This concept considers a method of marking birds with paint on their legs in order to track them without adding a device that will cause additional drag. Figure 25 shows an example of using marine paint on a boat. Eco-friendly marine paint is made to be completely waterproof, anti-corrosion in salt and freshwater, prevents buildup of algae and other small marine life, and is long lasting. These paints used to leach toxins so care must be taken to find a paint that is environmentally friendly. Eco-friendly paints do not contain copper but offer a slick surface and are usually silicone-epoxy. This should be non-toxic if ingested but could cause skin irritation. There is a need to research how paints would react to skin to find the best kind. A stamp applicator could be used in the field to apply paint quickly. A concern with marine paint is not knowing whether it would cause skin irritation, and most paints do not appear to last more than 10 years [32].

Figure 25. Example of using marine paint [33]

Design Concept #8

This alternative concept would include tattooing the loon's leg. Tattooing is often used for cattle and goat identification, as shown in Figure 26, where the tattoos are done on ears for easy identification. To tattoo animals' restraint is often needed to keep them from moving and further injuring themselves [34]. After getting a tattoo, advice to keep it from getting infected include, keeping it clean, and avoiding swimming and sun. This makes it difficult to tattoo a loon, who spend most of their time in the sun and water. To counter this problem the loon's leg could be wrapped in a material to protect it from contaminants.

Figure 26. Example of a tattoo on a calf's ear [34]

Design Concept #9

Figure 27 is our ninth design concept. This concept is based on a fishing line ring cutter and adding this to other band designs could meet all of our criteria. Two sided blades are set in plastic, meaning no harm will come to the bird, but any netting or fishing line wrapped around the leg/band would be cut away as the bird struggles. This design could be modified and added to other designs to meet our design criteria.

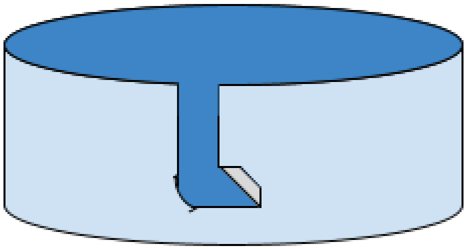


Figure 27. Example of a fishing line cutter

Design Concept #10

In an attempt to manage environmental damage, the band design that is decided upon can be covered with a thermal spray coating or an electroactive conducting polymer. This coating would help provide protection from environmental damage and add years onto the longevity of the bands. Figure 28 shows a comparison of different advanced anti-corrosive coatings.

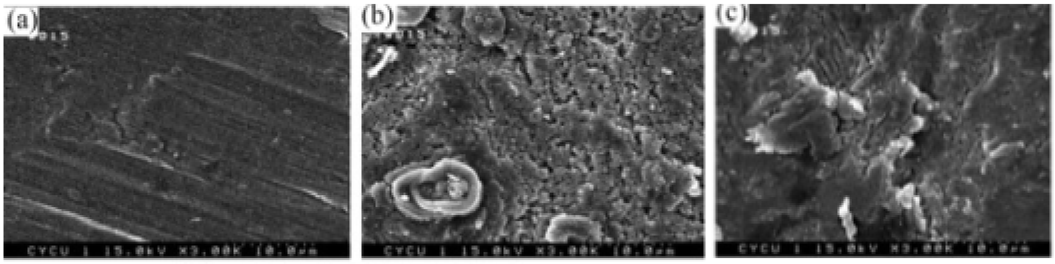


Figure 28. Example of a protective coating, SEM image for (a) polished, (b) electroactive copolyimide-coated, (c) electroactive polyimide-coated CRS surface [35].

4.4 Alternative Designs

The following introduces the four designs that we selected as potential options for our final design. Each one either attempts to solve one or more problems with existing bands or introduces novel band characteristics. They were developed with influence from the design concepts as well as using band functional specifications and criteria.

4.4.1 Bioinspired Band

The bioinspired band is an upgraded representation of the current commercial bands used in the field. It is engineered to fit as well as possible to the loon leg and introduce the least amount of drag and/or interference with loon swimming, diving, flying, and foraging. The following figure shows the initial model of the design.

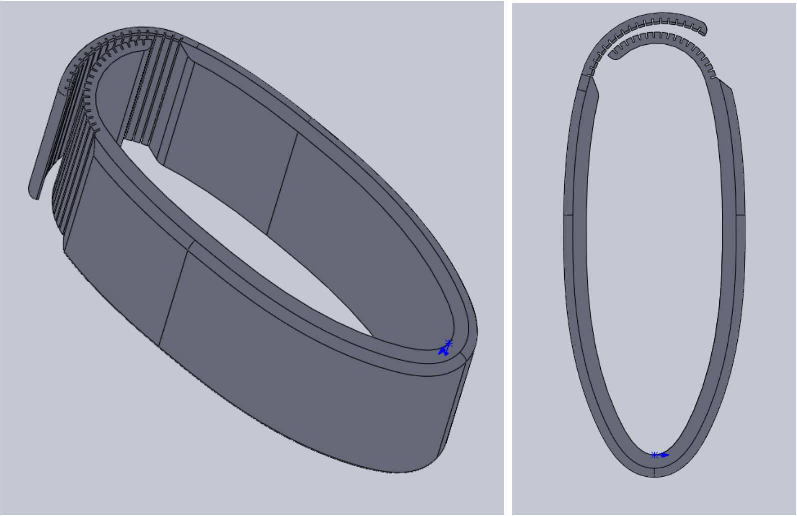


Figure 29. Solidworks CAD model of bioinspired band: isometric and top view

The dimensions of the band were determined primarily based on the measurements of the loon leg, with a length equal to 28.7 mm and the widest width equal to 10.6 mm, as shown above. We also observed and compared measurements of the current commercial bands in an attempt to improve upon their dimensions. The 3D CAD model was made in Solidworks using two splines connected at the bottom, then semicircles to build the tabs at the top. The body of the band is smooth and filleted around the outer edges. The two tabs have divots in a circular pattern that give them more flexibility and thus increase adjustability during application of the band. They are also layered and offset so that when attached together, the band maintains a consistent thickness all the way around. This could potentially introduce a higher mode of failure in terms of structural integrity, but the benefits outweigh this problem in that it offers the loon higher efficiency and lower overall bulkiness. Then, during band application, the tabs can be adjusted to the appropriate size, and to secure the tabs banding glue (already widely used in the field) is needed to secure the band around the leg of the loon. The glue used in the field is called Gravo-bond glue. Figure 30 shows the first high resolution printed prototype of the design.

Figure 30. Bioinspired band printed version

4.4.2 Hydrofoil Band

The hydrofoil band is the most efficient design concept, due to the fact that it was developed using a hydrofoil shape equation. A hydrofoil shape has the best hydrodynamics, which is why it can be seen repetitively in biology. For example, the shape of a dolphin can be seen in Figure 31.

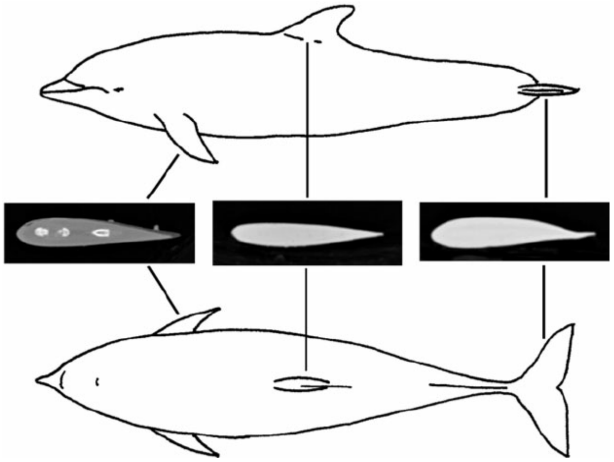


Figure 31. Dolphin flipper fin hydrofoil design [36]

Like a dolphin, the hydrofoil shape has a rounded edge in the front, allowing it to move smoothly through the water. It tapers into a pointed edge at the back, which helps avoid creating any turbulence. The hydrofoil design is similar to the bioinspired design in that it would be attached with two flaps in the front, but the shape of the band is different. To be able to modify the hydrofoil design as needed, we applied the Airfoil Tools by NACA [37] to develop the best hydrofoil shape for a band.

We developed one model that fully resembles an airfoil from the Airfoil Tools website, as well as a second model that was rounded and optimized for loon leg banding. This latter design is the design that we call the hydrofoil design because it is more appropriate for use on the loon and thus for use in the water. Our main focus with this design was to minimize its physical energy impact and drag coefficient. Considering the safety issue and convenience for loons, we also modified the ratio between thickness and length close to loon legs. The airfoil design is longer than the loon leg and has a pointy end, which could increase the chance of harm to the loon, shown in Figure 32. To avoid that, the hydrofoil version is shortened, changed to a dull end, and the interspace area is also increased to provide a better safety usage. Besides the shape design, this hydrofoil leg band would use the same overlapping tabs method as the bioinspired leg band to provide an easy application method.

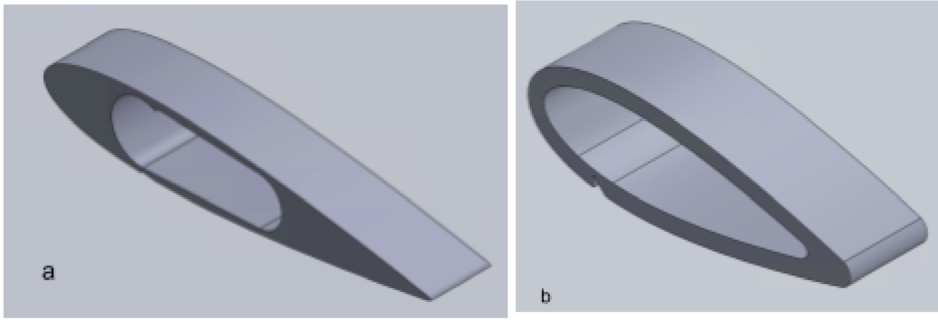


Figure 32. a) Airfoil and b) hydrofoil versions in isometric view

4.4.3 Reverse Ratchet Band

The reverse ratchet band design was based on Design Concept #5. With the inner ratchets on both sides, this design can be easily adjusted to fit different sized loon legs. Its dimensions are based on the measurements of loon legs and the commercial plastic bands. These dimensions are shown in Figure 33 as a Solidworks drawing. Compared with the commercial plastic band, the ratchet band has pre-shaped two curves with different arcs as needed. This sample will save assembling time for researchers in the field. The band also has two junctions of the two parts to provide an even extension and stress on both sides.

The major focus of this design is the inner ratchets on both sides of the band. The two pieces of the band are called the key and the lock, the key being the skinnier part and the lock being the larger part into which the key fits. One millimeter teeth on the lock part can hold the key in place and can only be moved with a strong applied force. With this printed prototype, the minimum required force to move the key into and out of the lock could be tested. The key has a ratchet tooth on each side's end, and with the blocks on the opening of the lock, the key has very little chance to slide out of the lock.

There are three main parts of a ratchet, the gear or linear track which is the line of teeth designed to limit motion to one direction. The next part is called the pawl, which is the part that comes in contact with the track of teeth, this is designed to move only in the correct direction. The third part is the mount, which is what the teeth and pawl are each mounted to, so they are able to interact. Our design is a reverse ratchet, where instead of getting tighter like a zip tie, the band should loosen as the pawl goes over the teeth. This means that there are different length teeth tracks that we should be able to test to figure out what is right for our design.

The printed model caused several limitations to arise. First, from the printed prototype, the resolution was not high enough to print the teeth as desired to stop the tooth going backward. The second limitation would be during band application. Although it would take less time to assemble when compared to the process of bending a strip of plastic into leg band shape for the commercial band, it still may take a lot of effort to assemble the parts. Another limitation is the sharp edges. The sharp edges may cause major issues for loon's swimming and diving function. For this reason, the ratchet band was excluded from fluid flow testing. Figure 33 below shows the CAD drawing of the design as well as the printed prototype.

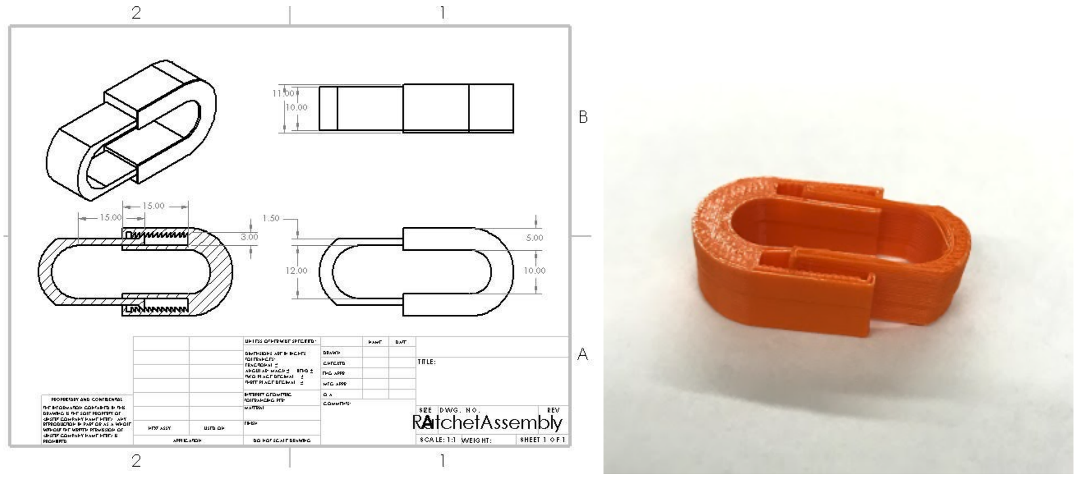


Figure 33. Ratchet band assembly drawing and printed prototype

4.4.4 Hair Clip Band

As its name suggests, the hair clip design is based off of a traditional claw hair clip, shown in Figure 34. These hair clips can be manufactured many different ways, but they all rely on the same type of torsion spring to hold the prongs in place. A torsion spring is a spring that stores mechanical energy as it is twisted and specifically has two legs that protrude at various angles. These springs are produced to use that energy to hold a mechanism statically in place. They are often made of music wire, oil-tempered wire, or 300 series stainless steel and can be finished in zinc, gold iridite, or other coatings [38].

Figure 34. Small traditional plastic claw hair clip and torsion spring [38]

When used in traditional hair clips the spring is often exposed and two large wings extend off of the legs to aid the user in opening the clip. In order to minimize energy costs and drag associated with a bulky band, our design would need to conceal the spring and not include protruding wings.

Our printed prototype for this design is pictured below in Figure 35. It features a similar concealed torsion spring to allow the researchers to easily attach the device and ensure a tight fit around the loon leg. The curved front of the design has a large surface area for imprinting or handwriting identification numbers and the entire device could be manufactured in vibrant colors as well.

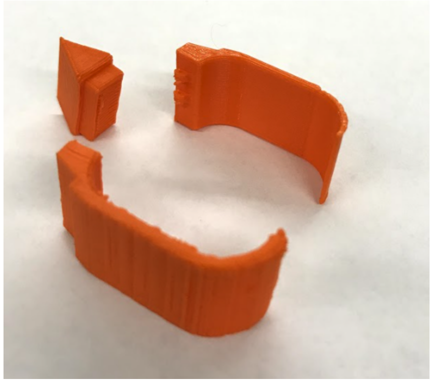


Figure 35. 3D printed hair clip band

4.5 Final Design Selection

After considering our ideas, we were able to narrow down our options to four main concepts. We accomplished this through group discussion involving topics such as feasibility and attainability as well as considering the opinions of our field experts, clients, and advisors. The first can be described as the hair clip design, which offers easy application. The second is a band with a reverse ratchet design, which offers the ability to adjust in size as the loon's leg grows. The third is a band that focuses on conforming to the shape of the loon's leg, called the bioinspired design. The fourth concept, which emerged after initial design brainstorming, is a hydrofoil inspired design whose main goal is to ensure energy efficiency. Our primary selection matrix, shown below in Table 3, compares each of the four designs to the existing commercial band primarily used in the field, using our primary functional requirements.

Table 3. Primary Selection Matrix Using Band Initial Criteria

Criteria	Weight	**Existing Band**	**Hair clip Design**	**Hydrofoil Design**	**Reverse Ratchet**	**Bioinspired Design**
Ease of application	4	0	1	0	0	0
Reasonable price	3	1	-1	0	-1	0
No damage/trauma	5	1	0	0	0	1
Energy efficiency	5	-1	0	1	-1	1
Low Chances of entanglement	5	0	0	0	0	1
Adjustability for application	4	0	0	0	1	1
Total		**3**	**1**	**5**	**-4**	**19**

The bioinspired design scored highest, checking boxes for convenient identification, minimal damage or trauma, energy efficiency, and adjustability during application. This design was followed by the hydrofoil design, which scored for convenient identification and very high energy efficiency. Third, the hair clip design gained points for convenient identification and ease of application but lost points for its potentially high price point. Finally, the reverse ratchet design trailed due to a potentially high price and low hydrodynamic and energetic efficiency while scoring for convenient identification and adjustability both for application and during loon leg growth. For design testing, our team chose to move forward with the bioinspired and hydrofoil designs as prototypes in order to obtain more testing information about these designs, such as drag forces in water. Based on the matrix, the bioinspired design was clearly the best option as our final design, but we tested it against the hydrofoil design to give a comparison between the best overall design and the most hydrodynamic and efficient design.

Chapter 5: Testing Methodology

To ensure the efficiency of our design, we ran different tests on our design. The fluid flow simulations were designed to compare the theoretical energy costs of each band and leg combination based on drag calculations, and the wind tunnel and water tunnel tests were meant to simulate real-life situations.

5.1 Solidworks Flow Simulations

Fluid flow simulations were performed on Solidworks to compare the hydrodynamics of each band's computer aided design (CAD). Each band was tested by itself as well as assembled onto a CAD modeled loon leg based on average leg measurements. In addition, several combinations of bands were tested to simulate real world conditions where a loon may have two of the same or two different bands on each leg. The following Table 4 represents all bands and band assemblies tested.

Table 4. Tested Bands and Band Assemblies

Single Items Tested	**Assemblies Tests**
Commercial band	Commercial band with leg
Federal band	Federal band with leg
Bioinspired band	Bioinspired band with leg
Hydrofoil band	Hydrofoil band with leg
Leg	2 commercial bands with leg
	2 bioinspired bands with leg
	1 commercial + 1 federal band with leg
	1 commercial + 1 bioinspired with leg

The flow simulations utilized the same basic parameters for each band test in order to provide accurate data for comparison. We used the Solidworks flow simulation wizard. SI units were predefined so that values would be defined in meters per second for velocity and Newtons for drag force. In the context of drag force calculation for loons (Equation 1), the fluid density refers to water density at a typical temperature and pressure for freshwater lakes and bodies of water (20 ℃ at 1 atm), which would be 998 kg/m^3. Flow velocity would be the maximum swimming speeds of Common Loons. The average loon's main body velocity is 0.86 m/s and leg speed may reach up to 1.06 m/s [1]. Reference area refers to an object's orthographic projection on the plane perpendicular to flow velocity [19]. The drag coefficient is based on an object's surface area and was computed through the simulations.

For flow type, we used the version of Equation 2 that uses kinematic viscosity to calculate the Reynolds number. Below shows the calculations for Reynolds numbers at both 0.86 m/s and 1.06 m/s. As in the equation for drag force, all parameters used were related to freshwater conditions at 20 ℃. The relevant length was set to 0.023 m, which was the average width of the loon legs. Water's kinematic viscosity was equal to 1.004 x 10^{-6} m^2/s.

$$Re = \frac{(0.86 m/s)(0.023 m)}{1.004 \times 10^{-6} m^2/s} = 19,700$$

$$Re = \frac{(1.06 m/s)(0.023 m)}{1.004 \times 10^{-6} m^2/s} = 24,300$$

Based on the Reynolds number threshold for external flow, it was safe to assume working with laminar flow conditions for the purpose of flow simulation.

For the simulation's water velocity, four values were used based on the average swimming speeds of a loon [1]. Velocity in the x-direction was set to +/- 0.86 m/s and +/- 1.06 m/s. For each velocity, a simulation was performed for all bands and assemblies. For an equation goal, we used the equation for drag force and changed the value of reference surface area for each band's orthographically projected area, as explained with Equation 1. Using these parameters, the simulation outputted values of drag force (in Newtons) and drag coefficient (unitless) for each band and assembly.

5.2 Water and Wind Tunnel Testing

We used water and wind tunnel testing to test out each of the bands in real world situations. CAD models for the loon leg, bioinspired band, and hydrofoil band were 3D printed using high resolution 3D printers available through WPI, and in addition we used a "good" commercial band from our client's supplied batch.

5.2.1 Water Tunnel Test

We used a water tunnel that generates water velocity of up to 5.0 inches/second. This translates to 0.127 m/s, which is not fast enough to simulate a loon's maximum swimming speed but realistically a loon's leg will hit velocities at all values in between the minimum and maximum velocities. Thus, we ran the water at its maximum velocity and attempted to create visualizations equivalent to our calculated flow conditions. The water tunnel can be seen below in Figure 36a.

At a lower velocity, the Reynolds number changed for water tunnel tests. Based on the equation for the Reynolds number, our calculation became the following:

$$Re = \frac{(0.127m/s)(0.023m)}{1.004\times10^{-6}\ m^2/s} = 2,910$$

This came out to a Reynolds number of 2910, which is laminar flow based on the threshold for external flow. In the water tunnel test, we also hoped to observe and prove that flow is in fact laminar.

5.2.2 Wind Tunnel Test

We were also given access to an industrial wind tunnel. The wind tunnel is usually used with larger objects in order to give accurate measurements, so we attempted to meet this requirement by printing bands on a 2x scale. The loon leg model, the bioinspired band, and the hydrofoil band were each doubled in all dimensions.

For testing, we needed to calculate wind velocities that would generate Reynolds numbers equivalent to those calculated for the water velocities of 0.86 m/s and 1.06 m/s. The input to the wind tunnel was frequency that corresponds to the output of airspeed in miles per hour. The following Table 5 shows the conversions for Reynolds numbers for wind velocity using kinematic viscosity of 1.516 x 10^{-5} m^2/s and doubled relevant length of 0.046 meters and the final frequencies used for the wind tunnel.

Table 5. Wind Tunnel Velocity and Frequency Conversions

Water Velocity (m/s)	0.86	1.06
Reynolds Number	19,700	24,300
Equiv. Wind Velocity (m/s)	6.49	8.00
Wind Velocity (mph)	14.5	17.9
Equiv. Wind Tunnel Frequency (Hz)	8.7	11

Thus, wind tunnel frequencies used were set to 8.7 and 11 Hz. The wind tunnel setup can be seen below in Figure 36b.

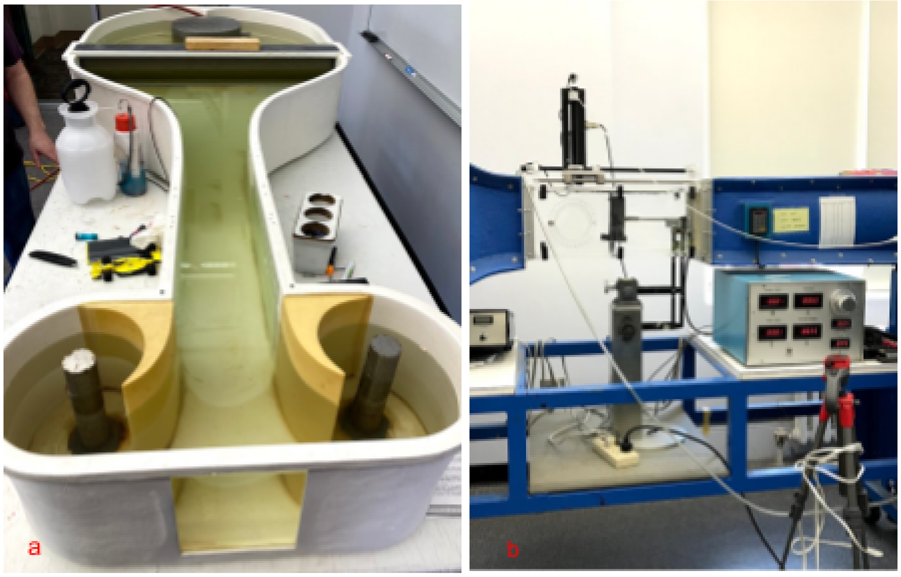


Figure 36. a) Water tunnel and b) wind tunnel with 2x scaled model

Chapter 6: Testing Results

This chapter shows the comprehensive testing results described by the previous chapter, which include the Solidworks flow simulations, water tunnel testing, and wind tunnel testing.

6.1 Solidworks Fluid Flow Simulations

As stated in the Methods section, the Solidworks flow simulations outputted a drag force and drag coefficient for test. For the purposes of comparison, the drag coefficient provides a more proportional value to each band and assembly's real world drag numbers. Therefore, the results reported focus mainly on each test's outputted drag coefficient.

6.1.1 Fluid Flow Simulations on Individual Bands and Assemblies

Table 6 reports each simulation at each of the four water velocities, as well as the average values for each band or assembly.

Table 6. Drag Coefficient Values for Select Bands/Assemblies

	Water Velocity (m/s)				
Band/Assembly	**0.86**	**-0.86**	**1.06**	**-1.06**	**Average**
Commercial band	0.047	0.041	0.047	0.041	0.044
Federal band	0.025	0.025	0.024	0.024	0.0245
Bioinspired band	0.031	0.029	0.031	0.024	0.0288
Hydrofoil band	0.028	0.049	0.027	0.049	0.0383
Leg	0.030	0.029	0.029	0.028	0.029
Commercial w/ leg	0.040	0.030	0.042	0.031	0.0358
Federal w/ leg	0.029	0.028	0.028	0.030	0.0288
Bioinspired w/ leg	0.028	0.027	0.027	0.025	0.0268
Hydrofoil w/ leg	0.023	0.029	0.021	0.029	0.0255

When comparing the band only simulations, the federal band model reported the lowest average drag coefficient of 0.0245. The commercial band had the highest value of 0.044. For the leg assemblies, the hydrofoil design reported the lowest average value of 0.0255, followed by the bioinspired design on the leg with 0.268, then the federal band on the leg with 0.0288, and finally the commercial band on the leg with a value of 0.0358. Since we were more interested in each band's effect when attached to the loon's leg, we graphed the values of the leg assemblies in the following two bar graphs (Figure 37&38), categorized by water velocity and direction (positive or negative x-direction).

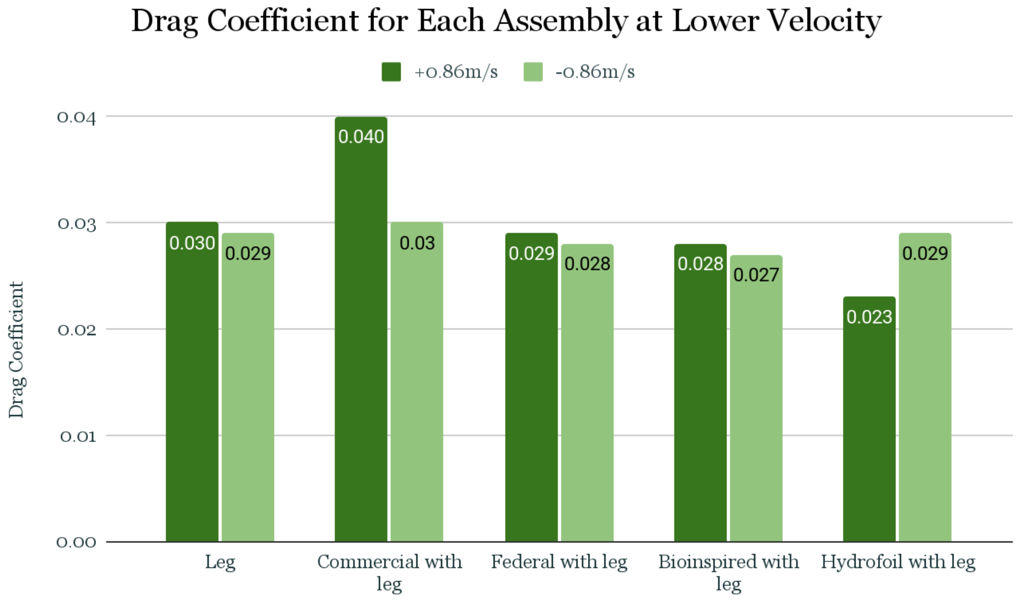


Figure 37. Drag coefficient for assemblies at +/- 0.86 m/s in the x direction

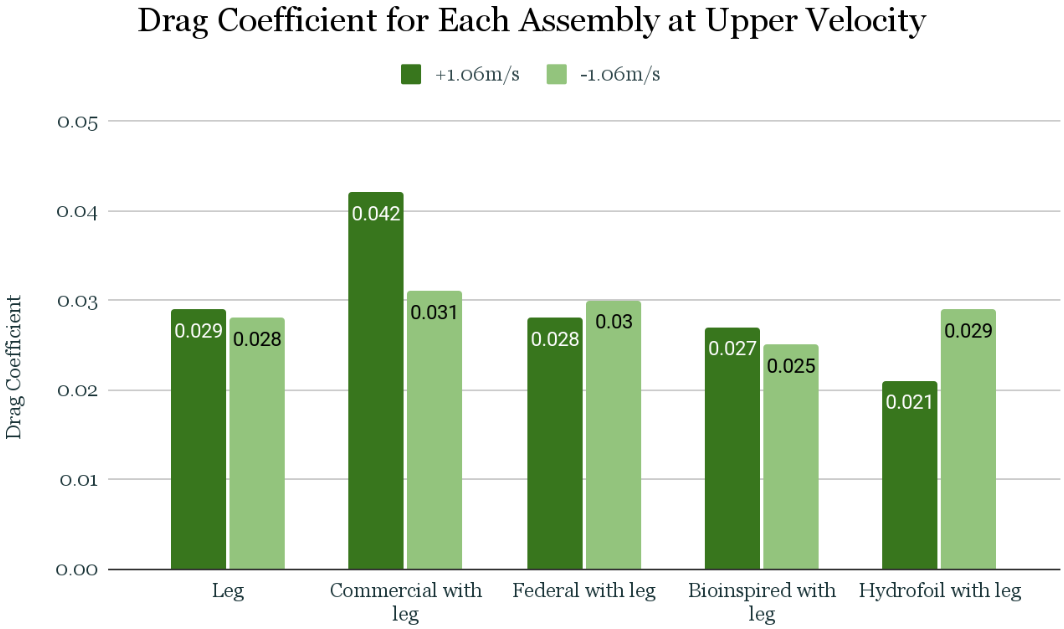
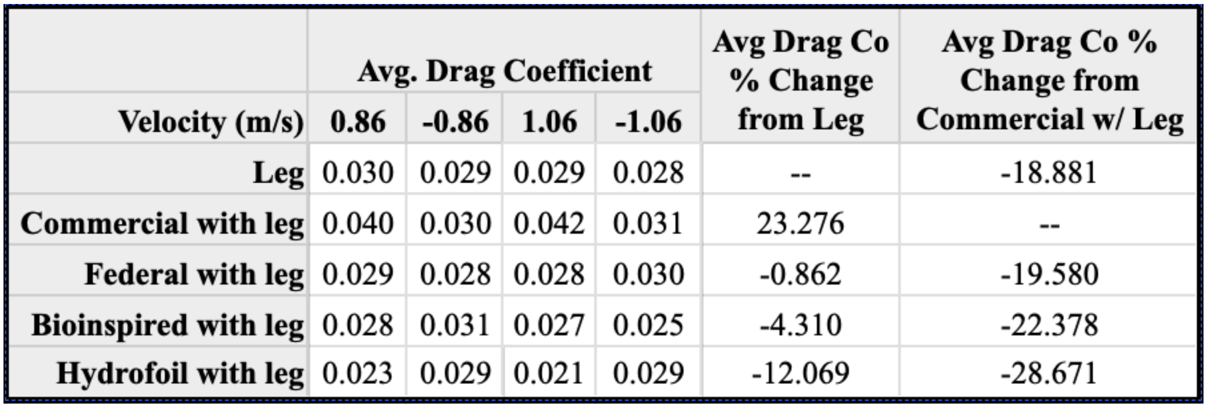


Figure 38. Drag coefficient for assemblies at +/- 1.06 m/s in the x direction

The lowest values in both graphs were the hydrofoil band with the leg, reporting values of 0.021 and 0.023.

Table 7. Measured Drag Coefficients and Percent Differences



	Avg. Drag Coefficient				**Avg Drag Co % Change from Leg**	**Avg Drag Co % Change from Commercial w/ Leg**
Velocity (m/s)	**0.86**	**-0.86**	**1.06**	**-1.06**		
Leg	0.030	0.029	0.029	0.028	--	-18.881
Commercial with leg	0.040	0.030	0.042	0.031	23.276	--
Federal with leg	0.029	0.028	0.028	0.030	-0.862	-19.580
Bioinspired with leg	0.028	0.031	0.027	0.025	-4.310	-22.378
Hydrofoil with leg	0.023	0.029	0.021	0.029	-12.069	-28.671

Based on the results, we calculated the average percentage differences of each test result compared with the results with the bare leg model and the assembly of one commercial band with leg model. The positive average percentage change means an increase in the drag coefficient, and a negative value means a decrease in drag coefficient. When compared to the leg model alone, Table 7 shows that the commercial band increased the drag coefficient by 23% whereas the bioinspired and hydrofoil bands decreased drag by 4% and 12%. When compared to the commercial band, our bioinspired band showed a 22% lower drag coefficient and our hydrofoil band showed a 28% lower drag coefficient.

6.1.2 Fluid Flow Simulations on Different Sized Bands

As an extension of Solidworks fluid simulation, we used this to optimize the drag coefficient. We tested the absolute drag coefficient of nine bands with different lengths and widths of the federal band. From this group of simulation, we found that the band with 30.7mm length and 10.6 mm width has the lowest overall absolute drag coefficient. Other than finding a good size for our design, this test group also has immediate benefits for loon study researchers. While our federal band is an idealized model that loon researchers are aiming for, we believe this test can provide them a quick reference. The full dataset can be found in Appendix F: Table 12.

In this evaluation, we used the federal band size as a 28.7mm length and a 10.6 mm width as our baseline, and adjusted its length and width by 1 mm each time to have a reasonable range of band sizes. This results with nine groups of data, with length varying from 27.7 mm to 31.7 mm and width varying from 9.7 mm to 13.6 mm. Among the groups of data, shown in Figure 39, the band with the lowest average drag coefficient is sized as 31.7mm-10.6mm. And the band with the highest drag coefficient is sized as 28.7mm-13.6mm. We can see a decreasing tendency of the absolute drag coefficient with the increasing of the band length with the same width as

10.6 mm. However, we cannot tell a clear tendency of drag coefficient with the change of width, since the 28.7-9.6 and 28.7-13.6 bands have similarly high drag coefficients.

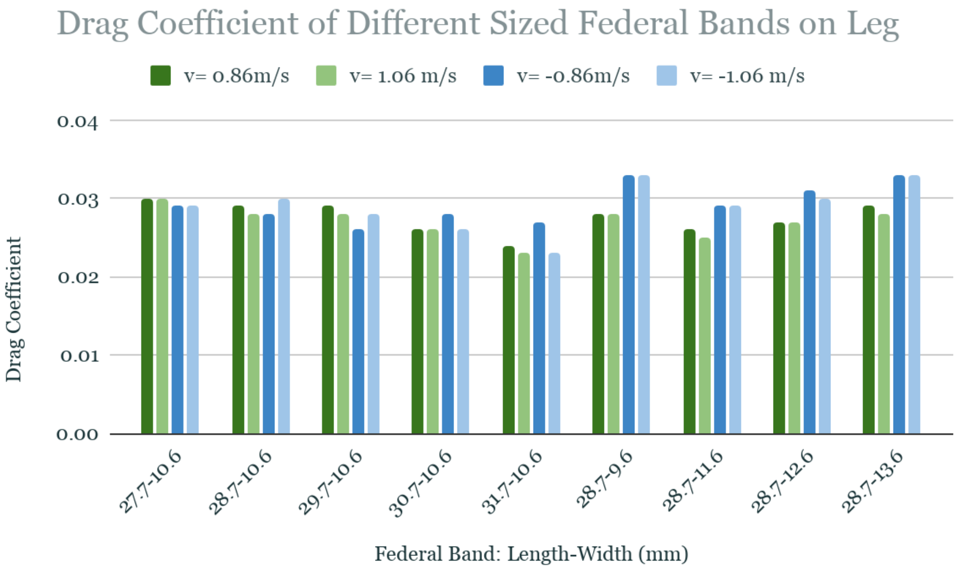


Figure 39. Absolute value of drag coefficients of different sized federal bands on leg

6.1.3 Fluid Flow Simulations on Combination Band Assemblies

In the field loon research process, researchers sometimes need to place four bands in total on loons. At the maximum, there could be two commercial bands or one commercial band and one federal band on one leg, making it two bands per leg. In this group of tests, we created a Solidworks assembly with each of these combinations, and also generated the same combinations but using the bioinspired band instead of the commercial band. These results can be seen in Figure 40. Any assembly containing our bioinspired band presented lower drag coefficients at all velocities. The assembly with two bioinspired bands on the leg had the lowest drag coefficient in the positive velocity direction, which is 0.027. The bioinspired federal band assembly gave the lowest drag coefficient in the negative velocity direction of 0.025.

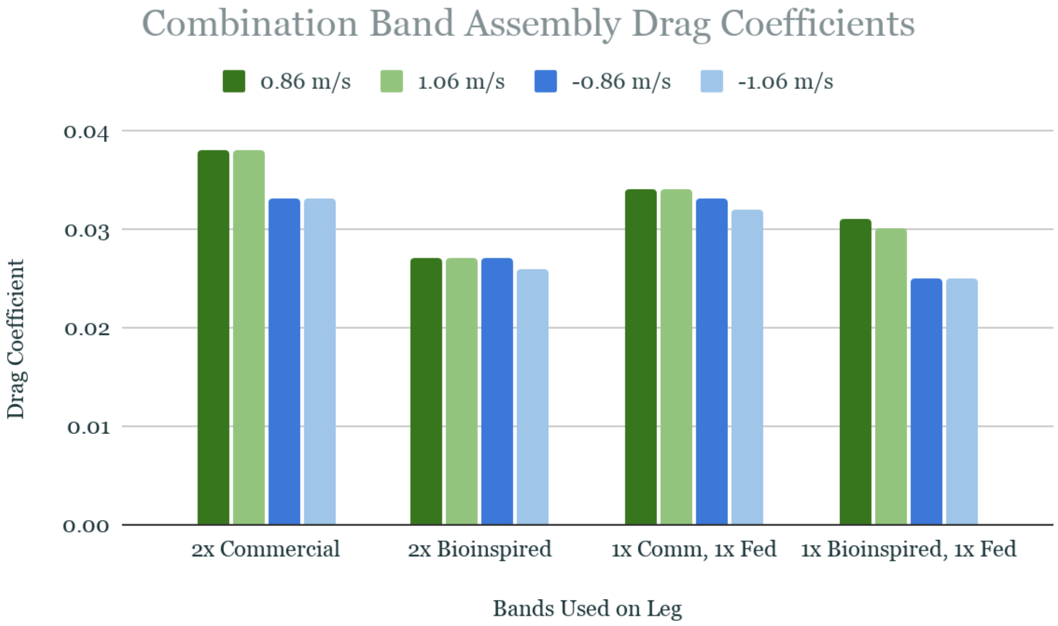


Figure 40. Absolute value of drag coefficients of combination band assemblies on leg

To compare the respective assemblies, we calculated percent differences. Between the two commercial and the two bioinspired bands, the percent difference was -24.6%. Between the commercial and bioinspired band each with a federal band, the percent difference was -16.5%.

6.2 Water and Wind Tunnels

Below describes the results from the water and wind tunnel testing methods. While we did not obtain quantitative results, we were able to make observations in each case.

6.2.1 Water Tunnel Results

To visualize water flow in the water tunnel, we were able to add a stream of dyed water to better observe the flow surrounding the leg and the band. The figure below shows the side view of water flowing past the leg and band from left to right.

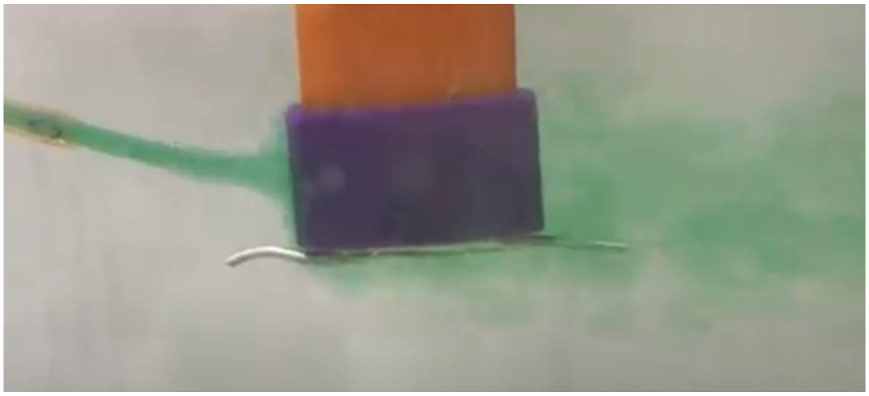


Figure 41. Side view of bioinspired band on leg in water tunnel

We were able to observe, especially with the hydrofoil design, that the dyed water parts in the front of the band is laminar water flows, as well as in the back where the dye smoothly merges back together, with gradually more dispersal as the flow leaves the system. Figure 42 below shows the top view of water flowing past the leg and band from top to bottom.

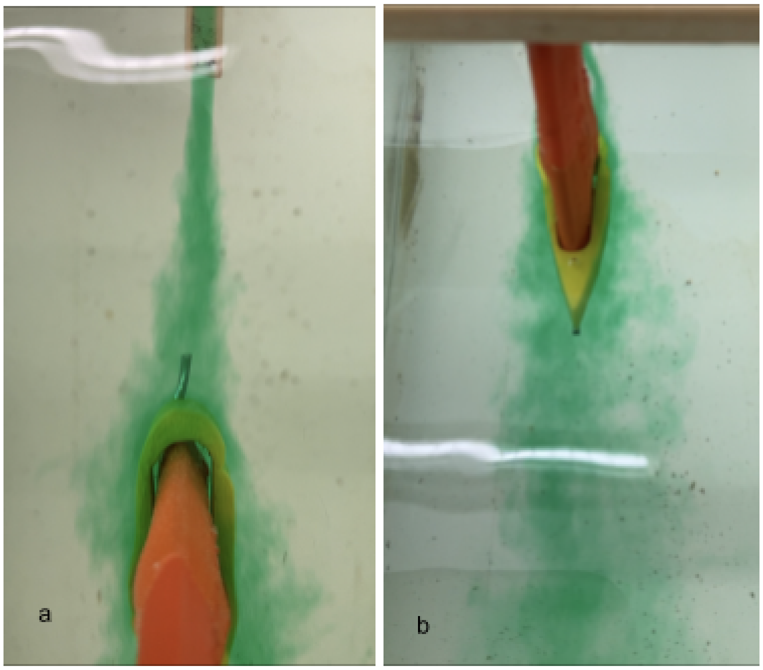


Figure 42. a) Top front and b) top back view of hydrofoil band on leg in water tunnel

Thus, the water tunnel testing allowed us to realistically compare the bands and properly visualize flow patterns in external, laminar flow. Based on observation, it seemed that the leg by itself created the smoothest flow patterns, followed by the hydrofoil band which had the smoothest flow patterns of the bands, then the bioinspired band and the commercial band with similarly smooth flow patterns. We were unable to quantify or validate these comparisons except by comparing videos taken of each band side by side.

6.2.2 Wind Tunnel Results

The wind tunnel was run at the frequencies calculated in the methods. The expected results would be axial force measured by the wind tunnel sensors which we would be able to translate to drag force for each test. However, the 2x scaled leg and bands were still not large enough or different enough to output accurate measurements. In addition, we encountered calibration issues with the wind tunnel sensors when trying to zero the forces. Visually, we were unable to glean any results because we could not add anything to the air flowing past the band like we did with the water tunnel. If we were to repeat this test, we would try using a smaller wind tunnel, more sensitive sensors and instruments, or larger bands. However, our main concern throughout this project was the hydrodynamics of the band so we do not prioritize wind tunnel testing. Even so, we were able to understand how a wind tunnel works if needed in future research.

Chapter 7: Final Design and Validation

Based on the evaluations in Chapter 6, we decided that the design of the bioinspired leg band will be our final design due to its outstanding performance and overall superior characteristics. It gives better hydrodynamic efficiency than the existing commercial band, low risk of entanglement due to its low profile nature, and theoretical adjustability during band application.

When comparing the commercial, bioinspired and hydrofoil bands, we found various significant results. Both the bioinspired band and hydrofoil band reported drag coefficients well below those of the commercial band. Between the bioinspired and hydrofoil bands, the bioinspired always had higher drag than the hydrofoil in the positive direction, but lower drag than the hydrofoil in the negative direction. For the hydrofoil band the results followed our expectations, that the drag coefficient in the positive x-direction was lower than that in the negative x-direction. This makes sense because the hydrofoil is optimized only for forward movement (rounded edge leading) and should not perform as well when moving backward (pointed edge leading). For this reason, as well as the looser fit and higher entanglement risk of the hydrofoil band, we chose the bioinspired band as the most appropriate solution. Although as shown by the hydrofoil, there is potential for improving the drag coefficient of the bioinspired design by making tweaks to its hydrodynamic shape.

7.1 Economics and Manufacturing

The market for loon banding is quite small. According to field experts, the number of loons banded per year can vary from about 200 to 500 birds. However, since there are so few loons banded per year, then it makes a difference if even a single loon is hurt or dies due to bulky bands on their legs, thus further magnifying the importance of our project. But while appropriate size and shape bands are needed, it is necessary to take into account pricing in order to validate manufacturing a new design. Field experts typically buy existing commercial bands at about $4 per band. For our design, it is reasonable that a more specialized band justifies a higher price, but we still aim to keep a relatively low price.

One price factor is the type of material used. The plastic currently being used is polylactic acid (PLA) because it offers a decent balance of rigidity and flexibility, where flexibility is necessary for initial application and rigidity is important for band longevity for the loon in the wild. This is our main option for material, especially because it offers competitive pricing to existing bands. A second price factor is the mold for creating bands. We would pursue injection molding for the manufacturing of our bands, which is more accurate and more efficient than 3D printing for larger batches. This on top of operational costs will likely increase the cost of producing our bands. We hope to target the price range of $8-10 per band. This would become more manageable if we reach mass production, which would drastically reduce the price per band.

7.2 Environmental Impact and Sustainability

The goal of our project is to help loons live at a higher quality of life and wellbeing. Although it is untested, existing bands are bulky so have a probability of negatively impacting a loon's lifestyle. We hope that tracking loons using our bands will minimize this impact. Bird populations are often indicative of the health of, or changes in their habitats, ecosystems, and the environment as a whole. Species that are used to monitor changes in their environment are better known as indicator species. On top of that, loons are very sensitive to human disturbance. Therefore, if we make sure to avoid impacting their lifestyle by using the best possible tracking bands, then we can use their individual identification as indication of human environmental impact as well as the overall health of freshwater lakes and ponds and the coastlines that loons inhabit.

If manufacturing our bands becomes more long-term, we would consider adding to or changing the plastic. Many plastic manufacturers and companies are introducing a percentage of ocean plastic into their production. Ocean plastics are available through several companies who offer different types of plastics, which are collected from the ocean, melted, and sold as pellets. This would be in line with our goals for loon conservation by decreasing plastic waste hazards in their habitat, as well as moving closer to our implicit sustainability goals. Since ocean plastic does not have the highest structural strength, we could mix it with a durable, non-biodegradable bioplastic. Bioplastics are made from renewable resources or they are biodegradable. We would use the former option since we want our bands to last as close as possible to the lifespan of a loon. The right proportion of ocean plastic to bioplastic should offer high structural strength and flexibility while still meeting our long-lasting target.

7.3 Influence on Loon Studies

There have been no previous studies on the impacts of leg bands on loons. The results from this project are a step forward in understanding the effects of leg bands on swimming and diving. The drag coefficient values show that there is an impact on the loons from leg bands, and shows that there should be further research done on the impacts that leg bands have on birds. Our bioinspired band has a lower drag coefficient than the commercial band, which decreases the impact from the bands.

Researchers have to shape federal and commercial bands in the field to make sure that they fit the loon's leg properly, and occasionally get bands in shapes that they can not use. The bioinspired band makes it easier for the researchers to apply the bands to the loons in the field. This design decreases the time that the researcher will need to spend handling each loon while banding.

7.4 Ethical Concerns

The topic of animal identification naturally raises many ethical concerns for wild animal welfare. Keeping the safety and avoiding lowering the survival rate of animals are the most significant ones. As listed in our primary needs, our leg band design is following the aim of protecting the loons' safety and survival. From our interviews with loon field researchers, we learned that loons can be entangled in fishnets or other nets, which can sometimes be fatal. To limit the entanglements caused by bird bands, our final design has no sharp edges or loose openings. After the researchers band the loons and glue the opening flaps of our design together, our design has a smooth surface to eliminate the entanglements.

Besides avoiding entanglements, our design also limits the dynamic impacts on loons. Maneuvering speed and capability is essential for wild loon survival. As we evaluated in previous chapters, our design has the smallest drag coefficient, which means the smallest impact on loon speed in the water.

Chapter 8: Discussion

The Solidworks flow simulation testing provided us with ample information on the potential effects of each band while on a loon's leg. It seemed logical that the commercial band on the leg resulted in a higher drag coefficient than just the loon leg itself, and we found it interesting that the rest of the bands attached to the leg resulted in a lower drag coefficient than just the leg by itself. It is possible that the federal band, bioinspired band, and hydrofoil band all add a more hydrodynamic shape to the part of the loon leg that it was attached to. However, increasing the hydrodynamic performance for loons by adding bands is unlikely going to happen in real-life situations. Due to the band's weight added to loons and the inconvenience for loons, it is reasonable to say it can hardly increase the loon's speed in nature. This case indicates that our fluid simulation has some imperfect predictions.

Referring back to Table 7 to the individual band tests, the federal band reported the lowest average drag coefficient. However, the CAD model of the federal band may have a more optimized shape than it would be in the field. A modified federal band in the field would have large imperfections and indentations for the identification number, but our CAD model was unable to account for those. Furthermore, modifying the federal band while in the field would result in a very unpredictable and inconsistent shape. Therefore, a federal band out in the field would likely have a higher drag coefficient and drag force. We ignored federal band results for this reason as well as the fact that our new designs are meant to replace the plastic commercial bands, not the federal bands, which are still required for federal identification.

Both the bioinspired and hydrofoil bands made significant drag improvements over the commercial band, showing a decrease of about 22% and 28%, respectively. This evaluation proves that both of our designs can effectively lower the drag coefficient of existing bands. We also saw that both of our bands made drag improvements when compared to the leg model alone. This is likely due to the optimized shape of the bioinspired and hydrofoil bands, but we would only see this drag improvement in simulation. It is unlikely that adding any device to a loon's leg in real life would positively impact their swimming ability. Nonetheless, this shows that the shape of our band can effectively match the loon's own level of capability, and will thus lower the impact on the loon's physical fitness and total energy costs.

For the combinations of different bands, we again saw drag improvements. Between the two commercial and the two bioinspired bands, the percent difference was -24.6% which showed that two bioinspired bands will effectively decrease the drag coefficient when compared to two commercial bands. Between the commercial and bioinspired band each with a federal band, the percent difference was -16.5% which showed that the bioinspired band paired with the federal band will effectively decrease the drag coefficient when compared to the commercial band paired with the federal band. While we did not test the hydrofoil band in the combinations, it is likely that it would further reduce the drag coefficient, telling us that it is possible to make enhancements to our bioinspired final design. The best design would be the right balance of the hydrofoil design's efficient shape and the bioinspired design's closely fitted loon leg shape.

8.1 Engineering Standards

With respect to bird and loon banding, there are very few official engineering standards to follow when researching and designing a loon band. We found generally engineering guidelines to follow. These include the following, many of which come from the North American Banding Council [39]:

1. Selecting a band size should be governed by the size of a bird's leg
2. The total weight of bands should not exceed 2% of the bird's body weight [40]
3. 2 metal bands should never be used on the same leg
4. Colors, color combinations, and on which leg used should be recorded
5. Banders must be familiar with the data needing to be collected
6. Birds should be released unbanded if they have waited to be banded for over an hour

While these guidelines are important to follow during the banding process, none really apply to the design of an improved leg band for loons, except for the weight. With this in mind, we saw an opportunity to establish some of our own engineering standards that could be adopted or referred to in future banding research or development projects. Our standards were developed based on performance specifications discussed in the Project Specifications section, which emerged through various conversations with our loon banding clients/field experts. The following represents our engineering standard recommendations:

1. Band material and design should allow it to theoretically last for upwards of 20 years when used on a loon in the wild
2. Application time (amount of time that the bander is in contact with the bird for band application) should be at a maximum of 15 minutes
3. The cross-sectional fill ratio (cross-sectional area of loon leg divided by inner cross-sectional area of the band used) should be greater than or equal to 80%
4. The theoretical impact of the band on the total system drag coefficient, should be less than 10%

If these standards are used in future studies, Standard 1 could use existing information to choose the right material, but a long-lasting design would require long-term testing. Standard 2 would also require long-term testing so we are not able to verify these for our study. Standard 3 values can be approximated using *in vitro* models, but *in vivo* situations would be unpredictable and should be estimated and evaluated in a logical manner. Standard 4 can be achieved without real-life or long-term testing, so any study that carried a similar format to this study would be able to meet this standard using fluid flow simulations.

8.2 Future Research

Future work and research related to this project might include several aspects related to the design, materials, and research of loon banding. First, we would switch the manufacturing materials to an ocean or bio-based plastic. Typical ratios of ocean plastic might include 10% ocean plastic mixed with 90% bioplastic or post-consumer recycled (PCR) plastic. This ratio would be able to keep structural integrity since ocean plastic can sometimes have lower mechanical strength. To define these terms, ocean plastic means plastic that has been recovered from the ocean and turned into plastic pellets. Bioplastic means a plastic that was generated from bio-based materials instead of petroleum, such as cellulose, corn, or avocado pits. This would be in line with our goals for loon conservation as well as overall sustainability.

Next, we would pursue long-term loon testing with bands. This would allow us to collect more significant data about whether bands affect loon survival or fitness and whether better fitting bands really decrease this effect compared to existing worse fitting bands. A future experiment would include using our bands on a small sample of loons, then monitoring these loons along with a sample of loons that are banded with existing commercial bands. In such an experiment, much more thought would need to be put into the details and logistics of the study because the ultimate goal is to prevent bands from causing injury or mortality, so if anything threatened loon survival then the study would need to be stopped or changed.

Finally, we would attempt to look into expanding our research to other birds and wildlife. Many species are monitored by tracking bands or devices, but there have been very few recent engineering advancements in wildlife banding. Using the structure of this study as a template, we would be able to offer our research and data toward the banding industry as a whole, and potentially generate catered solutions for other animals who may benefit from more attention to detail with regard to tracking and identification. This might include other birds and waterbirds, as well as larger animals such as bears and wolves.

Chapter 9: Conclusion

The Common Loon's leg anatomy and the loon's method of swimming make it difficult to use the standard leg bands that are commonly used in the field. Researchers and field experts who study the Common Loon and loon banding understand this. We had the privilege of working with some of these experts in the field who have experience banding birds and working closely with loons. To assist them, we developed our improved, bioinspired band, tested against our other hydrofoil band. Our bioinspired and hydrofoil band designs both showed lower drag coefficients when attached to a model loon leg as compared to a model of the existing commercial band, and the bioinspired band also lowered the drag coefficient when used as a pair with itself and with the federal band model. While these are only simulations and we do not have the ability to quantify physical energy costs on loons in real life, it is possible to extrapolate that our designs could translate to lower drag and energy costs for loons when swimming and diving and allow loons to enjoy higher fitness, higher quality of life, and potentially higher chance of survival out in the wild.

Our band design can provide significantly lower drag coefficients and drag forces, but as our project focused on hydrodynamic performance, another important step would be material improvement. The right material offering sustainability, biocompatibility, and long term durability would offer immense benefits to improving leg bands for the Common Loon and even to improving the wildlife banding industry as a whole. Using different percentages of plastic or other material and performing mechanical and degradation tests, future research could provide a long-lasting, sustainable material to match the up to 30 year long lifespan of the Common Loon.

Appendix

Appendix A: Budget Report

Item	Cost/Item	Quantity	Total Cost	Link
Rolyan Splinting Material Sheet	$18.48	1	$18.48	Source
Goody Women's Classics Assorted Sizes Claw Clip, 8 Count	$6.88	1	$6.88	Source
BME Department 3D Band Prints	$0.50	15	$7.50	
BME Department 3D Band 2x Scale Prints	$2.00	4	$8.00	
Rapid Prototyping Lab 3D Prints	$0.74	3	$2.22	
		Total	$43.08	

Appendix B: Initial Inventory

Before we began measurements or tests, we initialized an inventory to account for all materials received from our client and from the Tufts Cummings School laboratory. We received a packet of leg bands and a package of loon legs from our client. We received a package of loon legs from the Tufts lab. From these we laid out our working materials as shown in Table 8 using the individually grouped bags within each package. All labels provided on the bags and the bands themselves are recorded. If a band did not have a label, “N/A” designation was used.

Table 8. Band inventory

Group, Group Label	**Band Description, Band Label**
Shaped plastic color bands, GOOD	Blue, 24.0 White, 28.4 Orange, 25.5 Red, 25.5 Red, 25.6

Shaped plastic color bands, BAD	Blue, 23.3/23.5 White, 23.6 Orange, N/A Yellow, N/A Black/White Stripe, N/A
Unshaped plastic color bands	3x Green 3x White 3x Orange 2x Red
Federal metal band, size 8, 27 mm	1238-08064, www.reportband.gov
Federal metal band, size 8A, 27 mm	1278-51024, www.reportband.gov

Figure 43. Side and top view of plastic colored bands deemed “BAD”

Figure 44. Side and top view of plastic colored bands deemed “GOOD”

x

Figure 45. Side and top view of the federal leg bands, with (bottom row) and without (top row) manual modification to fit loon legs

After taking band inventory, we organized the loon legs. In each of the packages, individual bags contained two loon legs (left and right). Each individual bag came labeled except for several bags, which we labeled in accordance with the patterns observed with the existing labels. The following table reports all loon legs received and their labels.

Table 9. Loon Leg Inventory

Description	**Value**
# individual bags (2 legs/bag)	18
# loon legs	36
Individual bag labels	TV200058 TV200059 TV200060 TV200061 TV200062 TV200063 TV200064 TV200065 TV200066 TV200067 TV200068 TV200069 TV200070 TV200086 TV200087 TV200088 TV180084 TV1800004

Figure 46. Pair of frozen loon legs

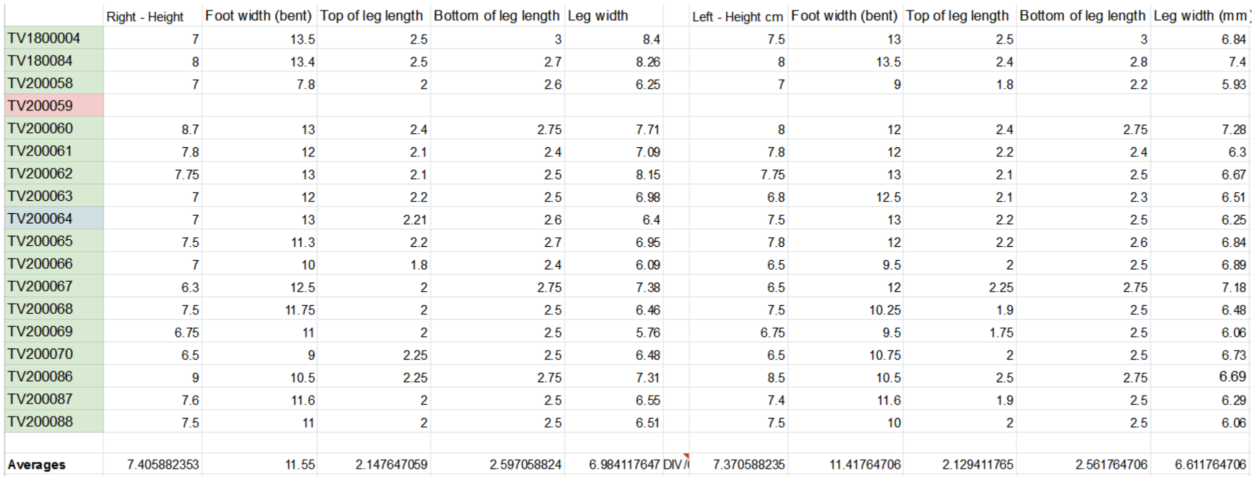
Appendix C: Loon Leg and Leg Band Measurements

After taking stock of our assets, we then moved on to specific measurements for both the loon legs and the leg bands. This was important in order to analyze the existing solutions as well as to gauge the level of compatibility between these solutions and the specimens given to us.

Loon Leg Measurements

During preliminary observations of the loon leg samples, we took pictures of several legs to document their structure and size. We then proceeded to take various measurements, including height of leg from upper joint to lower joint, length of leg (dorsal to ventral), and width (medial to lateral). Table 10 shows the measurements of each loon leg.

Table 10. Specified Loon Leg Measurements



	Right - Height	Foot width (bent)	Top of leg length	Bottom of leg length	Leg width		Left - Height cm	Foot width (bent)	Top of leg length	Bottom of leg length	Leg width (mm
TV1800004	7	13.5	2.5	3	8.4		7.5	13	2.5	3	6.84
TV180084	8	13.4	2.5	2.7	8.26		8	13.5	2.4	2.8	7.4
TV200058	7	7.8	2	2.6	6.25		7	9	1.8	2.2	5.93
TV200059											
TV200060	8.7	13	2.4	2.75	7.71		8	12	2.4	2.75	7.28
TV200061	7.8	12	2.1	2.4	7.09		7.8	12	2.2	2.4	6.3
TV200062	7.75	13	2.1	2.5	8.15		7.75	13	2.1	2.5	6.67
TV200063	7	12	2.2	2.5	6.98		6.8	12.5	2.1	2.3	6.51
TV200064	7	13	2.21	2.6	6.4		7.5	13	2.2	2.5	6.25
TV200065	7.5	11.3	2.2	2.7	6.95		7.8	12	2.2	2.6	6.84
TV200066	7	10	1.8	2.4	6.09		6.5	9.5	2	2.5	6.89
TV200067	6.3	12.5	2	2.75	7.38		6.5	12	2.25	2.75	7.18
TV200068	7.5	11.75	2	2.5	6.46		7.5	10.25	1.9	2.5	6.48
TV200069	6.75	11	2	2.5	5.76		6.75	9.5	1.75	2.5	6.06
TV200070	6.5	9	2.25	2.5	6.48		6.5	10.75	2	2.5	6.73
TV200086	9	10.5	2.25	2.75	7.31		8.5	10.5	2.5	2.75	6.69
TV200087	7.6	11.6	2	2.5	6.55		7.4	11.6	1.9	2.5	6.29
TV200088	7.5	11	2	2.5	6.51		7.5	10	2	2.5	6.06
Averages	7.405882353	11.55	2.147647059	2.597058824	6.984117647	DIV/(	7.370588235	11.41764706	2.129411765	2.561764706	6.611764706

Leg Band Measurements

Next, we measured the leg bands that we were given, both shaped and unshaped. This gave us a sense of the shape and size of the bands carried around by researchers in the field. Normally, they carry several varying pre-shaped sizes with them so that they can simply choose the best fitting band for each bird. Pictures of the bands were taken and uploaded into ImageJ software to collect these measurements. An example of how measurements were collected can be seen below in Figure 48. The collected data can be seen in Figure 49.

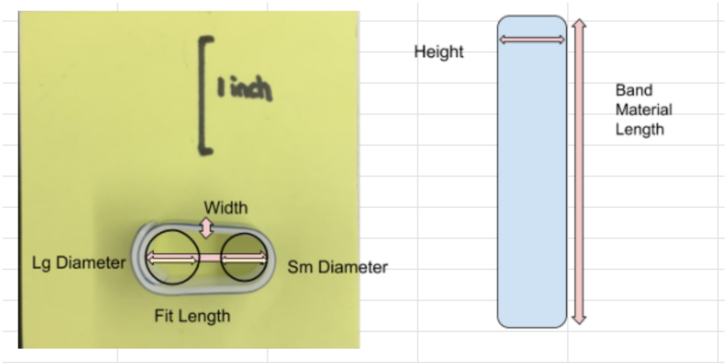


Figure 47. Sample ImageJ measurements

Table 11. ImageJ Current Band Measurements

Federal Band Averages	
Band Material Length	73.0 mm
Fit Length	19.6 mm
Width	1.6 mm
Height	15.9 mm
"Good" Commercial Band Averages	
Band Material Length	103 mm
Fit Length	28.7 mm
Width	1.55 mm
Height	18.6 mm
Lg Diameter	12.0 mm
Sm Diameter	10.6 mm
"Bad" Commercial Band Averages	
Band Material Length	98.1 mm
Fit Length	27.7 mm
Width	1.53 mm
Height	19.1 mm
Lg Diameter	12.4 mm
Sm Diameter	10.9 mm

Appendix D: Intellectual Property

In order to claim rights to our final design as WPI students, we will be looking into applying for a patent. A patent allows us to obtain property rights in relation to an invention or design. It is a limited duration declaration given by the United States Patent and Trademark Office disclosing the owner(s) of the invention to the public, and it usually lasts 15 years [41]. Before thinking about a patent, we asked ourselves several initial questions. The first question was whether our design is patentable. We determined this to be affirmative for several reasons. First, according to the USPTO, any article of manufacture can be patented which is novel, not obvious, and clearly defined in specific terms by the inventor. Our leg band design meets those criteria. Second, the invention cannot be patented if it is already publicly disclosed in a patent. Using the Seven-Step Strategy laid out by the USPTO, we compared the details of our invention to existing patents with components or ideas closest to our invention. After confirming the validity of getting a patent for our invention, we then made the distinction of a design patent, rather than a utility or plant patent.

There are several written parts in a patent used generally for most inventors, including a title, images, abstract, classifications, description, claims, and citations. As we begin the patent application process, we will be considering these sections closely. It is important for us to have a title that most closely matches the idea and application of our invention, so that the public as well as inventors in the future can easily find information about our invention using keywords. The images section is not always used, but we will benefit from using images to clearly show our design, both as a distinct device and as individual parts. The abstract will include a broader explanation of the device, stating its main design components and most important details about its structure and function. For our leg band, this will include information about the shape and size of the band, use for loons, spring and ratchet components, method of applying the band to the loon's leg, and material composition. The classifications include some preset categories in regard to the use and function of the invention, and make the invention more discoverable by general categorization. A likely classification for our invention is A01K35/00 which specifies "Marking poultry or other birds", among other details related to banding. This is also a convenient classification for us to use to search for similar patents. The description provides the reader with all collective information about the invention including background, prior art, need, and existing patent references. The claims section, if utilized, provides a more succinct list of design components, listing the specific ideas and stipulations that make the invention different and unique.

Using the classification mentioned in the previous paragraph as well as keywords and phrases, we attempted to find any existing patents for devices or design similar to our device. Our search returned several bird band designs for different types of birds, although many have expired. These included "Binding band for bird band and bird band structure" [42], "Self-locking leg-band for poultry or birds" [43], and "Identifying band for birds" [44]. Each of these patents hold loose similarities to our invention, but none capture more than a little of the novelty and creativity associated with our design, further proving our ability to create a patent. It may be useful for us to cite some of these patents or similar ones in our own patent, in order to give credit to any ideas produced by them, assuming our design overlaps with certain ideas given by them.

Appendix E: Glue Test

We were provided Gravo-bond glue, which is the glue used by experts in the field to hold the bands together. Since this is a material that experts already use, we experimented with the use of the glue on several of the commercial bands we were sent as well as some experimental thermoset plastic. We copied the typical procedure that might be performed in the field, which was to open the band, place it on the loon leg, apply a small amount of glue to the overlapping flap region, and then realign the flaps so that the glue would dry and seal them together.

Figure 48. Picture of a bottle of Gravo-bond glue

Appendix F: Different Sized Federal Bands Full Dataset

Table 12. Drag Force and Coefficient of Different Sized Federal Bands with Leg

Simulation results of different sized Federal band with Leg at different velocity									
		v= 0.86m/s		v = -0.86m/s		v= 1.06 m/s		v = -1.06 m/s	
Width (mm)	Length (mm)	Avg. Drag Force (N)	Avg. Drag Co	Avg. Drag Force (N)	Avg. Drag Co	Avg. Drag Force (N)	Avg. Drag Co	Avg. Drag Force (N)	Avg. Drag Co
10.6	27.7	0.08	0.03	-0.077	-0.029	0.121	0.03	-0.117	-0.029
10.6	28.7	0.077	0.029	-0.073	-0.028	0.113	0.028	-0.122	-0.03
10.6	29.7	0.078	0.029	-0.071	-0.026	0.115	0.028	0.115	0.028
10.6	30.7	0.073	0.026	-0.076	-0.028	0.107	0.026	0.107	0.026
10.6	31.7	0.067	0.024	-0.075	-0.027	0.098	0.023	0.098	0.023
9.6	28.7	0.078	0.028	-0.091	-0.033	0.115	0.028	-0.136	-0.033
10.6	28.7	0.077	0.029	-0.073	-0.028	0.113	0.028	-0.122	-0.03
11.6	28.7	0.071	0.026	-0.079	-0.029	0.104	0.025	-0.119	-0.029
12.6	28.7	0.075	0.027	-0.084	-0.031	0.112	0.027	-0.125	-0.03
13.6	28.7	0.079	0.029	-0.091	-0.033	0.117	0.028	-0.136	-0.033

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