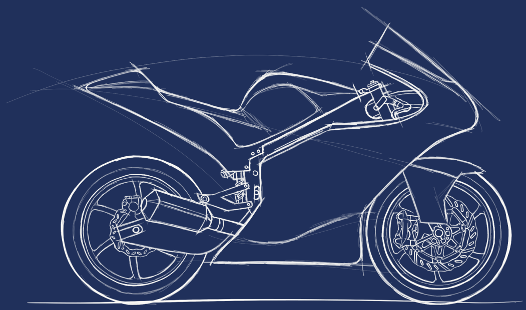

Building Collaboration Awereness

Designing an interdisciplinary collaboration method with the help of a motorcycle prototype

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Abstract

Design is a young discipline that focuses its strength on reaching out to more structured fields to enhance the project outcome. Such ability is taught to design students through constructive learning practices implemented in study courses. However, not all fields share such flexibility.

The research focuses on applying a constructive approach in a university context that lacks a guiding figure to facilitate interdisciplinary communication. Precisely, the thesis analyses the social role of objects in a design process to leverage communication between students from different cultural backgrounds and fields of knowledge. Such objects are used to establish abstract communication channels via a material infrastructure to improve brainstorming in the design and development of two racing motorcycles.

The study highlights how students implement their competencies to enhance project goals promoting collaboration awareness between workgroups and designing related components. The goal is to understand how objects' roles influence communication and subject-to-subject relationships to develop more integrated project solutions.

Moreover, the thesis is structured in four parts, going from the macroscopic context surrounding the team to the focus on developing the fairing set. Finally, such a component is used as a case study to demonstrate the application of a new methodology to implement integrated solutions to a non-critical component highly related to the prototype's most critical elements.

Summary

Thesis introduction

Politecnico di Milano's approach includes the constructive learning method through group projects guided by a teacher. Knowledge and competencies are enhanced through solving problems by setting goals shared by the whole workgroup and the teacher. Such a method implies the learners are active participants in the learning process, collaborating to achieve shared goals. In such a process, the teacher represents a guiding figure for the workgroups regarding knowledge and competency acquisition. However, there is an extracurricular project inside the university where students gather to design and manufacture two racing motorcycles.

They unknowingly apply a constructive approach lacking a guiding figure constantly present. In such a context, students acquire technical knowledge and personal competencies by designing a high-complexity project with high hazards. Because of such complexity, previously developed knowledge and present communication must be effectively transmitted. Since students are still building their competencies, they support their interaction by using material objects representing the prototypes as an infrastructure to support complex interactions inside an interdisciplinary and cultural plural workgroup.

Given such an opportunity, this thesis focuses on the relationship between components and how they reflect subject-to-subject relationships to make explicit the use of material infrastructure as boundary objects to increase collaboration awareness between workgroups developing dependent prototype elements. The research question has been articulated in two different remarks:

. How can component-to-component and component-to-time relationships help identify collaboration touchpoints between workgroups developing related components of a high-complexity prototype?

. Starting from the collaboration touchpoints, how can a structured method of defining shared objectives and constraints leverage the collaboration between workgroups developing related components?

A new meeting protocol was developed to build maps that made explicit the dependencies between components to construct the net of relationships between workgroups. Making explicit components' interconnections means using the same material infrastructure the team uses to avoid introducing complications to an already saturated context. The protocol applies a guide list during brainstorming and aims to leverage shared and contrasting goals of related components to achieve a better integrated overall result. Furthermore, such a protocol has been applied to a specific case study, the design and development of the fairing set for the petrol prototype, to retrieve data exploiting the material infrastructure regarding designing outcomes. Such a set shows criticalities regarding dependencies because it interacts with many different elements at different development stages. For example, the fairing set requires most of the inner structure set and ready-for-production to achieve good-enough aerodynamic optimization, which means that most elements of the bike come into touch with the fairing design process at a certain point of their development. Moreover, the fairing set design and optimization were assigned to a workgroup where I was an active participant both as a designer and a knowledge facilitator. I worked specifically on the petrol fairing and guided the students in developing the electric fairing.

Finally, this thesis is divided into five parts representing different stages of the research and design process. Each of these parts is divided into chapters, sections and subsections by thematic content from abstract macroscopic concepts to concrete methodology and project application.

Part 1 encompasses the context surrounding the Polimi Motorcycle Factory team and how it approaches the prototype design internal organizational structure. Moreover, the part focuses on the prototype's social role in building the team's material culture.

Part 2 highlights the criticalities regarding the excessive power granted to the prototypes and how it affects subject-to-subject relationships based on the collaborative design process—the part ends with the research questions.

Consequently, Part 3 describes the methodology implemented in designing and optimizing the fairing sets to increase interdepartmental collaboration awareness. At the end of the part, the protocol outcome can be found regarding opportunities, requirements and constraints applicable to the design process. Hence, the last chapter describes such a process, focusing on how brainstorming has affected the fairing morphology.

Finally, Part 4 summarizes the conclusions regarding the method outcome and the consequent optimization outcome in the final general discussion. Moreover, it includes limitations found during the thesis and possible future developments.

Glossary

Word	Definition
Parent components	Components on which the designed part depends on
Children components	Elements depending on the designed component
Dependent components	Components related to each other
Fairings set	All parts composing the motorcycle's aerodynamic shell, such as the upper fairing, the sides, and the lower fairing
Upper fairing tip	The most prominent area of the upper part of the fairing usually corresponds with the region with higher pressure
Frontal side edge	The fairing side edge, pointing towards the incoming airflow
Appendices	Aerodynamic devices mounted on the fairing of the rear chassis can be passive or active
Flow separation	Detachment of a boundary layer from the surface of a blunt body into a wake
Wake	The region of recirculating flow immediately behind a blunt body
Slipstream	Is the region behind a body where the wake is
Airflow	Is the fluid surrounding the object and impacting it at a given velocity
Straight	The most extended straight section of a track
Corner	Corners of the trach covering less than 180 degrees of a circumference

Part 1:
Context

Chapter 1
Introduction to the context and role of the prototype

The Polimi Motorcycle Factory team are part of the racing context. This chapter will give a general overview of professional racing and student racing contexts, using their format to describe the relationship between students and prototypes. Finally, the chapter focuses on the MotoStudent event, comparing it with the equivalent racing championship for the formula SAE students team.

A brief history of motorcycle competitions

Motorcycle competitions have existed since the beginning of the last century, allowing drivers and manufacturers to test their skills and passion for speed and engines. After the two world wars, motorcycle competitions took a more definite shape around the fifties, and specific categories and regulations were born to follow.

In its evolution, races have started as a single casual event for cars and motorcycles. There was no continuity in a championship-like structure, no racetrack, and no organization behind the events. Races matured staidly during the XX century, alongside the cultural growth around them. Even though they may look very similar, car and motorcycle races are separate, parallel contexts. Over time motorcycle competitions have branched out between those on asphalt and off-road and by engine power. Nowadays, many divided categories give space to the infinite passions of motorcyclists, visitors, and manufacturers. Races are getting more complex, building an entire culture around the race, the prototypes, and the riders.

Moreover, the structure of the competition changed, becoming an annual championship with multiple appointments in official tracks worldwide during a six-month season. Today, the competition is not merely the race itself along with the championship but is an entire weekend, including qualifications, tests, and post-race brainstorming (Redbull,2022; Rendall, 1997). The weekend is considered one event for both car and motorcycle competitions since it includes all the parts to have a whole experience and comprehension of the race, even if the actual race is still the most crucial moment. In the evolution from casual to official events, many professional figures were born during the decades. They all aimed to enhance the performance of the bikes and riders on the track. In this evolution, the championships became more professional than they started. The necessity of forming younger professionals was born. Students' competitions and championships were born thanks to this in the early ’80.

The automotive world is quite advanced regarding competitions dedicated to students, whereas, in the world of motorcycles, the first international competition dedicated to university students was established in 2009. However, this date is quite late if we consider that in 1981 the Formula SAE Student Design Competition (Case, 1996) category was founded by the Society of Automotive Engineers (SAE) in the United States. This category is dedicated to teams of university students participating in races by designing and building a racing car with an endothermic or electric engine. Nowadays, the Formula Student category has a season repeated annually, with a world ranking and appointments held on international tracks worldwide. Moreover, the competition has a championship format, similar to professional races with appointments in many countries (Formula Student Germany, 2022). For this reason, students' car races are well-established traditions within technical universities, while motorbikes races and student teams have only begun to consolidate recently.

In 2009, the private company Dorna, organizer of several international competitions, including MotoGP, founded Moto Engineering Foundation (MEF), a non-profit foundation that organizes and manages the international MotoStudent competition (MEF, 2020). The latter is the first competition of its kind; unlike the other races, it takes place over two years, during which the teams develop and build the racing prototypes. Finally, the competition culminates in a race weekend that includes all the tests and the final race, usually held in October of the second year on the international track of Motorland in Aragón, Spain.

With the advent of electric vehicles, universities and companies have invested more in developing electric prototypes. MotoStudent launched the first edition, including the Electric category (2015/2016), to widen the competition. In 2019, Dorna inaugurated a new category of international racing, the MotoE World Cup, exclusive to racing bikes with an electric motor. In 2021 Moto Engineering Society founded Moto Engineering Italy, an official spinoff of MotoStudent, exclusively for electric prototypes. To expand motorcycle student competitions. They kept the MotoStudent format with an annual appointment in the Imola international track. To give more opportunities for students to compete and enhance their prototypes.

Student competitions: the MotoStudent format

As mentioned above, MotoStudent is a competition for university students that has a biennial format. Given a set of constraints, each student team develops a prototype to compete in the final race. Coherently to its academic nature, MotoStudent is composed of two macro-sections before the Final Race; the theoretical section, in which the development of the industrial project is presented, and the technical section, in which the prototype is subjected to static and dynamic tests to access the final race. All the prototypes in the same category compete in the Final Race, held on the Sunday of the race weekend in the Motorland international circuit. These two macro-sections are MS1 (i.e., the theoretical) and MS2 (i.e., the technical) and weigh half the overall points each. Nor does the MS1 or MS2 score preclude any team from participating in the Final Race. Prototypes must pass the static tests to access the track.

Figure 1 - VI MotoStudent edition

MS1 is a dossier divided into chapters that must be delivered on specific expiration dates during the two years preceding the race and includes:

> *F.2.1.1 The MS1 Project must include the following chapters: A) Concept development; B) Product design; C) Prototyping and testing; D) Innovation; and E) Management plan.*

MS2, on the other hand, takes place entirely during the race weekend in Aragon and includes:

> The dynamic tests referred below as "Test 1: Brake Test", "Test 2: Gymkhana" and "Test 3: Acceleration" may be performed twice, taking the best score of the two as the valid for the team.

To access the track, however, the bike must also pass a static scrutineering that consists of checks on the rider's equipment, a press bench check where the bike is subjected to a static load, and a brake check. In addition, some checks are specific to each category. For example, for the internal combustion motorcycle, a sound check of the exhaust is carried out, while for the electric motorcycle, assessments are made on the circuit's safety, an insulation check and a rain check consisting of vaporizing water on the prototype.

After static checks, prototypes receive a badge that must display on the chassis during the entire duration of the event. The badge permits access to MS2 tests, qualifying and the Final Race.

The importance of the race weekend

MotoStudent, unlike the other competitions described above (i.e. Formula SAE, MotoGP, Formula 1), has a single-race format. The single-race format implies that the competition has a single event instead of multiple appointments during a race season. Most professional racing competitions have a championship format instead of a single-race event. Also, lesser competitions (i.e. PreMoto3, Moto3, Moto2) have a season format instead of the single-race format. Nonetheless, the student competition Formula SAE has a season format. The chosen format profoundly impacts how participants experience the project and its culmination. Due to the two-year duration, students who develop and construct the prototype, on average, join the team a year and a half before the race; compared to the duration of academic courses, this is a significant timespan. Considering most bachelor's degrees, in engineering and design, in Europe have a duration of three years; to this period, some students add a master's degree of two years to start a process of specialization that can conclude with the title.

The importance of the MotoStudent project for the participants also emerges from its crucial role in shaping their study choices. For instance, some students participating in the PMF project have decided to change their study path to enhance the learning experience or contribute more to the project. More in detail, some students get more involved in university life after entering the team and are more enthusiastic about finishing the degree path and continuing studying; other students get absorbed by the project, prolonging their studying.

Figure 2 - The Polimi Motorcycle Factory team

Having MotoStudent just one race per edition distributed over a weekend, those few days represent the final milestone for the student team. Especially for the students that enter the project early, the weekend race is crucial as it represents the closure of a two-year project during which they have understood and managed its complexities. Furthermore, the event weekend acquires importance two years before the race because it represents the final milestone and the only opportunity to test the prototypes. Due to the single-race format, the slightest mistake during the weekend race might mean that the students lose the opportunity to participate in the Final Race, with no second opportunities.

The beginning of the weekend, when the teams meet for the first time, is an emotionful moment. Those days dedicated to the race are one of the most crucial ones in which the competition becomes concrete. It is the moment students meet the rest of the participating teams and share the results. Moreover, the motorcycle prototype is the first time in the racetrack, the environment it had been designed for.

On one side, the single-race format triggers positive emotions in team members; on the other, it is also a stressful moment for them. Not having a second chance to test their work means being at the mercy of irreparable unexpected events in a short time and losing the opportunity to participate in the final event. Moreover, being a student competition, likely, those students will hardly have the opportunity to live the same opportunity again. Unlike MotoStudent, the sister competition, Formula Student, has a seasonal format, allowing teams to have more opportunities to live the race moment and also refine the project during the race season.

This uniqueness is one of the reasons that led some former members of the student teams to want to expand this competition by creating spin-offs and other races to give more opportunities for students to refine their prototypes and raise the competition level. Moto Engineering was born from these initiatives and is a race for electric prototypes based on the official MotoStudent regulations - without having a dependence on participation.

The possibility of participating in multiple races does not only serve the purpose of recreating the race weekend environment, healthy competition, and mutual support. It allows students to refine their skills and knowledge about the prototype and therefore develop a more refined strategy for developing the new prototype, raising the level of competition and increasing the level of safety and reliability. Increasing the number of events would create a more uniform competitive environment. Furthermore, the possibility to test the prototypes in different races decentralises the focus from the race weekend itself and moves it to prototypes. In other words, having more race opportunities allows student teams to focus their attention and energy on improving the prototype from one race to the other, creating intermediate milestones to iterate the prototype-refinement process. Nonetheless, MotoStudent does not have a season format, but the prototype gains a particular meaning for the students because they have only one chance to see it perform.

The prototype meaning: an unrepeatable reality

In the racing championship, the focus is not on the prototype alone. As said before, the culture born around the racing season embraces more aspects, like the teams, the riders, the design strategy and the performance strategy. In student competitions, the focus is on prototypes alone. Because the aim of racing championships and student competitions is different, in the latter, the objective is to put into practice theoretical knowledge and build new know-how by developing a working prototype, which means the relationship to the prototype changes from racing championships to student competitions. In the former, the prototype represents a medium used by the rider to perform better. In motorcycle competitions with the seasonal format, teams have spare parts or entire spare prototypes for each rider.


MOTORLAND
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The reason behind this choice is that the bike, more than a car, is an unstable vehicle that, brought to the limit of its performance, might lead the rider to make ruinous slips or falls. Since most components are in sight, breaking more parts of the bike is common during these falls. Racing prototypes are equipped with support points to minimise damage during slips; very different is the case of high side falls where the prototype jumps, due to the inadequate grip of the rear tire, causing a fall with rolling. In this type of accident, the prototype usually slams to the ground repeatedly and violently.

Therefore, teams need spare parts, but having spare parts for each prototype component is not a trivial task. Looking at the professional teams of the highest categories, they are more likely to have more spare parts for each piece and even a new bike already made and refined. There is a limit for smaller teams because having spare parts means having a sufficient budget to produce two bikes. Therefore, they often divide the spare parts by priority classes, between the components purchased and those produced. Also, they can be classified by their impact on the budget or the prototype structure. For example, the components of the fairings always have a spare part because, during a fall, the probability that they break is very high, while the tiny components inside the bike are more likely to last over time. In the middle, they exist in components with very high criticalities, which, if they break or damage, indicate that the entire prototype is compromised, for example, the frame or swingarm, along with the other main structural components. These components are generally also the most expensive to manufacture. Student teams design and manufactures their frames, making it challenging to produce spare parts for these components, especially for a single race weekend.

This irreparability gives the prototypes of the MotoStudent teams an aspect of uniqueness. Each MotoStudent edition has its regulation. Prototypes designed to participate in an edition cannot be presented again in the following edition. With a single-race format, the teams have one chance to present their prototypes. The reason why the teams try to find a trade-off to do the necessary running-in, find the limits of the prototype with the right set-up but try to minimize the falls. The precarious combination that leads the prototype to turn into something more than a simple object resulting from hard work, it adopts greater importance and almost a personality as if it were something superior around which the group gathers and depends strongly.

Insights and next steps

This chapter briefly explained how racing competitions work and their differences from student competitions—helping to introduce the MotoStudent International Competition format and the meaning of the prototype in this reality. The following chapter will describe the structure of the Polimi Motorcycle Factory team and how it works.

Chapter 2
Introduction to the case study: Polimi Motorcycle Factory racing team

The team Polimi Motorcycle Factory will be introduced here by focusing on its history and founders, its evolution and its core goal. Such a timeframe allows an understanding of the interaction between actors and prototypes. Moreover, this chapter will introduce the timeline of one prototype development. Despite the young age of the team, the development shows significant improvement and a cyclic project approach related to the biannual race and the professional growth of team members.

Timeframe, the history of Polimi Motorcycle Factory

The Polimi Motorcycle Factory (PMF) is a motorsport team of Politecnico di Milano. The team was founded in 2015 by five students enrolled in the Mechanical Engineering bachelor who wanted to enrich their university experience with a project able to put into practice their bachelor's knowledge, blending it with the great passion they shared for racing motorcycles. In the beginning, less than thirty students formed the team, all enrolled in engineering bachelors. The Department of Mechanical Engineering was asked to host and subvention the team since there was already the Formula SAE team, Dynamis PRC. In the beginning, the team was granted a small area and few tools to build the first prototype in 2016. By the end of 2017, the department granted both PMF and Dynamis PRC teams a bigger and better-suited space for both teams, so it decided to build a mechanical workshop. Since then, the team has shared the area where they develop their prototypes, better suited to enhance the quality of their work.

The workshop shared by the teams, PMF and Dynamis PRC

The team started as a small project, as a place for students to gather and build something with their own hands, putting into practice their theoretical knowledge. Nowadays, the PMF is a cross-disciplinary team that includes students from different engineering, design, and architecture branches. From 2015 to the present, it also growth in number, from less than thirty to more than one hundred students.

The team's aim didn't change significantly from the beginning as MotoStudent enriches students' university experience through a semi-professional project. The project challenges students' learning through the direct experience of a *self-guided* development of the prototypes for the MotoStudent International Competition. Such a process is coherent with a *constructive learning* approach, one of the most relevant contemporary views on learning and education (Mattioli, 2022).

Focus box: the constructive learning approach

In her PhD thesis, Mattioli focuses on the *constructivist learning* approach, opposite the *objectivist* approach (Vrasidas, 2000). She explains how, in the objectivist approach, knowledge exists independently of the knower and is transmitted from the teacher to the student. In contrast, the constructivist concept is part of a personal process, which implies that reality and knowledge are not absolute truths, but the result of the learner's construction. Moreover, she defines contemporary learning with three more keywords, explaining that learning *is self-regulated*, *contextual* and *collaborative* according to the constructive theory. Learning is *self-regulated* because learners actively participate in learning by developing self-regulatory skills. Constructive learning is *contextual* because it depends on the socio-cultural context in which it takes place. Finally, this learning theory is considered *collaborative* because of the social interactions the contextual aspect implies (de Corte, 2010).

Moreover, students' work is self-regulated, meaning that milestones, deadlines and goals are not set by teachers but by the same group of students (Mattioli, 2022). Such reality permits students to work in a reality that is very much like a big company, where professionality and commitment are very important and where consequences and negligence also weigh on other students' work (see "Focus box: the constructive learning approach").

The team have participated since the fourth edition of the MotoStudent Petrol category. The first prototype was designed and built in less than one year by less than forty students; in that case, the goal was to pull together what was necessary to pass all MS1 and MS2 milestones and finish the race. This goal was achieved, and the team's prototype arrived in the eighteenth position. The achievement gave the team a big sprint to better stress the problems and give more attention to details and theoretical milestones. Such passion and carefulness were repaid in 2018 with first place in the Petrol category, becoming world champions. With that achievement, the PMF conducted a high-speed race to the top. However, after winning the competition, the team experienced several difficulties finding a new goal to set the standard. Hence the group came up with a different idea; they decided to enlarge the project, participating in both Petrol and Electric categories. The goals for the petrol bike were to work on little details such as making a more reliable system, a lighter bike, and a better set-up. For the electric one, the team decided to translate the dynamic project of the 2018 project onto an electrical system, aiming at reproducing a similar behaviour on an entirely different kind of bike.

Even if the team worked hard to achieve such goals, a few technicalities during the competition led to problems on both bikes; the petrol was unable to race, and the electric bike had a systematic shutdown during to an error. As said before, a small mistake can eventually lose the opportunity to race. Therefore, after the 2018 race, the team had to work even harder to achieve the 2021 goals; indeed, the global emergency of Covid-19 set rigorous standards to work in small spaces such as the workshop.

Each edition, each biennial cycle represents a bond between a bike and a group of students. Since the project is driven by passion, the students are volunteers and cannot stay for a long-term run into the team, and their participation is related to their study plan. Consequently, many students leave the project every year, and others get recruited, but only a portion follow the project from start to end. Nevertheless, usually, after the final race, there is a big gap. So the students become a group, and they reflect on themselves in the prototypes that are their creations. This bond between the specific prototype and the group that created it emerges from the experience in the team. Indeed, even if team members always refer to the prototype as the ”team’s bike”, it often transpires that a specific prototype is “someone’s bike” as it belongs to those that created it. Hence, particular prototypes and student groups that designed them are mutually bounded. It is impossible to pass on this bond to the next group, which is why each cycle differs. What is passed from cycle to cycle is a strong respect for the work developed previously, even when no student who has worked on developing a specific prototype is left in the team.

Today, the team is developing new prototypes, working on both projects, with a new batch of students, in a brand-new cycle. New goals have been set for future prototypes, and the project is once more restarting with a new wealth of experience to use as the starting point for new progress.

An added difficulty in the last MotoStudent edition: the global emergency due to Covid-19

To contextualise the research presented in the thesis, it is worth mentioning how the team coped with the increased stress level provoked by the global health emergency during the last MotoStudent edition. It is widely acknowledged that lockdowns in Italy largely influenced people's mental health, causing increasing levels of stress and anxiety in the population. Among others, young people and students have shown intense symptoms because, due to confinement regulations implemented by local authorities, universities had to stop face-to-face courses forcing students to change their habits (Allen, Kannangara, Vyas, & Carson, 2022). Furthermore, the enclosure and daily uncertainty about the future provoked frustration, lack of motivation and anxiety (Aristovnik, Keržič, Ravšelj, Tomaževič, & Umek, 2020). Unfortunately, the team was not spared such symptoms, making it more challenging to finish the prototypes on time for the race.

Some students found shelter in the massive amount of work yet to be done, but for others, not being able to meet and work in the workshop led to a lack of motivation, and they abandoned the project. For many, PMF represented one added source of stress that was difficult to bear. The outcome was that the task of finishing the prototype was left to a smaller group of students already saturated with stress. When the pandemic started, the team hardly believed it would have been possible to have two functioning prototypes by the end of June 2021, considering the extreme contextual conditions, the lack of workforce, two bikes to build, and the many vicissitudes they had encountered along the way.

Despite the difficulties, the team kept working on the prototypes without considering abandoning the project as an option. In the end, both prototypes were built and tested intensively before the race in June 2021. Interestingly the team's driving thought throughout this stressful process was the following:

> "They (the prototypes) deserve to see Aragon's track!"

In these words, the bike prototypes were humanised to motivate the team. Indeed, the team members referred to the machines as if they had feelings and desires as if they were alive. This way of referring to the prototypes was a crucial insight to link the developed bikes with the concept of *fetish idols*, as theorised by the philosopher Bruno Latour; this concept will be analysed in the following chapter.

The humanization of the machine is related to its importance to its creator. Latour theorizes that the fetish idol is born when the creator grants it the power of will. Inside the team, the humanization practice has been recurrent since its start in 2016. This led to the belief the prototype could carry on team know-how regarding production and organization. However, this is an excessive expectation for an object. However, students should carry on know-how between cycles because transmitting know-how helps the evolution of the project in terms of quality and organization. The Polimi Motorcycle Factory team is still very young to have a solid organization, but it becomes less solid when it is given for granted that the prototype has a role in establishing it. The following section aims to present how the current team organization works and how it subdivides the timeline of a cycle.

Focus box: the fetish idol

In his book On the Modern Cult of Factish Gods, Latour describes the origin of the word fetish. The meaning is associated with the Portuguese word *feitiço*, the past participle of the verb "to do, to make". The word as a noun means "form" or "figure", and as an adjective means "artificial", "factitious", and "enchanted". However, Charles de Brosses invented the word "fetichism" in 1760 and linked its origins to the concepts of "fatum" by taking its roots from the French word *fée or objet-fée, fairy-object.* The fetish idol is a material representation of a god. Once the creator finishes the artefact, he acknowledges its aliveness (Spyer, 1998); by this act, the creator grants the fetish idol power over his destiny, forgetting he was the one grating that power (Latour, 1996).

The team's organization: the pyramid of responsibilities and the implemented workflow

This section will explain how the team is organized, and the tools used to manage such a significant project. It is worth clarifying that the team is one and develops both bikes in parallel; this means that some students work on both projects simultaneously. In making the team's organisation explicit, the following section analyses the main tasks, timelines and milestones.

Structure of responsibility and acquired experience

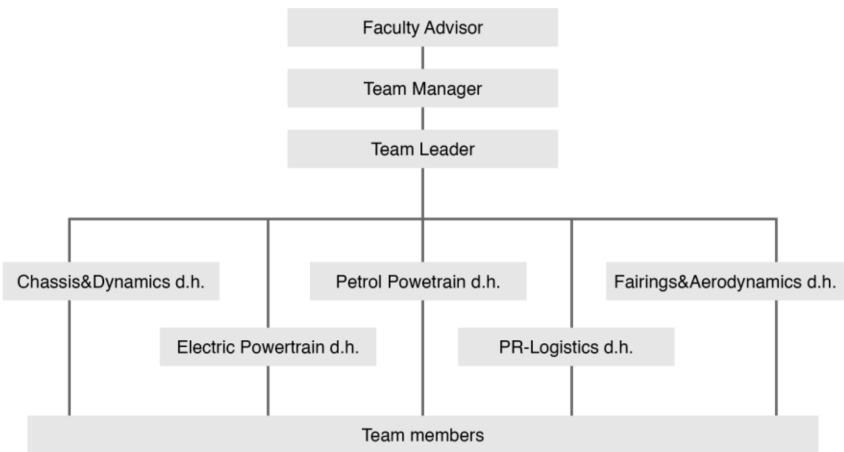
The team is organized in a pyramidal hierarchy based on a responsibility chain, as shown in Figure 3. The structure is very fluid; students who show specific soft skills, such as maturity and the ability to see the project as a bigger picture than a single task, acquire more responsibility. From top to bottom, the pyramid is composed of the *team leader*, *heads of departments* and *team members*. Moreover, the whole team is supervised by a tutoring professor and the Dipartimento di Meccanica of Politecnico di Milano.

Taking a closer look at the single task, the organization is more flexible depending on each task. Such flexibility permits having much space to find the best workflow for each group of students. However, considering the group renews almost yearly, there is a lack of continuity, meaning that new members hardly acquire know-how learned by senior students.

As mentioned, the team is organized into thematic departments, with a student in charge of leading each of them. Each department focus on a specific area of development. These *technical departments* are the following:

- **The Chasis&Dynamics department** focuses on developing and optimising both prototypes' frame and dynamics calculations.
- **The Fairings&Aerodynamics department** focuses on the aerodynamic optimization and design development of the fairings set for both prototypes.
- **The Powertrain Electric department** focuses on the electrical system and the optimization of the electrical engine, including all possible supports and sensors. This department works exclusively for the Electric category.

Figure 3 - The PMF organizational structure



- **The Powertrain Petrol department**, like the electric powertrain, focuses on the combustion engine. This department works exclusively for the Petrol category.

Each department has a *department head* that organizes and supervises tasks and duties to achieve all department milestones, collaborating with the rest of the departments to ensure the best possible outcome for each part of the prototypes. *Department heads* have many responsibilities, and the cooperation between departments relays on good communication between them. *Team leaders and department heads* form a management board called *Gestione Sportiva*. The committee meets weekly to make a global update about each department project. It discusses the technical aspects of the project, aiming to achieve a good integration of each designed component. The board also discusses the management aspects regarding project deadlines and team organization.

Each *department head* is in charge of one *technical department* composed of *team members*. Each department meets weekly to update about projects and brainstorm about unsolved problems. *Team members* are at the base of the responsibility chain, participating in one department at a time. However, everybody is invited to help and participate in any possible way.

Ideally, the responsibility chain works the following way:

- the management board sets the pace, milestones and deadlines, divides the whole project into small tasks and assigns them to groups of students;
- heads of departments check the results and decide whether to approve them or not;
- team members work on single tasks focusing on small parts of the prototype at the time.

The responsibility chain aims to distribute the workload to a larger group of students by dividing the bike's components' development into small tasks. Thanks to it, *heads of departments* can focus on the technical and management aspects of each design group because they have a global view of the project and have to have in mind criticalities coming from other departments. It is their responsibility to decide whether a component can be produced or not, which means that they are responsible if the component has issues once produced.

Because of this, *heads of departments* are chosen based on their technical knowledge rather than their management abilities. The team lack a management board aimed only at setting the pace. The same group of students that set the pace is also responsible for project quality and technical decisions regarding the components. Global decisions about the dynamics, production method for principal components and milestones are set by the management board and translated into tasks developed by groups of *team members*.

The workflow dynamics: flexibility does not always pay off

Following it will be described the design process dynamics for developing the prototypes. Instead of being rigid, the workflow significantly varies between departments, though overall, the team follows common steps and milestones. The process is very similar to the creative design process; there is a concept and requirements stage, a more creative stage, a refinement stage and the production stage. Most of this work is developed in small groups that gather together to design, analyse and test each component. Because of this reason, team members that work in small groups have less idea of the big picture of the whole project. This problem is partially solved when students of different groups meet to work, and communication becomes instantaneous. Meetings are significant for speeding up problem-solving and the workflow itself. Team organization has always relied upon having a designated space in the Dipartimento di Meccanica to have such meetings and work together.

Figure 4 - Task setting and subdivision

Regarding the design process of a newly started cycle, there is a similitude with the design of an industrial object, as shown in Figure 4. The first activity is to evaluate the behaviour of the previous prototype to gather weaknesses and strengths, keeping a communication line between new members and senior members. This process helps to create continuity between the prototypes. These weaknesses and strengths are then translated into design constraints and requirements used afterwards to set the goals of the new prototypes. Then it starts the design process; the whole project is divided into smaller tasks assigned to small groups of students that work together to achieve the better possible solution within the given deadline. Each group has a deep understanding of their tasks but less understanding of the bigger picture of the entire project, though it is important to avoid isolation. The aim is to achieve the best possible trade-off between the requirements and constraints of each component. Hence, working together is encouraged and meeting with other groups to get updated about different parts of the prototype, share ideas, and help brainstorm. Most of this process is done with the help of software for CAD and simulation. Before releasing a component, manufacturability and assessability are checked by the board of management. Once the whole project reaches sufficient maturity, the production phase starts, divided into outsourced and in-house production. From then on, the workshop's work moves gradually from digital to manual. Once the bike skeleton is produced, including the chassis and rear swingarm, the assembling phase starts. Afterwards, when all the components necessary to permit the pilot to ride the bike are assembled, the testing phase starts till the final race.

The previous paragraph shed some light on how the team holds the design and assembling process of the prototype. However, the phases overlap, designing and producing the last small components easy to design and fast to manufacture. Moreover, the team strategy considers the possibility of optimizing some components during the testing phase. The phases are not hermetic; they imply a certain degree of flexibility. Such a strategy permits the design phase to be ongoing for some less critical components during the production phase. However, designing and producing components while most parts are already done compromises quality and details.

Once the race finishes, the process starts again, beginning with evaluating the prototypes and setting goals for the next project. Also, this is a crucial moment for team building, especially between new and senior members that aim to pass on their experience. Due to the frequent turnover, communication between new and senior members is essential to maintain continuity between the prototypes, ensuring the team's growth. The built prototypes have a crucial role in this.

Prototype as a time and knowledge capsule that connects the past to the present

Many students leave the team when a new cycle begins, and others get recruited. For example, during the 2021 race, the team was composed of forty-five students. After that, most left, and only eleven stayed. After October 2021 recruitment, the team reached nearly one hundred members. The turnover represents a generational gap; the more students leave the team, the more significant the gap. Indeed team's activities are based on the *competencies-based learning* concept (Mattioli, 2022). Most of the competencies developed during the participation in the project are personal *attitudes* based on personal experiences, which made them difficult to pass on. Every new cycle begins with a phase called, in this thesis, the *adjustment phase*, in which recruits have to learn the team's design method to design and develop racing motorcycles.

Students interact with the prototypes developed during the previous cycle during the adjustment period. Their first approach to the team is dedicated to understanding and, if possible, solving issues that emerged during the testing and racing with the previously developed prototypes.

This process helps create a bond between a cycle and the next one, a connection through time between who designed a component and the present, where different students have to solve the same issue, creating continuity and evolution through the years, avoiding errors that have already been solved. This way, the prototypes represent a bounding object between past and present that permits the team to be perceived as one evolving entity through time. The design process starts with understanding what came before to set new goals and standards. Otherwise, the process will have no continuity or evolution, as if different teams designed the prototypes. Furthermore, creating a bond with the prototypes means being less isolated from the work of the students that participated earlier in the project. The contact with an older prototype helps set the context's boundaries, set new goals and create the feeling of belonging to a project with a history.

Focus box: definition of *competencies*

Since the late '90s, pedagogy has increasingly embraced the idea that learning should aim to develop competencies. Competence can be defined as a combination of i) knowledge (knowledge is composed of the facts and figures, concepts, ideas and theories which are already established and support the understanding of a particular area or subject), ii) skills (defined as the ability and capacity to carry out processes and use the existing knowledge to achieve results) and iii) attitude (describe the disposition and mindsets to act or react to ideas, persons or situations) (Mattioli, 2022).

A history that is very difficult to maintain alive if it is considered that most of the competencies acquired by the students are personal and intrinsic to each person, and turnover is frequent. An object helps to create a connection between past and present but is not enough to understand the design process surrounding it. The bigger the project, the more difficult it is to grasp the process that led to each decision. Because a project is not composed only of a material body, much information also exists in a digital form. Moreover, all that information is part of the project at the same level as the material body but less easy to store and find. A motorcycle design project is considered a big and complex project, where more professional figures interact in a multidisciplinary context to analyse and redesign each component of a complex system, such as a racing motorcycle. Nonetheless, being able to retrieve data from previous studies and analyses helps to preserve continuity and guarantee the evolution of the project. Some years ago, the team decided to use a newly developed software to preserve historic digital data and help new generations have easier access to it.

The implementation of software for the Product Lifecycle Management: 3DEXPERIENCE ENOVIA [1]

The manufacturing industry has gone through a digitalization of manufacturing processes during the last decades. In history, humanity has gone through two industrial revolutions; the third is ongoing. The first industrial revolution was characterized by the first implementation of mechanized systems in textile factories, steam engines and so on. The second industrial revolution gave birth to the concept of the refined production line by H. Ford, starting the so-called mass production of goods of any kind. From the beginning of the twentieth century onwards, Western economics started supporting a high consumerism system, which relied heavily on how much people

[1] This segment cite the thesis "Gestione ed integrazione del progetto di un motoveicolo per competizione MotoStudent" written in 2018 by Andrea Danese

buy and spend. It is an economy that demands mass-produced goods to fuel mass consumption (Rampino, 2022). This cycle stopped with the 1930 Great Depression and restarted after the Second World War to restart the economy. Due to the establishment of mass consumerism and the advent of the internet in the late '80, companies could manage *new product development* (NPD) to compete in a saturated mass production market (Rampino, 2022). In addition, thanks to the internet, it was possible to change communication and file-sharing approaches to support the new NPD. The third revolution is the digitalization of the production method, implementing computer-based systems and using specialized robots and software dedicated to production. More and more companies decided to rely on a digital infrastructure structure, from the digitalization of documents to the implementation of robots in the assembly line or the implementation of software to organize and administer project lifecycle management (PLM). As a result, companies worldwide have changed how they organize resource development, production and management.

Such revolution can also be seen in the university approach; many courses have implemented lectures and laboratories about implementing digital tools to form students with basic knowledge. Moreover, entire bachelor's degrees and master's courses have been born during the last decades to enrich knowledge about specific tools and digital systems. All this knowledge helped to guide the third revolution towards the digitalization of systems and resources by having professionals already introduced to the new technologies. Nowadays, software and digital tools are very common in university courses, linking the professional and educational worlds.

Moreover, such a revolution has been embraced by software developers. Companies have seen an opportunity to improve the workflow between the software of the same suit or software that works together, to reduce dead time and improve communication between different actors inside the company. For example, the Adobe suite includes a significant amount of software from different developers, but they are compatible between them. As a result, workflow became more complex, permitting different professionals with different goals to use the same platform to do their job faster and more efficiently. Software and suits have started to work with a cloud system and PLM tools to permit reviews and simultaneous work, considering the operational flow of small teams and entire departments. New-generation software helps automate simple processes to cut down dead time.

As mentioned above, the product produced by a company is the synthesis of the entire design and development process but is not by far the only information managed by the company. Most of the data is in digital form and in many different formats. Data can be in the form of CAD, FEM and CFD simulations, Excel tables, Word documents, .pdf files, presentations, renders, illustrations, images edition, and audio or video documents, to mention a few.

Managing such extended diversity requires organization, time and resources; the goal of the third revolution is to automatize most of the actions, creating connections between software, resources, machinery and production lines. One of the newly developed software of the company Dassault Systemes was born to combine and automatize different aspects of industrial product design, development and production. The software is called 3DEXPERIENCE and incorporates four aspects of the development process: design, optimization, communication and project management, CAD modelling software, simulation optimization, Gantt, task management, a cloud service, and apps to gather reports for brainstorming.

The team Polimi Motorcycle Factory, born in 2016, has worked with a digital infrastructure, though very rudimental during the development of the first two prototypes. The team relied on a could service and the manual synchronization of new data. Every day, students working on the project had to manually sync their developments and inform the rest of the students working on related aspects. Afterwards, in 2019, the team wanted to improve its management by implementing a more organized structure and the 3DEXPERIENCE software to support a more automatized and digital workflow.

3DEXPERIENCE: the implementation of a collaborative digital infrastructure

The team workflow resembles the one of a company that produces goods. However, instead of producing at a high rate, the team produces two products in a biennial cycle. Smaller subassemblies and single components assemble motorcycle prototypes; some are bought components, the team develops others but outsourced, and others are developed by the team and produced in-house. Each prototype is assembled with components developed by the three technical departments, each composed of several students. Moreover, some developed components are optimized and need moulds or a welding jig. Before the implementation of the 3DEXPERIENCE, the team had the same pyramidal structure and the same subdivision into departments; the workflow was similar but ended in having excellent time loss during development steps.

The 3DEXPERIENCE significantly transformed the design phase by creating an instant connection with the work of every group. Before its implementation, the system was organized differently. Every member was more isolated from the bigger picture of the project because it was more challenging to stay updated without asking each group of students directly. It will be explained how it worked before implementing the new PLM software to help understand the difference better. Before the change, the workflow had an added complication; the groups working on single components could not have access to a live updated assembly. They worked locally, and every once in a while, they had to download the updated assembly to find out all the new modifications and adapt their components or ask the others to adapt theirs. To keep the assembly updated, one student had the skill to keep up with the entire project, update the assembly, and give feedback to different groups to guide the project to a successful outcome. Though it was difficult, not everybody had the skills and knowledge to develop a bike fully. Implementing the 3DEXPERIENCE made having such a role in the team less necessary. Finally, the opinion of one student was more relevant than the one of the whole board of management, relay on his shoulder many essential decisions regarding the design of the prototype.

Project analysis, tasks and milestones related to the product evolution

As described previously, the workflow the team implement is similar to the one used in most design processes. It encompasses an evaluation of the strengths and weakness phase followed by the setting of a concept that includes new goals and constraints. Following the *concept phase*, there is the *design and optimization phase*, characterized by the development and refinement of all the components of the prototypes, starting with the ones that require more time and are more significant to achieving the previously set goals. Once the main component reaches manufacturing maturity, it starts the *production, refinement and assembling phase*. The main difference between the design and production phases is that the first is mainly developed through 3D modelling and simulation; the production phase develops primarily in the team workshop, where components are assembled and manufactured. The final phase is the *testing*, where all components are assembled, and the prototype is tested on track. All these phases have some distinct characteristics related to the workflow, interpersonal interactions in the team, and the prototypes.

Concept phase: an abstract start

Starting with a new cycle means finding oneself at the beginning of a white page, ready to start writing. There is a lot to do, and most things are not set. Moreover, new members enter the team and need guidance. Bonding with senior members is necessary to learn about previous prototypes and feel less detachment from them and the whole team. Estrangement is due to the lack of bond with the prototypes and the new project mainly being abstract in the beginning because it exists only in a digital form, and most components are yet to be developed. Besides, new members interact only with other department members because interdepartmental meetings happen further into the project. Sometimes the compartmentalized interactions within each department translated into a poor team culture, which starts with an isolated culture in each department. In this phase, the existing prototypes serve the purpose of the *boundary object* (Bender, 2017), creating interaction and shared understanding.

Focus box: definition of *boundary object*

A boundary object is a concept that characterizes objects that foment good communication in interdisciplinary design groups because they adapt to the meaning given by each group member without losing a common identity (Bender, 2017).

Design phase: 3D modelling and shape optimization are used to create e a digital body

Once the goals are set, this phase begins. An increment use of 3D modelling and simulation software characterizes it. Members work in small groups, and communication starts with groups of different departments, which increases interaction, while the new prototypes become more concrete as more components are designed.

In this phase, the focus switches from the previous prototypes to the new digital ones. The 3D models, even if still incomplete become the new common ground to open cross-disciplinary discussion about the project; they become the new *boundary objects*.

The component development characterizes this phase by making a trade-off between the goals of related components to achieve the best possible solution for each bike part. Because of this, good communication and teamwork are important.

In perfect reality, this phase ends when all components are developed and ready to be produced. Instead, it overlaps the production and testing phases to have the possibility of validating some designs that need testing, and because of the strategy of designing the essential components first, this topic will be developed further in the following chapter as part of the problems.

Production phase: from digital to physical

This phase is characterized by the switch from digital development to actual production. During this phase, the work moves from the software to the workshop. The prototypes acquire a physical body built piece by piece by the students who invest time in the workshop and manufacture all the components together. In this phase, the culture around the prototypes became solid at its best, and the prototypes acquired a new significance. The students gather in the workshop to finish their creations; at this moment, the prototypes acquire a different meaning, in a certain way, for the students they become alive.

Testing phase: the prototypes become alive

The testing phase begins with the first ignition of the engine. Usually, most students working in the workshop stop their activities and assist to this moment together, gathering around the bike in a way that reminds a *ritual*, defined by Evangelos Kyriakidis as those activities that address the gods or other supernatural forces.

During this phase, the prototype is tested on track aiming to optimize the set-up through telemetry data. Moreover, during this phase, the rider gets to know the prototype but the possibility of a fall increases.

During this period, all components are subjected to periodic checks; others get redesigned after testing. In this phase, the bond between students strengthens, driven by a common goal and united by the prototype *fetish* power.

Figure 5 sums up how different aspects change from phase to phase, characterizing each differently. It shows how the more the project acquires a material body, the more the group builds a stronger bond, leading to more participation in creating prototypes that become *fetish idols*. Moreover, it shows how communication is related to quality, as it helps solve problems by considering a bigger range of related issues and reaching solutions with higher maturity and more awareness.

Figure 6 distributes the main components on a cartesian graph comparing the *buy-make* axis with the *dependent-primary* axis. The result shows that most primary components are partially manufactured in the workshop, while the fairing set, considered one of the main components, strongly depends on other bike elements, so it can be found in the second quadrant.

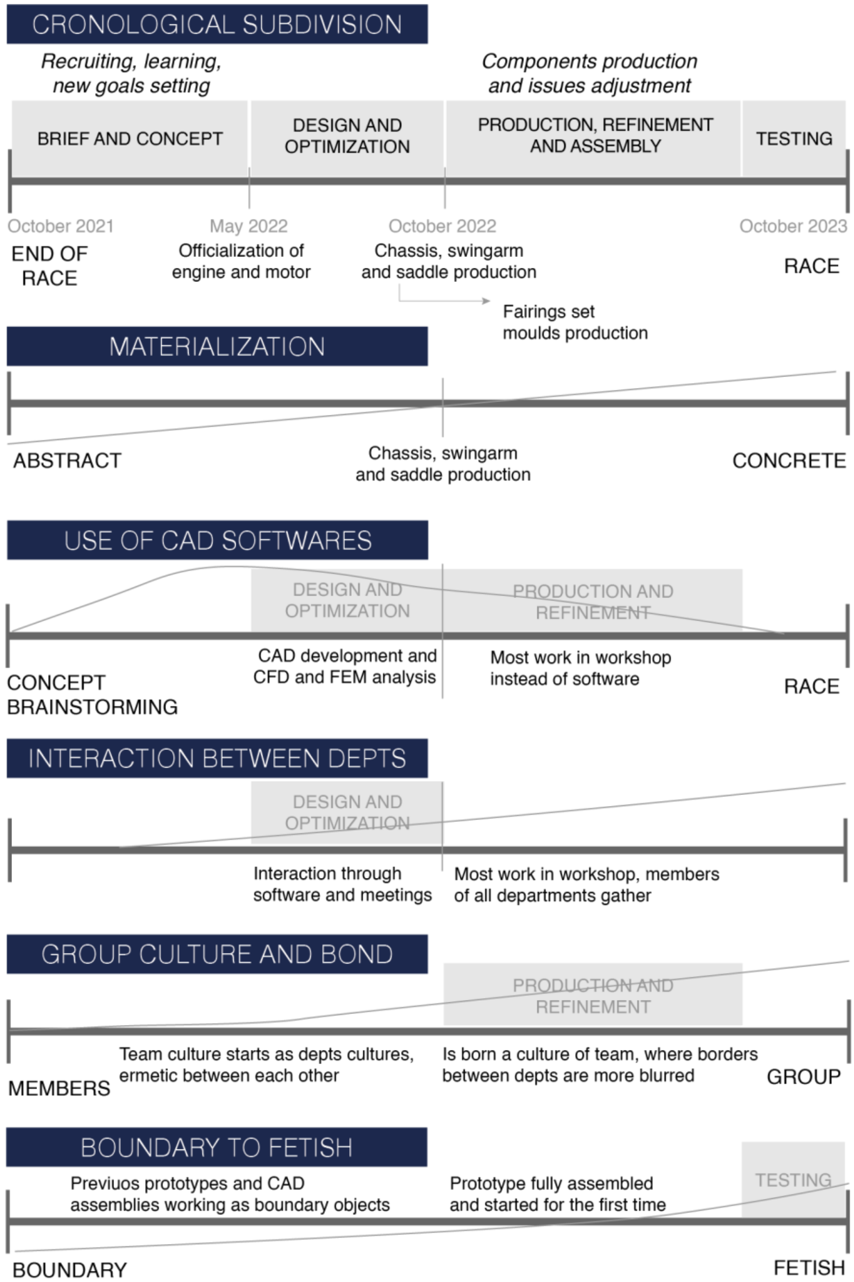
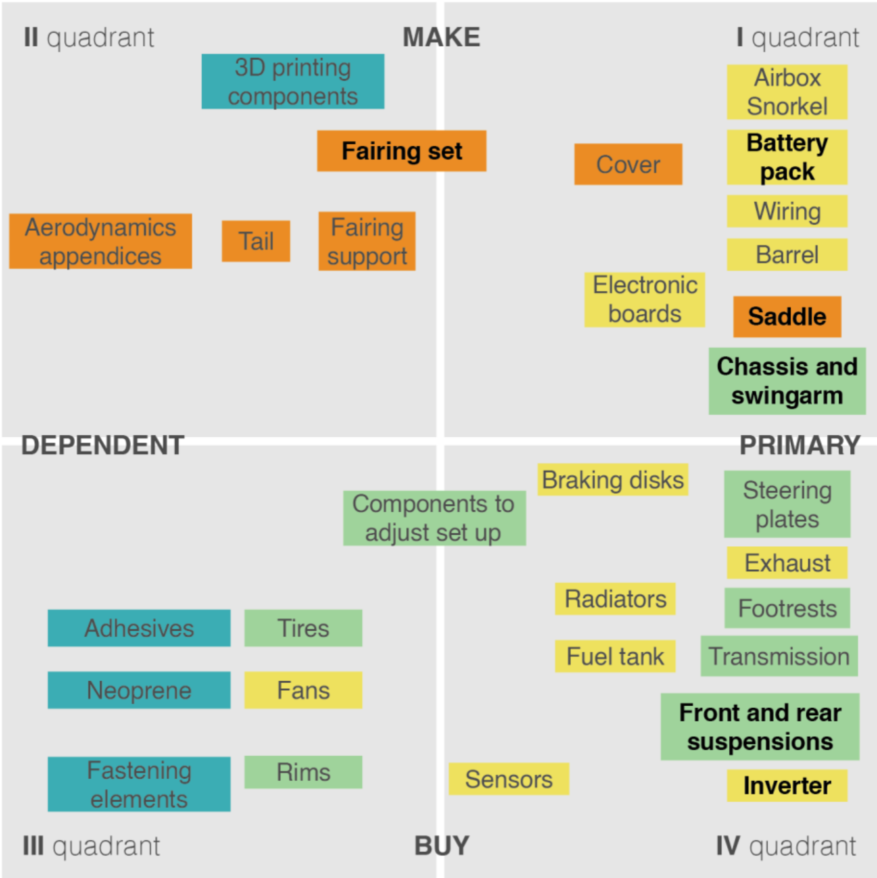


Figure 5 - Aspects comparison



I quadrant

Components necessary to ride the prototype and manufactured in the workshop

III quadrant

Components not necessary to ride the prototype and easy to find on the market

II quadrant

Components not necessary to ride the prototype and manufactured in the workshop

IV quadrant

Components necessary to ride the prototype and necessary to set during the design phase, cannot by bought different type

All departments

Petrol and Electric Powetrain

Chassis&Dynamics

Fairings&Aerodynamics

In bold those elements that requires critical budget

Figure 6 - Comparison between components the team considers essential by the means that are necessary to make the bike drivable and dependent and to what department they belong

Insights and next steps

This chapter described the case study of Polimi Motorcycle Factory, focusing on the team’s history and organization. The chapter explains the management structure and the project phases to understand the design approach to developing motorcycle prototypes. Moreover, the chapter describes interactions between new members and old prototypes. Such interactions set the ground for understanding relationships between members and prototypes, how interactions influence the project outcome and the teamwork's linearity. The next chapter will examine the subject/object relationship through various concepts. Firstly it will analyse different meanings attributed to the object. Secondly, it will explore the relationship between those different attributes and the different roles of the subject. Finally, the last section will apply these to the relationship between members and prototypes and how this relationship influences collaboration.

Chapter 3
The prototypes and their social role in students' motorcycle competition context

In the Polimi Motorcycle Factory, students rely strongly on prototypes to communicate. Furthermore, they use the bikes to brainstorm about the project's criticalities. Such practice is so strong that old prototypes are seen as the heritage of previous groups. This chapter aims to explore the subject/object relationship by analyzing different meanings attributed to objects to later focus on the study case of the 2021 Petrol prototype by exploring the prototypes' social role inside the team material culture.

The material culture around products

Our society has had a strong relationship with the objects that accompany everyday life since humanity started using and creating minor artefacts to interact with its surroundings. Objects have shaped the evolution of different societies and human relationships, permitting an increment of complexity that results in a culture rich in correlations and layered interactions (Latour, 1996). But objects are not just mediums to foster human interactions; sometimes, they acquire self-character. This character transforms the object into something more than a tool or a feature. Moreover, this importance is shared only between persons in contact with the object for a long time.

In her book, Wild Things, Judy Attfield analyses *material culture*'s role in understanding the relationship between users and what she defines as "*wild things*". She explains that objects suffer an evolution regarding how their users perceive them. At the beginning of life, an object is a well-defined product that is part of a category and has a general goal. Once the product is bought by someone and becomes part of the user's life, the object goes from product to what Attfield defines as a *wild thing*. This transformation implies that the object gets uncategorized and is disenchanted from its superior position given by the definition of product design. Becoming a *wild thing* means having a special significance for the user that goes beyond its mere practical usefulness.

The concept of *material culture* was born in an archaeological and sociological context. In its early stages, this concept was a tool to understand better the relationship between a group of people and an object. It describes the *culture* people build around an object or a space, such as artefacts or places of cult. Later, *material culture* extended its horizon, reaching more disciplines and transforming it into an umbrella term flexible enough to expand. During the '80 and '90, it was associated with the History of Design (Attfield, 1999)relating it to the production/consumption phases and including the *social life of things*. The primary correlation studied between design and material culture is relegated to the relationship between the consumer and the object through the consumerism lens. However, humans don't interact with objects only through consumerism. Design objects can have a strong bond also with their creators. This relationship is quite different because the object does not start with a well-defined identity.

In some cultures, the act of bonding with an object goes further than the concept of *wild things*. In Border Fetishism, Patricia Spyer explains that asserting the aliveness of an object means the interruption of a process considered by Freud as human-derived. Spyers and Pels believe acknowledging the *spirit of the matter* as an independent force offers the fetish "a chance to unfold its otherness". This means that the physicality of an object can carry a form of signification that transcend human construction. Acknowledging the aliveness of objects evokes a wide range of negative emotions like fear. Indeed, *fetish objects* are characterized as being able to act upon their creators (Spyer, 1998).

Understanding the objects

The chapter aims to understand the *object/subject* relationship under different aspects. This section starts by defining the word *object* to analyse later different definitions attributed to objects that never become products. Such as the definition of *prototype*, *boundary object* and *fetish object*. The chapter ends with a focus on how the relationship object/subject between team members and prototypes evolves during the biennial cycle set by the competition duration.

> Object: a thing that you can see or touch but that is not usually a living animal, plant or person; a material object. (Cambridge Dictionary, s.d.)

The material object is not defined by the market or the consumerism machine. According to the Cambridge dictionary, materiality and inanimate substance define an object. At the same time, Kristie Miller separates *objects* from *things* because objects are composed of parts that can change over time and depend on their essential properties

(Miller, 2008). So, a *thing* can be considered an *object* even in the early stages of its creation when properties are latent.

Objects have been part of the everyday life of human society from its dawn. Since then, many categories of objects have been born, from survival instruments to religious representations. The more society evolved, the more varieties of objects spread. For example, with the advent of the industry, the word *product* referred to mass-produced objects for the selling market. Moreover, mass production-related things have acquired even more categories depending on their production stage.

Another related example could be the word *component*, which refers to components not yet assembled in the product. After the Second World War, when the consumeristic concept was restarted, production companies introduced New Product Development (NPD), aiming to optimize their production period to introduce new products faster (Rampino, 2022). The introduction of such a process implies the companies implemented an innovative product management method during the design and manufacturing phases. The more the process was structured, the more specific terminology was required to refer to the design and manufactured objects.

The word *product* refers to objects ready for the selling market, but there is a long way to go before reaching that market. Therefore, o*bjects* are associated with the word *product* when they reach a status belonging to a widely accepted category (for example, bottle or car category). Quoting Attfield, once the consumer buys the *product*, it becomes a *wild thing*; before entering the selling market, the object belongs to a category meaningful only inside the production company. The word *prototype* is a widely used term for products belonging to the design phase. A prototype is a mock-up of a project, a physical representation of the product. There are many different prototypes, but each has the same purpose. They are used to corroborate various aspects of an object or system. For example, they help check the shape, the electronics, the ergonomics, the usability, etc. Another peculiarity is that prototypes are *unique* because they belong to the product design checking phase. Because of this uniqueness, also the university context uses the word prototype. Such context uses the term to refer to objects created by the students to represent their project shape. In both contexts, the prototype has the same purpose, is part of the project development and helps designers to have a material approach to the project. Such an approach is helpful since the digitalization of many project activities doesn't permit the designer to interact physically with the project.

Moreover, materializing the project through mock-ups and prototypes helps designers use it as a tool for group brainstorming. In such cases, the object becomes a *boundary object* besides being a prototype. *Objects* working as *boundary objects* strongly link with the subject/subject relationship; their goal is to improve communication between subjects of an interdisciplinary design group.

> Star and Griesemer (1989) define why boundaries object suit this so well for this goal: "Boundary objects are objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites, they are weakly structured in common use, and become strongly structured in individual-site use. They may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable means of translations. The creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds." (Bender, 2017)

So, boundary objects represent intermediary objects between social worlds or disciplines; they help to translate means across the intersected worlds during the design phase. In semi-professional realities that approach the design halfway between the *innovation* and *NPD processes*, boundary objects can be helpful materializing ideas and concepts (Broberg, Andersen, & Sein, 2011)—considering that the *innovation process* is less structured than the *NPD process* because the former is more creative, and the latter aims to put a product on the market as fast as possible (Rampino, 2022). Inside the PMF context, where diverse realities and culture meet in an interdisciplinary group, a boundary object help the design process success. Moreover, since the subjects are students, they have little experience approaching complex problems. Therefore, fomenting and easing communication helps the group achieve its goals faster, reducing time-consuming misunderstandings and possible errors. Boundary objects serve groups in situations where each participant has only partial knowledge and partial control over the interpretation of an object or a project (Fominykh, Prasolova-Førland, Divitini, & Petersen, 2015) (Anisetty & Young, 2011).

At the beginning of this section, an inanimate substance defines objects that are mediums and tools helpful to humans in different activities. This definition coincided with Dieter Rams' definition of Braun electro domestics in 1957.

> Our electrical appliances should be quiet, unobtrusive helpers and servants. Like a good servant in days of old, they should come and go silently, there when wanted but unnoticed. (Kinchin, 2011)

However, a group of such objects breaks this rule: *fetish objects*. Moreover, such items have the peculiarity of being granted power upon their creator. Because of this, they are considered physical idols or gods, like religious symbols. These physical representations are more than everyday objects; their creator indulges himself by giving them human characteristics.

> "Idols have eyes yet they do not see, mouths yet they do not speak, ears and yet they do not hear.[...]According to them something else animates these lifeless bodies, dead statues: our belief, the social life that we project onto them. The fetishes do not count for anything in themselves. They are merely a projection screen." (Latour, 1996)

These objects, created by the human hand, acquire power over their creator's life. However, while grating this power, the creator forgets his role as the fetish object craftsman. Latour and Spyers explain that being *acted upon* provokes, in the subject (i. e. the creator), *alienation* towards the object and himself; he loses control over the relationship and his destiny. *Fetish objects* depend strongly on their relationship with the creator and between the creator and other subjects around the item. Such objects are not inanimate tools bought to serve a purpose; they never transform into wild things because they hold control of the *subject/object* relationship. This reversal of roles causes the *alienation* mentioned above. The following section describes the subjects and their interactions with the objects defined in this section.

Understanding the subjects and their interactions with the objects

Human has introduced objects in their society till its early stages as tools to interact with the world and other subjects. Such interactions depend on the context, and they determine the subject/object relationship. As said earlier, Attfield identifies the subject/object relationship as *user/product* because she inserts it in the consumeristic context. Her book Wild Things describes the relationship between the user and a product once it becomes part of its owner's everyday context. In this case, the subject becomes a user, and the relationship is strictly between him and the object that goes from being a product to a wild thing. In such a situation, the subject is not the product's *creator*, but he acknowledges the object as a *wild thing* through ownership and usage. This thesis focuses on the relationship between subjects as *creators* and objects as *prototypes* when they are identified as *boundary objects*. Prototypes interact mainly with their creators; they use the creation as a conceptual representation for project evaluations. In these contexts, the subjects become *designers* while interacting with such objects because they interact with a product during its early stages of development. Sometimes, prototypes help transmit the project's concept to subjects outside the design group, like someone working on different aspects of the project or potential users (Carlile, 2002). In this case, the object-prototype works as a *boundary object*.

Design is a recent discipline compared with others, such as architecture. It relates to the quality of craftsmanship and the efficiency of industrial production. Design during its evolution did not specialize in one topic; instead, it spread more and more, creating relationships with other disciplines. The strength of today's design concept is its ability to reach out to more fields, enriching the design process. This ability, though, has its downsides. On one side, some disciplines, similarly to design, are structured and willing to reach out; on the other side, other fields struggle outside their knowledge zone.

Moreover, the design process includes different groups of individuals, such as engineers, designers, and potential users. In other words, today's design process has many subjects from diverse backgrounds and different aims. Therefore, when these subjects meet during the design process, they must find a way to communicate with each other. Therefore, words are often not enough, and the object they aim to design works as a communication channel. In other words, a *prototype* working as a communication bridge becomes a *boundary object*.

It is widely acknowledged that the industry context uses prototypes as development tools. For example, motorcycle companies use prototypes to make assessments about dynamic behaviour and user interaction. The prototype works as a development tool and boundary object in this context by establishing a communication line between designers and users. During the design and manufacturing, the company (considered a group of *creators*) interacts little with the product. The *prototype* is perceived merely as a tool. At the same time, it becomes a *wild thing* for the owner who buys the *product*.

Moreover, the word *prototype* defines also objects not produced in big batch sizes. For example, in a context closer to Polimi Motorcycle Factory, such as professional racing teams, the racing motorcycles are called *prototypes*. Here, the *object* doesn't work as a *tool*; there is an affectional subject/object relationship. Instead, the bike is part of the team effort to reach first place. In this context, *creators* keep in contact with the *prototype* during its lifespan. However, this prototype is not *unique*; professional racing teams have more than one bike per rider in case of a severe crash. The fact that the object can be *substituted* shifts the emotional connection from *the material object* to the *project concept* as a well-developed bike that brings joy and thrilling moments to the team members and riders.

The MotoStudent's reality is different; the prototype is unique. As said earlier in this thesis, teams hardly ever have enough budget to have spare parts for primary and critical components, such as the chassis and the swingarm. Not having such spare parts means that the team loses the bike in case of a severe crash. Hence, in MotoStudent teams, the emotional connection is established with the *material object* instead of the *project concept.* Furthermore, subjects (i.e. the creators or team members) perceive the prototype's uniqueness as a synonym for its fragility; when it happens, the *subjects* humanize the *object* acknowledging its aliveness; by this action, the *object* becomes a *fetish object*.

Moreover, the idolization of objects sets the grounds for complex social interactions. Because in contrast with animals' interactions, human society has a very *complex* net that exists on various levels and timelines (Latour, 1996). Objects are necessary to permit such *complexity* to exist; they let subjects of different timelines interact at different levels and moments in time. Nonetheless, *fetish objects* make some of these complex interactions possible; they make subjects gather around them and sometimes, it helps to give a purpose or an aim to a group or a single actor. In contrast with this aspect, the idolization of objects provokes the creator's alienation, making interaction less flexible. The lack of flexibility interferes with the brainstorming process typical in design groups such as the PMF team.

The case of Wilson in Cast Away[2]

The Cast Away movie represents the transformation of an object into a fetish idol and the social role it acquires. In the beginning, after the

[2] This concept was taken from Prof. G. Festi's fifth lecture 2019

crash, the main character starts browsing through the FedEx boxes, looking for objects that may be used as tools, till he finds a white volleyball. As a start is just a common object found between the wrecks of the plane, it doesn't have a special meaning or a role in survival. While the main character is manoeuvring the ball, he leaves a mark of blood on its surface; such a mark resembles a face. Such action gives the volleyball human features that lead the main character to acknowledge its aliveness. At this point, the main character becomes the creator of the idol. This transformation introduces the social role the volleyball acquires in the main character's survival. However, a fetish object exercises power and control upon its creator. He starts talking to the volleyball, gives it a name (Wilson), shares his discoveries and associates the success of creating fire with the volleyball. Over time, the ball ages resembling more to its creator. Finally, a piece of debris that arrives on the island opens the possibility of leaving. Such disruption creates a disruption that leads to a fight between the creator and the idol. During the fight, the creator remembers to be the one who granted the power to the idol and deconstructs it (Latour, 1996), relieving it from its social role and removing its powers, calling it "just a volleyball". Nevertheless, right after fighting with his companion, he regrets his decision, almost afraid of his gesture toward Wilson. The main power the creator associates with the volleyball is related to his survival on the island, besides from the daily company.

The movie described the born of a fetish object. To interrupt the link creator/fetish object, either the creator destroys the idol to be free from the gods and remains a rational being, or else the creatures of his creation will take him (Latour, 2021). But there is an in-between fetishism and *iconoclasm*, meaning that there is a middle ground between being a *slave* of its creations and destroying it all (Latour, 2021).

In a similar example, in its book On the Modern Cult of the Factish Gods, Latour describes how the peoples of the northern reaches of the Atlantic worship their god. They destroy the statues and images of their gods on bonfires or with hammers, insulting them and calling them "lie, nonsense!". They benefited significantly from these ceremonies as they freed themselves from their gods. But, ultimately, they fall into deep despair and, terrified by their doing, repair the Moh Dun gods, making countless offerings and sacrifices. Such behaviour resembles stressful moments inside the PMF team. During this period, team members perceive the bikes as fetish idols. When things go wrong, sometimes, they are willing to destroy the idols out of madness against them to feel relieved from the pressure imposed by the design and manufacturing of the prototypes. Nevertheless, they never dare to do such a thing because they understand the damage will be unrepairable.

Objects create communication through space and time

Objects work as an interaction framework beyond the design context. Latour describes the role of things as the interaction infrastructure of society. Such material infrastructure makes stratification of the interaction between subjects along different timeframes possible. For example, the team's prototypes work as boundary objects when they behave as a communication medium and as fetish objects when they act as a gathering force for team members. Moreover, such prototypes have another social role in transmitting project data through team cycles. Each built prototype remains in the Dipartimento di Meccanica displayed in the entrance hall; this way, new members can see the design decisions taken in the previous cycles. Unfortunately, though, senior members assume this to be enough to understand such decisions and to develop better design solutions. In other words, senior members expect the bikes to tell their story, linking the perception of the *object's aliveness* to the design process. Hence, senior members rely on the fetish object power to pass on knowledge. This act of giving for granted the object's social influence is related to the passive role the creator has towards the fetish that Latour and Spyer describe. As a result, part of the acquired knowledge gets lost during the turnover.

However, during a biennial cycle, the prototype's social role has a positive outcome. During this period, the object works as a boundary object and a material representation of the design constraints and solutions. The object links the present decision-making with the future when those decisions are put to the test.

Bruno Latour explains how communication is more straightforward in monkeys' societies. This simplicity happens because the communication occurs exclusively in the present between two subjects, hardly extends through time or is paused and resumes later on. In human societies, communication becomes *complicated* and *complex* because human communication happens strongly through objects. Latour describes objects as a medium used by humans to communicate with one actor in the presence and simultaneously with actors in different timeframes, from the past to the future. Decisions taken now on the design of an object will have implications on the usability of that object in the future, and human society strongly relies upon infrastructure to work correctly and keep the link between its subjects.

> "Human interaction is most often localized, framed, held in check. By what? By the frame, precisely, which is made up of non-human actors. Do we need to appeal to determination by material forces or to the power of structure to go from interaction to its framework? No, we simply transport ourselves to the places and times where the frame has been conceived and built. (…). We do not suddenly land in "society" or in the "administration." We circulate smoothly from the offices of the post office's architect, where the counter model was sketched and the flux of users modeled. My interaction with the worker was anticipated there, statistically, years before-and the way in which I leaned on the counter, sprayed saliva, filled in forms, was anticipated by ergonomists and inscribed in the agency of the post office. (…) I was inscribed there as a category of user, and today I have just carried out this role and have actualized the variable with my own body. Thus I am indeed connected from the post office to the architect by a slender but solid thread that makes me go from being a personal body in interaction with a worker to a type of user represented on a blueprint." (Latour, 1996, p. 96)

Similar to what Latour describes above, the prototypes represent the material outcome of the anticipation activity the ergonomists do to design the counter. During the design phase, students set constraints regarding the future users of the bike. Such future users are the rider and the mechanics. The former interacts with the bike when it is fully assembled; he hardly participates in the design of the components. The latter group mainly comprises students participating in the design and manufacturing phases. In other words, the subjects designing the object become the users, and the subject/object relationship evolves during the object's lifespan.

Prototype evolution as a social object

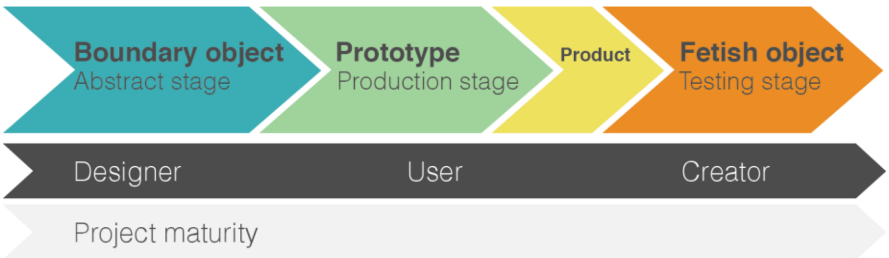
Previous sections helped to understand the role of *objects* in human interactions. Such objects go through an evolution thanks to their *social role*. In the PMF context, the bikes transition during the *design*, *manufacturing* and *testing* phases. The bikes evolve from being *boundary objects* to being perceived as *prototypes* and finally becoming *fetish objects*.

Before introducing the object's shift is helpful to refresh the team's goal and process. The PMF team is a semi-professional racing team for university students. Students gather together to design, manufacture and test a racing motorcycle. The PMF team develops two bikes, one for each category, the Electric and the Petrol. Moreover, the team participate in the MotoStudent International Competition; such competition includes the design and manufacturing of the prototypes. Finally, all participating teams gather for the Final Race on the MotorLand racing track. Hence the competition goal is to promote university experiences to enhance students' *competencies*. The competition last two years per edition; in the beginning, MotoStudent shares the regulation book and the kit. Such kit includes the engine and the braking system. The rest of the motorcycle is designed and manufactured by the teams. The PMF aims to develop most components, trying to buy as little as possible. Since the starting point is minimal, the bike project starts as an *abstract* concept in the beginning. Over time the project acquires more *materiality*, whereas the prototype shape gets set. The more the students collaborate to develop the bikes, the more the object's materiality evolves. Communication plays an essential role in achieving *materiality*. During the design phase, the bike is an *abstract concept*; it hardly has a well-defined shape. Each workgroup visualizes a different representation of the project. During this phase, the object (i. e. the motorcycle) works as a boundary object, representing a communication link between workgroups. Once most components exit the *design phase* and start the *manufacturing and assembly phase*, team members perceive the object as a *prototype*. During this phase, most workgroups share the same project's physical representation. At this point, the bike is assembled, some components get tested and eventually redesigned. The more the bike reaches full design maturity, the more it is recognizable as a *product* belonging to the widely acknowledged "racing motorcycle" category. Though MotoStudents bikes never become products because they never reach the market, they stay in the testing category object. Finally, the object becomes *a fetish object* when the *testing phase* starts, and the driver tests the fully assembled bike on the track. Figure 7 shows the prototype evolution during its development phases. Team members see the rider as part of the motorcycle and associate the motion with the *humanization* of the object. Through such association, students acknowledge the object aliveness, granting it power over themselves.

Concurrently, also the subject goes through an evolution. While the project works as a *boundary object*, the *subject* becomes the *designer* of such an object; he is not yet considered a creator because, during the initial phases, the *subject* is still in control of the *object*.

Figure 7 - Project's evolution from boundary object to fetish object

During the *manufacturing and assembly phase*, the subject is halfway between being a *designer* and a *user* because some components get



tested. The next shift happens during the *testing phase* when the object becomes a *fetish object*, and the subject becomes its *creator*.

The next section will describe the evolution through the categories mentioned above of the 2021 Petrol prototype to better understand the bike's role inside the team. In the PMF context, the object represents the focus of students' efforts to enhance their competencies by exiting their comfort zone through a semi-professional experience. Furthermore, since most new members hardly have previous experience in the field, they use the bike as a communication medium to brainstorm and achieve common goals.

From “2021 Petrol prototype” to “Sciura”, the birth of a material culture

The following paragraphs will describe how the prototypes’ lifespan interacts with the team culture. Since the prototypes are objects not bought but created by the team members, they undergo an evolution. During its evolution inside the team, bikes go from being an inanimate abstract concept to a *fetish object* in their lifespan. Since the team is subjected to frequent turnover, cultural growth accompanies this evolution. The turnover is related to the biennial competition; the team designs and builds the prototypes during this time. This biennial turnover will be called *a cycle*. One cycle lasts two years, starting with recruiting new members and ending after the Final Race. The prototypes are the main subject of the *cycle* and the *objects* around which the material culture grows. Each *cycle* is strongly connected with the prototypes designed and developed during its period. The object’s (i.e. the prototype) evolution goes through three stages: i) *boundary object stage*, when the object is an abstract concept existing only as a 3D model, ii) *prototype stage,* when the manufacturing and assemblability phase starts, and iii) *fetish object stage* when the testing phase starts and the creators (i.e. team members) acknowledge the bike aliveness.

Both *culture* and *object* evolve together because they are related to the creation of the *object* rather than its use. Therefore, instead of considering the *material culture* of *use*, this thesis considers the *material culture* of *transformation*. Because of this, during its lifespan, the object is *a boundary object* that establishes a communication line in an interdisciplinary group, a categorized vehicle and a *fetish object* that naturally has a strong magnetism for the team members.

More specifically, the *material culture* grows during the cycle thanks to the *bond* between members and the prototypes. Latour describes a similar behaviour in its Symposium On Interobjectivity regarding the relationship between *creator* and *fetish object*. At the beginning of the project, new members have poor knowledge of previous prototypes and the work to do to develop the new one. Senior management board members of the management board manage the project by assigning tasks to small groups of members. During this period, the groups are not interdisciplinary or cross-departmental, so communication is poor.

Further on, the design activity becomes cross-departmental. At this moment, the boundary object is born naturally through the CAD model that helps communication quality during brainstorming. The material culture grows stronger during this period. Team members get to know each other and the work they are doing. When the manufacturing phase starts, the object acquires the denomination of “prototype” or “bike”, as if before this moment, it wasn’t yet part of a product category. If at the beginning of the *cycle*, each workgroup had its own abstract representation of the project, now such representation is shared across most team members. Finally, the prototype is fully assembled during the testing phase, and its representation is no longer fragmented. This representation is shared between enough members that the prototype gets named. During the last cycle, the Petrol prototype was named *Sciura* (a word from the Lombardian dialect meaning “madam”) thanks to team members' personification of the object. The name was because this bike was the fine evolution of the 2018 world champion Petrol Prototype. Moreover, now the team members, in the role of creators, acknowledge the aliveness of the prototype, personifying it and investing it with the power of a fetish god. The bond object/creator survives in time thanks to the relation *object/subject* kept together by the *fetish object* the bike is transformed into. The cycle repeats after each race when new members enter the team.

Insights and next steps

In conclusion, the PMF team base the design and development of the bikes on the evolution of the *subject/object* relationship. The objects actively participate in the design process as a *communication tool* and a *shared representation* of the project. The workshop, where the bikes are assembled, becomes a gathering place for team members to work together to achieve common goals. The prototypes become so meaningful for team members, and they spend so much time with them that the bikes are humanized, acquiring a position equal to or above their creators. The following Part will frame problems related to such relationships and how these issues impact the project outcomes.

Part 2:
Problem

Chapter 4
Problem Framing: flexibility and the finite power of objects

The subject-to-subject relationship shows the team as a society that strongly relates to the material infrastructure granted by the context and the prototypes. Furthermore, learning is important in how students interact since the team is a university reality. As a result, the team is a complex problem-base-learning group. However, no facilitator is present, so students use context and objects familiar to them to achieve interaction. The following chapter will focus on the workflow weaknesses and their impact on the overall project quality. The tradeoff given by a flexible workflow can be precarious and result in quality loss. Moreover, continuity is a strength that has to be cultivated through team culture to keep a steady improvement.

Flexibility as adaptability or as a lack of structure

Flexibility in a design structure is significant because it gives space to creativity, which is crucial during the early phase of the design and development of a product. Creativity is a powerful tool to come up with unexpected and clever solutions to design problems, not only in university projects but also in small and young realities, since creativity helps to solve problems even with little knowledge. Polimi Motorcycle Factory is a young reality carried on by university students who bring their personal and university experiences to the project, different from a company's knowledge. The creativity process tends to be *fuzzy* (Rampino, 2022), unstructured and flexible, though such flexibility can cause a lack of structure inside the project. Even in small contexts, *structure* helps to have a more understandable organization, and tasks and protocols are more explicit. Structures help those newly arrived to understand previous work. In the PMF context, where turnover happens frequently, keeping track of the acquired knowledge and the reached results are relevant.

Moreover, structure helps new members better understand how the team works and its responsibility chain, clarifying the role of the management board. With the understanding of the organization, having a well-defined structure helps trace the project's path by setting more precise goals and constraints. In different words, the structure represents the path of the project, which means a lack of path, which leads to losing the meaning of the project, transforming it into a summation of separated decisions instead of having a *holistic* result (Baudini Buti, 2008).

In the case of Polimi Motorcycle Factory, flexibility dictates the team’s organization; there are hardly any internal milestones that are not related to outside constraints coming from the sponsors or the competition. Such a lack of organization provokes an unbalanced subdivision of labour and an unclear project goal. This flexibility works as a double-edged weapon, bringing the organization’s complications on the one hand and more space for team members to express their competencies on the other hand. Thanks to such flexibility, individuals made the team and not numbers. Through this peculiar characteristic, the team's members can solve unexpected problems quickly because they must use their competencies and creativity to become resourceful. The related issue to this characteristic is that not all students bring previous knowledge to solve some unexpected problems.

The team has always lacked an official structure. Since it was born, the first group of students participating had a solid knowledge of motorcycles; because of this, the formation wasn't necessary. They had clear goals. Such goals were to build their first racing motorcycle. Over time, this spirit has stayed in the team, though finding resourceful students with already-acquired knowledge wasn't easy. Instead of creating a more organized system, the experience was passed on like a tradition from *senior members* to *new members*, resting the expectation of this transfer on the meeting between these different subjects. But the more experience the team gained, the more difficult it was to pass on experience as a tradition through some moments spent together in the workshop around the prototypes.

It isn't easy to maintain project continuity by passing knowledge through tales and contact with senior members. For example, if the senior member leaves the team earlier than expected, new members cannot spend time with them and gain some experience. An archive of knowledge acquired through the *team's constructive learning approach* is helpful for project improvement. Even though learning is *contextual* (Mattioli, 2022), a part of it can be stored as an instruction manual of the process that leads to acquiring that knowledge.

Material culture and the idolization of an object

Objects go through a transformation along their lifespan. For example, PMF objects go from a communication medium with flexible representation to a humanized fetish representation. Materiality evolves together with representation. Moreover, the subjects around the object evolve as the subject/object relationship changes.

How the object evolution impacts the knowledge transmission inside the team

At the beginning of a *cycle*, previously designed bikes are part of the design and development phase. Since such bikes have completed their cycle, they represent the starting point to set new goals and improvements. Because of this, previously designed bikes work as *boundary objects* for *new members*. While the same bikes are fetish objects for senior member*s*, they have already acknowledged the bikes' aliveness and granted them power. The acquisition of this power is related to the testing phase. Such a phase helps to verify the component's reliability. The more testing is done, the better students understand prototypes' weaknesses and strengths.

Meanwhile, the prototype shows usage signs resembling scars, representing ageing and engagement by the members. Age signs on objects are related to how much the user has engaged with them, also showing attachment. The more the user uses the object, the more the object becomes a *wild thing* (Attfield, Wild Things, 2000). In the PMF case, such attachment provokes the shift towards *humanization* because students see the ageing signs as scars, relating them to experience and long life.

Furthermore, senior members use such marks on the prototypes to pass on knowledge and experience to new members because there is a link between such usage signs and senior members' experiences. The possibility to test the object is a fundamental part of the *constructive* *learning* process held by the team. Students can put into practice and test their concepts, enhancing their knowledge and competencies. Since students don't have teaching experience, they get inspiration from looking at the bikes to tell a tale to pass on their knowledge. Old prototypes become a gathering point that arouses discourses about those prototypes' design, errors, solutions, and peculiarities.

In object-centralized culture, what happens when the object is removed, or senior subjects fail to pass on knowledge?

Latour explains that human society requires material infrastructure to permit today's complexity. Moreover, it is unlike to have such stratified interaction in an abstract system. For example, religious contexts, where the conceptual aspect is strong, don't lack the material infrastructure to permit believers to gather. Moreover, such contexts have physical representations of gods and saints that link believers with their beliefs. Fetishes differ from Western religious representations (Latour, 2021) though they have the same gathering power. Western culture doesn't consider fetish objects holy, though they are addressed with much respect by the society worshipping them. In fact, Western religious representation and fetish objects are part of *ritual* activities.

In the PMF context, the workshop represents the material infrastructure, and the prototypes represent the material focus of students' work. Students gather to solve design issues instead of worshipping, though in both cases, the gathering power is held by an object. By removing the object, the group dissolves. When nothing attaches a subject to a context, such a person tends to leave that context. In the PMF context, dismantling finished prototypes will result in senior members leaving the team. In the team's history, no prototype has ever been dismantled. Instead, finished prototypes are retired because of components ageing or damage; when it happens, senior students are more likely to participate less and leave the team. Prototypes usually retire six months after the Final Race. When damages provoke a precautious retirement, senior members more likely leave the team before having the possibility of meeting recruits.

For example, after the 2021 MotoStudent event, there was a severe generational gap. Furthermore, due to the global health emergency, strict regulations prevented team members from gathering, and the racing date was postponed from October 2020 to July 2021. The additional time was helpful though it forced students to stretch their effort. Project responsibilities already made the context stressful; such stress, combined with the extended time and the precarious health emergency situation, made the work difficult for team members. Consequently, after the July 2021 final event, most team members left the team before the recruits were formed.

Subsequently, when new members entered the team in October 2021, most of the senior members had already left the project without passing on their knowledge. The only senior members left were less than ten, and most became part of the management board, the Gestione Sportiva. As said earlier, the management board organizes the project, sets milestones and goals and subdivides the project into small tasks to assign to group members. The students on this board hold management roles and have very little time to dedicate to singular tasks and formation. Because of this, senior members not part of the management board are significant because they support the project's technical development. In October 2021, almost no senior students were left to fill such a technical gap. Consequently, heads of departments had to fulfil two roles, making it more difficult for the project to grow steadily during the first months after the 2021 recruitment. Such a generational gap caused a lack of organization, a loss of time and a loss of critical knowledge about the design and development method. The team hardly ever organized work tracking using reports or presentations.

Objects permit to add complexity to society, but they can't avoid complications

In the symposium for the journal Mind, Culture and Activity, Latour explains how objects permit adding complexity to human society by creating relationships between subjects that never met. The following paragraphs will compare Latour's analysis with the relationship between senior and new team members.

In On Interobjectivity, Latour explains the different roles objects can earn in a human society versus a simian society, comparing the simplicity of monkey society with the complexity of human society. He describes how the latter is mainly made of simple direct interaction between two or more members of such a community, is very unlikely that simians engage through objects for an extended period or complex interaction between multiple subjects. On the contrary, human interactions are much more dislocated than simian ones; far from limiting themselves to the physical plane, they involve other objects and subjects in indirect interactions much more frequently. It seems almost a necessity. The involvement of objects permits humans to interact through space and time with other persons far away. Latour explains how in human societies, it is difficult whether or not to involve the presence of objects as a determining part of it. The sociologist asks himself how common objects shape the frame of everyday interaction and if it is correct to construct the social with the social or patch it with the symbolic, whilst objects are omnipresent in all the situations when sociologists look for meaning. Latour explains that, during the modern era, thanks to exact sciences, objects can no longer be seen as accomplices of the social life since they become "objective".

> "Because of this, objects appear only in three modes: as invisible and faithful tools, as the determining superstructure and as a projection screen. As tools they faithfully transmit the social intention that traverses them, without taking anything from them or adding anything on to them. As infrastructure, they interconnect and form a continuous material base over the social world of representation and signs subsequently flow. As scenes, they can but reflect social status, and serve as a basis of subtle games of distinction… Slave, master

> or substrate of a sign – in each case they are asocial, marginal or impossible to engage in the construction of society" (Latour, 1996).

So arises the question of whether or not sociologists should consider objects as part of the structure of a society or if they should start from interaction alone. Sociologists prefer to resist attachment to objects they see as fetishes because idols reverse the sense of action. Fetish objects are born when their human creator becomes powerless before them. But Latour's idea of including objects again in the structure of society contrasts with the concept of seeing objects as mere retro-projectors of social life. Extreme positions of anti-fetishism and objectivity of natural force have to be abandoned to find an equilibrium between what sociologists define as "*good objects*" or *force* and "*bad objects*" or *fetish*.

Looking back to the social role the prototypes have acquired inside the team, it is possible to trace some of the concepts explained by Latour in his symposium. The prototypes are fetish objects manufactured by the students, who give them everything they have in terms of energy till they no longer recognize the prototype as their own creation but as an object that exercises power over them. What they take in exchange are experience and knowledge. This way, the object becomes alive and independent in the eyes of its creator. The acknowledgement of aliveness leads the creator to believe that the object no longer needs him to speak by its regard because it can tell its story on its own.

The inevitable outcome of surrendering to the power of a fetish object is that an object alone can't be the structure of society; it can only serve as a part of it. Making all interactions dependent on the fetish object instead of granting *complexity* makes communication more *complicated* and tortuous. Furthermore, wrong complexity brings other downsides to a design and development project. Bad communication between senior and new members means losing precious knowledge and experience between cycles; consequently, the project evolves more slowly. Another downside of bad communication can be traced down to wasting time revisiting problems and tasks. As a result, the final prototype shows inefficient solutions. The primary components require more time than expected to be developed, and the quality gap between primary and dependent components becomes more significant. Finally, the prototype is no longer competitive.

Humanizing an object is not necessarily a bad habit. For example, Judy Attfield explains that objects that are not products anymore surround humans in their everyday activities. Similarly, Latour cites the story of the puppeteer who is perpetually surprised by his puppets.

> "He makes the puppet do things that cannot be reduced to his action, and which he does not have the skill to do, even potentially. Is this fetishism? No, it is simply recognition of the fact that we are exceeded by what we create." (Latour, 1996)

What the philosopher explains is that there is a midway term between *fetichism* and *objectivity*. Team members create special bonds with the prototypes they create and with the older ones. As explained in Part 1, the prototypes' social role goes through an evolution from *boundary object* to *fetish object*, going from being a flexible object that provides a space to start an interdisciplinary discussion about the project to becoming an untouchable thing. However, team members should scale down their vision of their creation to not lose control over the project. Because the prototypes, when fully assembled, are more than the assembly of components, they represent the experience and effort the students put into the project, but they are not gods; they are *holistic objects* with a more significant meaning than the one directly attributed to the object itself. Once assembled, the prototypes are more than just racing motorcycles; they should not be attributed the power to decide over their creators' faith.

Latour explains that it is normal for a *bricoleur* (i.e. creator) to feel amazed by his creation, especially if he is a student. When an idea acquires a physical body, it gains a more significant meaning. It embraces its creator instead of rendering him powerless once completed. Most design objects are meant to be more than their materiality because of the designer's values and concepts reflected in the morphological and manufacturing decisions that give a body to the project. For this reason, a *design object* should never become a *fetish object* and overtake the designer because he is not an artist who reflects himself in his art. On the contrary, the designer should create objects to condense solutions to problems without getting emotionally involved (Munari, 1971).

Insights and next steps

In other words, one of the most significant issues about fetishizing an object is losing control over it. In the team social reality and workflow, the prototypes have a prominent social role, not only during the design and development phase but also as a boundary between team members and past and present. But such was the power granted to the prototypes that the expectations of their social role exceeded their abilities as time capsules and members' boundaries. As a result, during the ongoing cycle, the project has suffered a lack of structure and task organization and an essential loss of knowledge and experience. As a consequence, the team spent precious time between knowledge gaps to be filled and organizational issues.

Chapter 5
How poor organization impacts the project quality

The object-to-object relationships are essential to understand how subject-to-subject relationships work since students interact primarily based on how their projects relate to each other. The project structure and method reflect the human side of the team. This chapter focuses on team aspects that represent examples of poor organization, how such factors were born, and why they are still part of the team. Finally, it will conclude with the relationship between bike components by dividing them into primary and dependent ones.

Implementing an NPD process in a university context

The team management board synthesizes the work of the entire team and, in addition, is in charge of setting the pace. It is widely acknowledged that industrial companies have sections dedicated to managing tasks and resources. With the advent of the consumerism market, the company organization became crucial when industries had to develop new products faster. The *NPD* process described by Rampino is an example of companies attempting to improve their production efficiency. In addition to the implementation of *Fordism*, *consumerism* pushed companies to become more structured because they had more employees specialized in single tasks with a poor project overview, so more supervision was required. The PMF faced a similar problem that remains partially unsolved. Initially, the team was composed of a small group of students with high knowledge of the motorcycle context; because of this, no strict structure was necessary since everybody understood the project well. Over time, the group enlarged, and the project required a more detailed design. The more complex the project, the more the task into which is subdivided. The more tasks are, the more crucial the organization. To cope with this issue, the team implemented the Dassault System PLM software 3DEXPERIENCE. As explained earlier, the software permits the management of the entire *project lifecycle*, including the resources. The software uses a Gantt chart linked to tasks and evaluation charts to show and manage the project's evolution. Even though the software is not time-consuming, the team makes poor use of it because even if the workflow is intuitive, the responsibility of keeping up with the chart rests on the management board. Since the board already has many duties related to the design and manufacturing of the prototypes, it becomes difficult for them to keep the chart updated. The team management structure doesn't have figures explicitly dedicated to this task. In an attempt to keep up with the Gantt chart, department heads inside the management board took away time from their primary duties regarding the technical aspects of the project. Consequently, time diminished, and the team had to focus on *primary components* to ensure the bikes were ready before the race. Such complications significantly impacted the quality of *dependent components*.

Primary components and dependent ones

The team design method is similar to the one adopted in other products or vehicle development. However, in the team's case, the design starts by setting the dynamics' overall dimensions. Once such dimensions are set, the teams design the bike's bone structure. Such structure includes three components related to the chassis: the swingarm and the saddle. These components are the *primary* ones; they take their definition because they impact the design of other parts. In particular, the chassis and the swingarm hardly ever have spare parts due to their production cost. Once primary components reach certain design maturity, the design of dependent components starts.

Parts necessary to make the prototype move receive priority during the design phase. Since this thesis focuses on the design of Petrol fairings, they will be used as an example of dependent components. The aerodynamics set a component not necessary to make the bike move and depends strongly on primary components. Aerodynamics components are a group of components with a bigger size on the entire project; they are in carbon fibre using external moulds. A sponsor manufactures the moulds while the team makes the components in the workshop. The aerodynamics set is a peculiar dependent component considering the size and the number of resources required to make them. Figure 8 shows a Gantt chart that helps better understand the dependencies between components.

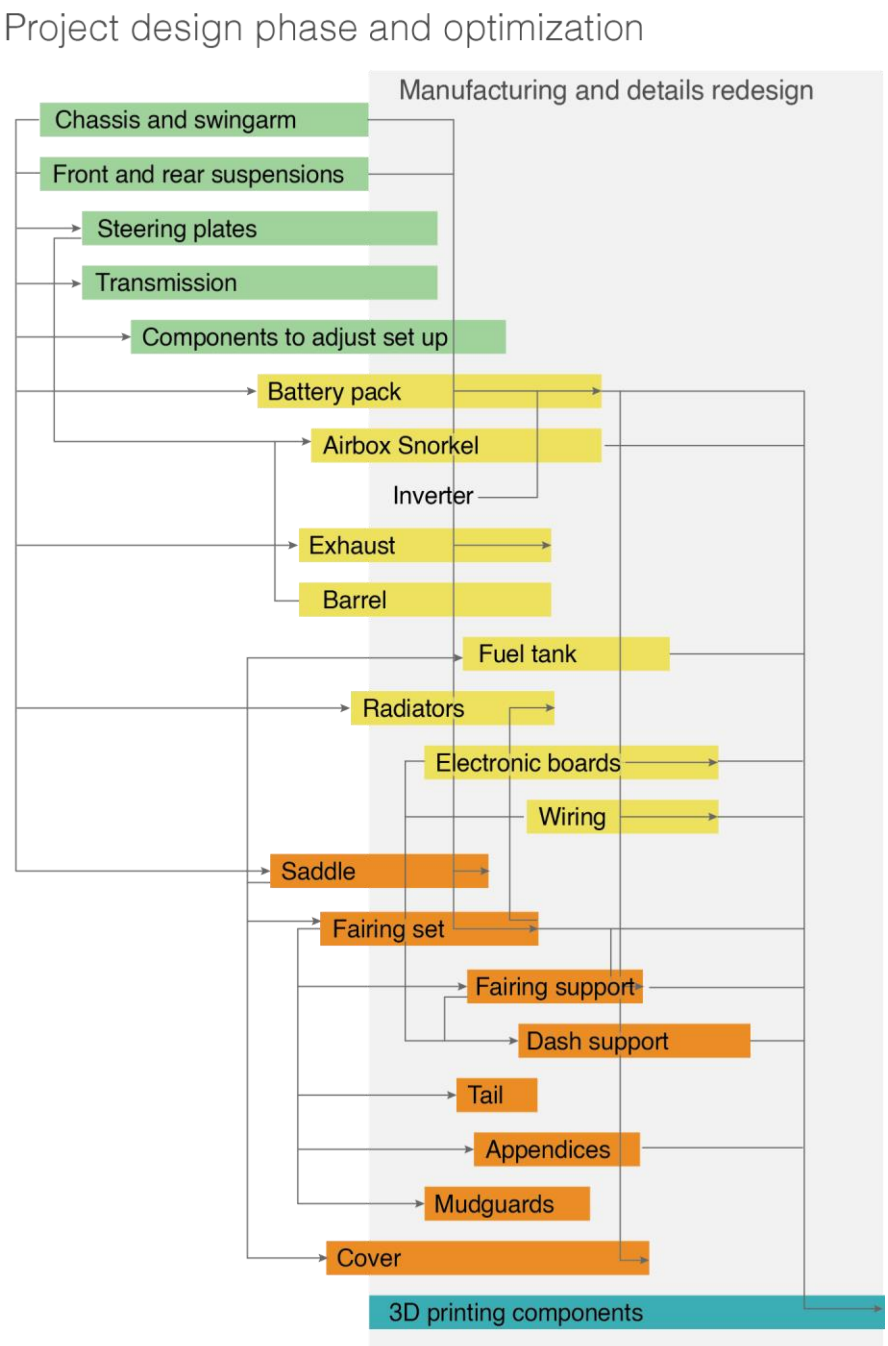


Figure 8 - Gantt chart of dependencies

The chart shows the importance of some components over others; components' design can depend on the start or the end of other components' development. Both chassis and swingarm require a lot of time and resources. Most other components are strongly related to the chassis and swingarm because they determine spaces and assembly between components. The delay in primary components affects most of the dependent components. Production is time-consuming; outsourcing complex components helps keep up the schedule. Sponsors set rigid deadlines, unlike internal plans, which are more flexible. Without internally imposed deadlines, dependent component production shifts forward on the timeline, reducing available time for the design phase.

Insights and next steps

In conclusion, project and resource organization help set goals and manage activities more efficiently. However, the PMF struggles to apply a steady organization to the design and manufacturing phases. To improve such aspects, the team implemented the use of the 3DEXPERIENCE software to manage the project lifecycle and process. However, the application was partially unsuccessful because maintenance was left behind due to more important tasks and activities. The lack of organization impacted mostly dependent components because the primary components' design period extended more than expected, taking away time for dependent components. The following chapter will focus on the fairing set history and design process to complete the overview of how issues impact such a component set.

Chapter 6
The team's approach to the fairing set design

The team approaches the project with an NPD method. The protoypes are designed from zero in a eighteenmonth time span. During this period new members have to be formed and the bikes have to be redesign starting from the race results and the project criticalities. Since the time is scarce, the assigns different priorities to main components. The section presents the team's design approach to the fairing set over the years. It will explain the development and manufacturing of such a component set, focusing on the relationships with related components and which criticalities have risen.

History of the PMF's fairings sets

The fairings set comprises all the parts of the shell surrounding the prototype, and its main aim is to enhance the bike's aerodynamics. Most racing bikes are equipped with a fairing set that can be custom or commercial, depending on the project, the racing category, and the team's budget. Moulds are produced by swarf removal processes using resin or aluminium, depending on the batch size. The set parts are made in composite materials or by thermoforming. Because of the materials used, the dimensions of the components, and the manufacturing process, the production cost of such elements is high. Despite this, the team has continuously developed a custom set for each prototype since 2016. The PMF chose to develop the aerodynamics aspect from the beginning to have a complete experience developing a racing motorcycle. The team has designed and manufactured four complete fairings sets and five aerodynamic packs. The aim has always been to enhance the project with custom aerodynamics to improve each prototype's overall performance. The team also enriches the fairing set project with more simulation details, better manufacturing solutions, and completer aerodynamics analysis. Despite all, these are *dependent components* because of their relationship with *primary components* that have priority over them in the *design phase*. They silently enhance motorcycle performances, and because of this aspect, they receive very little attention from members outside the Fairings&Aerodynamics department.

Figure 9 - All prototypes since 2016 till 2021

On the contrary, aerodynamics can significantly improve the overall behaviour in a competition where all bikes share the same engine (or motor for the Electric category). In professional motorcycle championships, MotoGP mainly studies aerodynamics, including appendices and wings; smaller categories dedicate less time to studying such aspects. Moreover, MotoStudent is the only motorcycle category where active appendices are allowed.

The first fairing set was designed and produced in 2016 and participated in the IV MotoStudent edition in the petrol category. The first prototype reached the tenth overall position in the classification. This set was developed using Alias software's *style modelling* by intersecting and trimming surfaces between each other. To be assembled, the set was divided into four parts assembled with screws and *quick releases* and then connected to the chassis with two *fixing clips* positioned on each side of the fairing. The manufacturing process used for this set didn't require the production of custom moulds. Instead, the fairings were divided into smaller parts produced by an additive manufacturing process called selective laser sintering (SLS) using a ceramic material called RAPID and a polymeric binder. Later the printed sections were glued together and used as an inner mould for the carbon lamination process. Because of this, the parts were heavy, fragile, and inaccurate due to the glueing process, and the manufacturing process required three weeks to produce a complete set. After this experience, in 2017, the team developed a second fairing set using the same mould-free manufacturing process. This set was called *Intermedia*. This set was the first developed using CFD simulation to optimize the aerodynamics. And it represents the starting point for developing the two following fairings.

In 2018 the third design was optimized and produced. This fairing used a different modelling strategy, the *freestyle* of the software PTC Creo. As a result, the surface was continuous with no interruptions of tangency and a more complex shape. Also, the modification was faster to be applied, and it was easier to introduce more iterations to optimize the aerodynamic behaviour. This set shared similar characteristics with the second fairing *Intermedia*; the sides were large and distant from the chassis, the *upper fairing* was long, and the shape covered half of the hands and feet of the rider. This fairing was called *BM0*. After the 2018 podium, the team decided to maintain the same design concept for the new electric prototype. Such a fairing set had a long *upper fairing* covering half of the hand and arm, the *lower fairing* was round, and the *sides* were narrow, exposing half of the leg; the fairing also presented inner surfaces to enhance the motor cooling. This fairing was called *MF04*. Both *BM0* and *MF04* fairings sets were optimized using the streamlines to trace the upper fairing curvature to enhance the *slipstream* behind the rider's back. In 2021 the team participated in the race, inscribing a prototype for both categories, Petrol and Electric. The petrol prototype shared the same fairing with the 2018 bike; a radiator conveyor enhanced the internal airflow.

All fairings sets designed till now shared similar shapes and similar aerodynamic goals; such goals aimed to optimize drag coefficient and reduce turbulences in the slipstream. These are the basic requirements to reduce the vehicle rolling resistance coefficient. In addition, in 2021, the team used aerodynamics to improve the bike's cooling system on both prototypes.

The aerodynamics is optimized through an iteration process between CFD simulation, analysis and CAD modification. The project starts with evaluating the previous prototype's pros and cons by analysing the CFD simulations and racing results. Then the simulation case (called a *base case*) is built, creating a simplified *mesh* of the bike structure, and setting the suspensions at the correct compression. The *mesh* remains the same for all simulations; only the fairing set is substituted. The base case is necessary to reduce, at minimum, the variations between simulations and focus the analysis strictly on the aerodynamic pack. Simulations are hardly comparable between them if some aspects of the mesh or the *boundary conditions* change. Because each component interacts with the air and contributes to the final result in terms of drag coefficient, lift, pressure and slipstream. The project must have reached a details-level maturity to build the structure for the simulations. Because of this reason, the fairing set is strongly dependent on most structural components and dynamic decisions. Otherwise, it would be necessary to rebuild the inner mesh. The iterative process would be less accurate and longer because the relationship between components helps to fix the project's goals and constraints used as guides to create the CAD modelling.

Because of such strong dependency, other workgroups outside the Fairings&Aerodynamics Department perceive the fairing as the prototype skin, as a simple cover. So is expected to show the best aerodynamic performances without representing a constraint for other components. And since it has a significant dimension, it depends on a large number of components developed by different departments with different deadlines. The *design phase* of some of such components finishes even after the fairing set must enter the *production phase,* but the dependency isn't inverted. Fairings depend on sponsors that impose deadlines, while manufacturing other components happens in the workshop, so the team sets the schedule.

From the beginning till 2021, the team was sponsored by a company that produced custom pieces for motorcycles using an additive manufacturing method to produce the moulds. This method requires machine time, and because the mould is divided into smaller pieces to be printed later in necessary to glue and sand them manually. The outcome is a fragile mould unqualified for the autoclave because the pressure generates cracks and breaks. The process is longer than the traditional one that uses slabs of milled polyurethane resins and is less accurate. Furthermore, because of its fragility, geometries with undercuts must be avoided, and draft angles must be abundant, restricting geometry freedom.

Because of mould manufacturing time, the fairings must be ready for production several months before the race, even if some *parent components* are not yet ready. Producing *children components* before *parents* haven't reached *production maturity* generates a discontinuity in the project, compromising project quality because of a lack of organization and prediction.

Dependencies between the fairing set and other components

Since the fairing covers most of the bike, it interacts with many elements to have a cleaner slipstream. It is helpful to take a step back and understand how the prototype is built and moves to understand the components' interactions.

The motorcycle is not a rigid body; thanks to the suspensions and steering, groups of components move relatively between them. Therefore, the team approaches the dynamics issue by dividing the CAD assembly into subassemblies with no relative motion between them. Such subassemblies are the following ones:

- **Rear rotating masses**: including the wheel, the braking disk and crown
- **Swingarm:** single component
- **Suspension link:** suspension arms
- **Mainframe:** includes all components of the powertrain such as the engine (or the motor for the electric prototype), the saddle, the tank or the battery pack and inverter, the dashboard, the radiators, the exhaust system and intake system, the fairings and aerodynamics pack all assembled to the chassis
- **Front suspended masses:** suspended parts of the front suspension
- **Front non-suspended masses:** suspension parts connected to the wheel and the brake
- **Front rotating masses**: front wheel and braking disk

The team designs most of the listed components, and a significant percentage are also manufactured in the workshop. For 2021 the prototypes the list of parts produced by the team included:

- The battery pack: including welding and production of the case

- The fairings set, mudguards and lateral fairing connections
- The cover of both prototypes, one being the cover of the battery pack
- The intake system, including the moulds
- The wiring, electronics and dashboard of both prototypes
- Both the transmission and electronics carters
- Several small cases and connection parts produced by FDM

Components that require specific infrastructure for production are left outside the list. Such a list includes big-sized moulds, both chassis and swingarm, radiators, exhaust system and saddle. The remaining components are *buy* products or part of the MotoStudent kit.

To create the *base case* for the simulations and to model the fairing is necessary to have the mainframe, exhaust system, radiators, chassis and swingarm, battery pack and intake system ready for production. Unfortunately, most of them are still in the *design phase* when the fairing development starts, forcing the base case to be subjected to periodic updates impacting simulations' results. Moreover, specific components block fairing production deadlines. These components are:

- Chassis and swingarm: critical development and sponsor dependent
- Exhaust system: sponsor dependent
- Position and dimension of the intake inlet: workshop production
- Shape and dimension of the battery pack: workshop production
- Electric prototype transmission and carters: critical development but no sponsor involved
- Dimension and position of the radiators: buy components and short-term development

Figure 8 shows *parents/children* dependencies around the fairing and a simplified Gantt chart. It is possible to see how critical and sponsor-dependent components must enter the *production phase* earlier than the one manufactured *in-house* or by an external company under commission. The chassis and the swingarm are the two main parts of the bike that dictates overall dimensions, dynamic behaviour and connections between the parts. Because they represent the prototype's bone structure, their development must start first and finish as early as possible so that other components can enter the production phase. Their development is subject to an iterative process between design and FEM simulations to achieve the best trade-off between low-weight and stiffness targets. Because of this, these components are located at the beginning of the Gantt chart. Differently, the exhaust system doesn't have many components that depend on it, but it affects the engine performance. So its optimization is longer and depends on previous prototypes' tests. Also, its manufacturing process is more straightforward and shorter than the one required for the chassis, so more time is dedicated to optimization.

Moreover, radiators require dimensioning to be produced using data provided by the engine data sheet. Because of this, its production is postponed closer to the track tests. The result is that the assembly between radiators, chassis, and fairings is not designed and optimized but put together in the best possible way when the parts are already finished. Ending up with radiators not optimized, bigger than required. Fairings can improve radiators' performance.

Insights and next step

In conclusion, a well-developed design process makes a difference the race day. Therefore, the team should aim to reach enough project maturity in most components, regarding their importance. Team structure and organization in fundamental to achieving good results. The more complicated the communication between departments, the greater the possibility on impact negatively the racing day. This chapter showed the complexity of designing a racing motorcycle, focusing on developing a dependent component. This part aimed to focus on the complexity and weaknesses of the PMF design process to attempt to implement a subtle design method to enhance the communication between departments collaborating in the design of the fairing set.

Chapter 7
The research questions

Some practices are commonly applied without analysing their effectiveness in a young team with frequent turnovers, such as the PMF. The team's organization and project structure do not result from an explicit application and analysis. Instead, the students give for granted subject-to-subject interactions weighting on the project quality outcome. The following chapter will introduce the research question by summarising the criticalities and problems regarding the team organization, the relationship between members and the prototypes, and how this impacts the project outcome.

This part reassumes criticalities appeared till now in the fairing set project development based on the relationship the team members have with the prototypes and the material culture that holds the team together.

As described in Part 1, team organization is based on responsibility. The team structure has a pyramidal shape with the management board on the top. Heads of department composed the board, representing each department. The board conveys the work of the departments guaranteeing crossover communication to achieve the best possible trade-off. They also help the project continuity by setting goals and constraints. Management of tasks and approval of single tasks and components control are also part of their duties. The team members are divided into departments on the base of the pyramid. The structure lacks further stratification creating an unbalanced work division. Furthermore, the team *culture* strongly depends on the prototypes to work as *gathering objects* and as a knowledge capsule, expecting the prototypes to be the *infrastructure* necessary to make the team works. Team members perceive the bike as *fetish objects* attributing power over the group. Latour and Spyers explain how acknowledging aliveness in objects takes away the control from the creators' hands. As a result, students place high expectations on the prototypes' social role.

Part 2 describes how the lack of structure becomes an issue for new members with little knowledge of the project because of a lack of guidelines and lack of contact with the work developed previously, impacting continuity and quality. Team culture is based on prototypes as the epicentre of all activities, creating a common ground for discussions and gatherings. However, this focus on the prototypes is insufficient to make an infrastructure to support the team's activities.

Students discuss based on the assumption that certain information about the project is well known by everyone resulting in misunderstanding, loss of time, low-quality outcomes and lack of connection between components. This thesis aims to empower the use of the object as a *boundary object* to *make explicit this tacit information* through a type of communication the team already know, which is the brainstorming process.

Considering all the analyses previously developed, the research question this thesis will try to answer is:

. How can component-to-component and component-to-time relationships help identify collaboration touchpoints between workgroups developing related components of a high-complexity prototype?

. Starting from the collaboration touchpoints, how can a structured method of defining shared objectives and constraints leverage the collaboration between workgroups developing related components?

Introducing a *new method* to approach discussion between groups of different departments working on prototypes communicating components will help answer the research question. This approach aims to exploit methods already known by team members to avoid refusal by team members. Moreover, the goal will be to propose a subtle change in the workflow without introducing new tools, exploiting what the members use daily to interact and maintain track of the project development. Hopefully, introducing a methodology will increase awareness of the project's teamwork and overall vision. Because historically, the team hardly ever took the time to actively understand the relationship between the components and the members working on their development.

Insights and next steps

Part 3 will introduce the new methodology applied in the design and development of the Petrol fairing set. The aim was to use brainstorming sessions to set constraints with groups of *parent components.* In addition, such structured methodology aims to create interdepartmental communication channels between workgroups developing related components. The meeting protocol aims to frame each component set of constraints to contextualize opportunities and common goals between related elements. Consequently, it is expected to create links between students working in parallel, partially sharing their component context and constraints to reach production maturity with a more integrated design.

Part 3: Methodology

Chapter 8
The introduction of a new communication methodology

This chapter will describe a new approach to developing a dependent component in the Polimi Motorcycle Factory team and the protocol structure applied during the meetings. Such a method introduces a protocol to organize meetings with project groups of components directly related to the fairings set. The aim is to exploit the material culture the team uses to build subject-to-subject relationships through object-to-object relationships to promote the construction of common goals between related components and make implicit communication explicit.

The implementation of a subtle change in the workflow

The approach implemented in designing and developing the 2023 fairings set was born from the team's idea of reusing the material infrastructure already known to avoid rejection. Since the team lacked structure and a balanced task subdivision, it seemed fair to implement a method that didn't require additional time and resources or had to be understood and applied. Consequently, the approach is a *protocol* for the meetings' organization with groups of fairing *parent components*. The protocol doesn't require the other members to change their design method; it should help them receive and transmit information more efficiently, possibly recalling it anytime they need it.

Focus box: collaborative learning

The term refers to learning practices built to acquire knowledge through co-labour activities structured by teachers. In such contexts, students work together to achieve shared goals through active participation in a design project. Often, teachers structure intentional learning activities and divide students into work groups. All group members must work together to achieve stated objectives. Moreover, all students must actively participate; if one student works while the rest of the group watch is not considered collaborative. As students work together, they must deepen their understanding of the topic. Such intentional activities foresee shifting responsibilities to students. (F. Barkley, Cross, & Howell Major, 2005, p. 4-5). The PMF team apply a collaborative learning structure in their design activities by setting meaningful goals and shifting responsibilities to students. However, the faculty advisor has little participation in their activities.

The aim was to avoid overwhelming, increasing the brainstorming efficiency and trade-off between designs of different departments to avoid independent design development and promote a more integrated approach. Furthermore, such change in the project approach should promote *competencies* growth in a *collaborative learning* environment.

Structure of the protocol

The concept behind this protocol was to give a structure to small reunions between interdepartmental groups about specified technical and design topics. Since it would have been useless to impose a complex routine on a team that wants to preserve personal contribution from the students, it has opted for a more delicate attempt. The goal of the protocol was to enhance the communication between designing different departments' workgroups to promote project continuity along the bike's parts. To achieve such a goal, the group developing the fairing set applied such protocol to technical meetings with workgroups of related components.

These reunions aimed to make explicit information about components design, discuss shared design topics, and achieve shared solutions. The protocol required that the reunions were in person whenever possible and that they followed the following criterion:

- Clarifying at the beginning of the meeting goals and topics,
- Decide a maximum duration for the meeting,
- During the session, analyse both the 2023 design and 2021 prototypes, inviting senior members when,
- Make a recap of all topics and check if all have been gone through before finishing the session
- At the end of the meeting, send a summary of all issues and solutions by email or Telegram channel.

This section introduced the protocol that has been applied to set constraints for developing the fairings set. Before describing the outcome of such an application, I will briefly introduce my personal experience as part of the PMF project.

Brief description of my experience and how my role evolved inside the team as a product design student

This section briefly describes my personal experience as part of the team, detailing the evolution from team member to head of the Fairings&Aerodynamics department. Moreover, the chapter will focus on the designer as a technical figure in a management role. My experience inside the team started in January 2018, ten months before the MotoStudent V edition of the competition. I started as a designer and surface modeller participating in the development of the *BM0* fairing. At that time, I had poor knowledge of racing motorcycles but was admitted because of my design background. The team admits designers mainly because the students learn to apply a project methodology independently from the object of the project.

During this period, I worked with aerodynamics students, learning to interpret CFD simulation results. My job was translating such solutions into morphological modifications to apply to the fairing to achieve better aerodynamical results. The main goals were a lower drag coefficient and a cleaner slipstream. Furthermore, I started participating in workshop activities, where students from different departments gathered together to manufacture components and solve post-production problems. The workshop activity helped build an overview of the whole project. In addition, it was the easiest way to learn about other components' development and functionality. My workshop activity was solving flaws regarding the fairing set since inaccuracy generated assembly issues. Participating in such activity helped retrieve information about components interaction and subject/object that could help the development of a new and better-integrated fairing.

One and half years later, after my entry, I was named head of the Fairings&Aerodynamics department while my previous boss became team leader of the electric prototype. At that time, till the race, the two of us and another student were the only three design students in the team. Our research for the *holistic* was mistaken for the research of beauty; because designers base their developing method on the morphological equilibrium of technical aspects. Part of the designer learning path aims to teach to build bridges between different disciplines (Attfield, 1999). Designers develop this ability as a design method instead of acquiring a large amount of theoretical knowledge. They learn to work on projects where their knowledge will hardly be to overcome all criticalities. Designers train to make a trade-off between technical requirements, merchandising aspects, semantic aspects, manufacturability, ergonomics, etc. The translation of constraints in morphologic solutions is the holistic meaning the designer grants to the final product, spacing between his field of knowledge and what is distant from his sphere.

Therefore, a design student in the role of technical manager for a department developing *dependent components* is more inclined to include the constraints of related motorcycle parts during the design process. As a technical manager, I supervised the development, checked geometrical constraints, and complied with MotoStudent regulations and project constraints. These responsibilities extend to all components developed under my supervision, including fairings' mould. As a technical manager, I supervised manufacturability, assemblability, usability, and materials constraints. After mould production, I was in charge of fairings manufacturing by carbon fibre wet lamination technique. Moreover, all heads of department must reassure the proper use of machinery, tools and, accident prevention design devices, components' correct assembly and that safety checks were made before track tests. Most of the responsibility for a positive outcome of the project and testing relies on a small group of students.

During the last year of my management experience, my department was assigned to develop the structural saddle, a structural component usually developed by the Chassis&Dynamics department. The saddle is a shell-like carbon fibre component that works as the saddle and the rear chassis holding in position, respectively, the inverter and the tank—subjected to a compression test that requires holding 250Kg on the farthest point from the junction to the chassis. It is designed and optimized by applying FEM analysis to choose the best plybook. For the department, introducing a structural part represented a new challenge. The fairings pack and inner ducts are not considered structural because they hold their weight and the force exerted by the air.

My experiences allowed me to follow a multidisciplinary group of students through designing and manufacturing fairing sets through three cycles. Allowing me to see how students from different backgrounds interact with each other and with the prototype and how important organization is. Moreover, I noticed that each team member focused on various aspects of the project. Frequently students focus on small details instead of looking for the overview aspects. Because of this, frequent updates and meetings help to keep in contact with members of different departments, which is crucial for the project outcome. During my experience, a recurrent problem was the lack of interdepartmental communication; each group worked isolated and met only once in a while. There is no protocol to address interdepartmental collaboration.

Insights and next steps

Thanks to my experience as a technical manager, I decided to approach such a lack of organization by introducing a subtle change in the design phase of the fairing set. The new method aims to optimize interdepartmental communication through the awareness of components relationships subject/subject relationships. The following chapter will describe the outcome of the meetings that have been made applying this method.

Chapter 9
Meeting description and discussion outcome

This chapter will include a description of the meetings that were held and the results in terms of information shared between departments. Such meetings were held separately with workgroups from all technical departments, such as Chassis&Dynamics, Electric Powertrain and Petrol Powertrain. The goal was to cross-departmental brainstorming to set goals shared by all related components to achieve a better-integrated fairings design.

Meetings introduction

Part 1 of this thesis describes team subdivision into thematic departments. Four of them are technical; there are two separate departments dedicated to the powertrain of each bike, a single department dedicated to the development of the structures and the dynamics called Chassis&Dynamics, and one dedicated to the aerodynamics and ergonomics for both prototypes. The meetings took place with the three technical departments with the participation of the department heads and team members. The goal was to achieve shared trade-off constraints through a brainstorming activity. The meetings were held one at a time. The meeting was also attended by the students in charge of developing the fairings set and running CFD simulations. All students were asked to participate actively and follow the main topic avoiding distractions. 2021 and 2023 complete CAD assemblies, shown in Figure 10 and Figure 11, were used as *boundary objects* during all meetings to promote comparison and brainstorming.

Moreover, I have participated as a *participant observer* (Spradley, 1980), coordinating and facilitating information based on my experience. Every meeting had a duration of two hours. Each meeting started with a list of objectives and ended with a recap of all discussed topics. Afterwards, I sent a message will all the discussed topics on a Telegram channel. I chose such a communication channel because the team already used it. In addition to these meetings and the Telegram channel, there have been other meetings for new updates. Likewise, there have been meetings internal to the Fairings&Aerodynamics department to discuss design optimization.

It will subsequently describe the meeting outcome. Afterwards, it will be explained how these results were analyzed and translated into morphological decisions applied to design the fairing set.

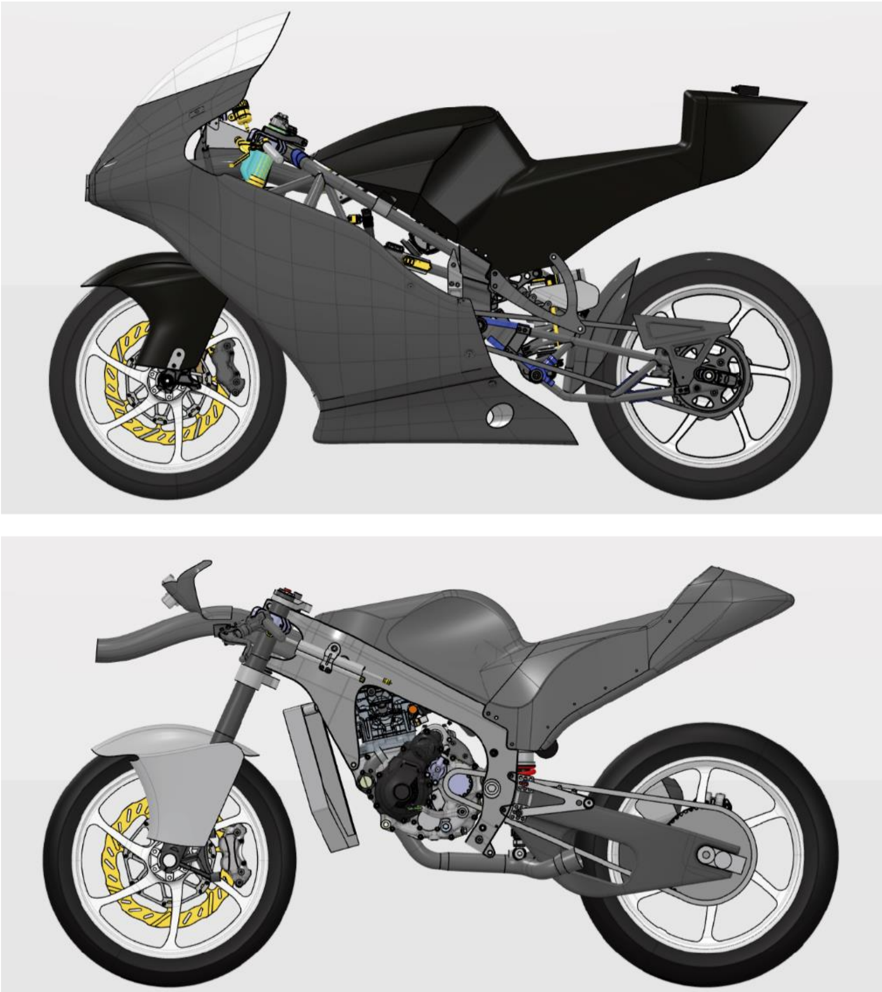


Figure 10 - The comparison between 2021 (above) and 2023 (below) petrol prototype CAD assembly

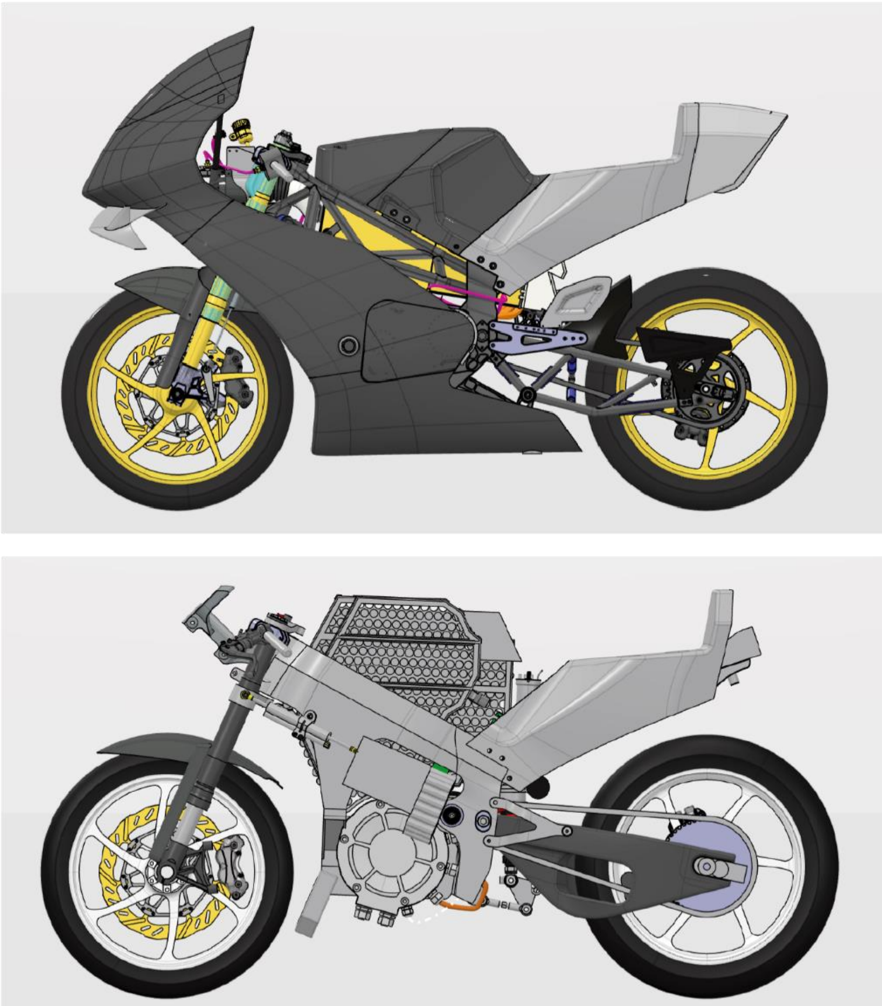


Figure 11 - The comparison between 2021 (above) and 2023 (below) electric prototype CAD assembly

The meeting with Powertrain Petrol

The first meeting was with the students from the powertrain petrol department. The meeting was attended by their department head, the student in charge of dimensioning the radiators, the student designing the intake system and the one designing the exhaust system. In the beginning, the goal of the meeting was clarified, and the topics to discuss. The goal was to brainstorm about the requirements and interaction between components and how they will be connected. The topics were the following:

- **Intake system**: dimension and shape of the snorkel intake to improve the design of the link between the snorkel and the fairing and improve CFD simulations, the junction between snorkel and chassis to understand if the snorkel will be single or split and if the snorkel will be structural,
- **Radiators**: minimum dissipating mass, maximum inclination angle to make them work effectively, shape, minimum distance from the exhaust system and airflow,
- **Exhaust system**: shape, minimum distance from the fairing, and height from the ground to comply with Motostudent regulations.

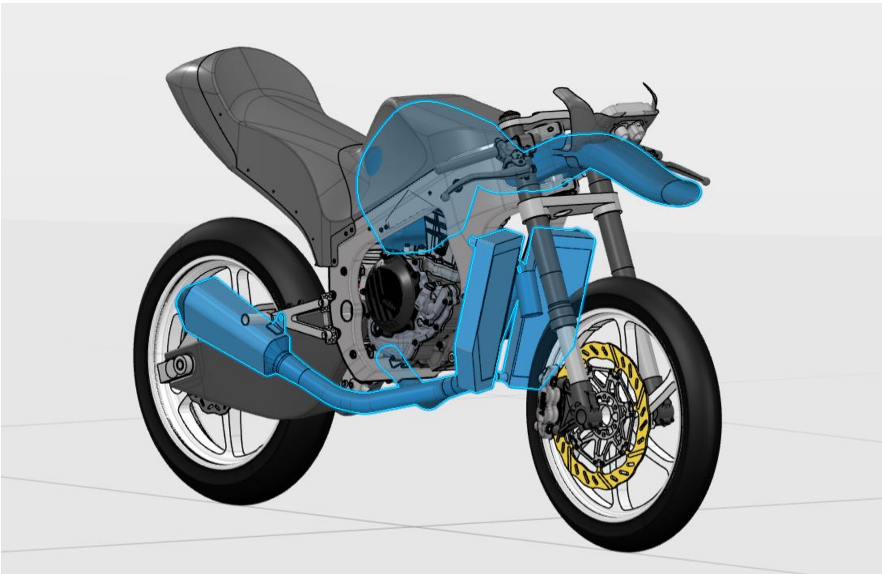


Figure 12 - Highlights of the exhaust system, radiators and airbox inlet

The first brainstorming was about the intake system; the student designing it explained that the inlet shape would have been elliptical and its size would have been identical or slightly larger to the older one. He explained that the best positioning was on the fairing tip, where the aerodynamic pressure was higher, equal to older prototypes. I suggested designing the edge of the snorkel as a quarter of an ellipse and producing the first section of the snorkel altogether with the fairing to avoid flow separation. The student also explained that the snorkel would have gone through the chassis without splitting around the front suspensions, which meant that the fairings would not have to consider its encumbrance. Then we agreed that the snorkel must be a structural component, able to support the fairing and eventual appendices, and screwed to the chassis.

The second brainstorming was about the radiators, considered a critical topic since the 2018 and 2021 prototypes mounted oversized radiators; in addition, the position of those radiators was wrong since no junction was designed before production. We agreed on dimensioning the radiators correctly and integrating them into the project for the new prototype, creating inner ducts to channel the air in the radiator and out the bike. The minimum mass must be equal to $65cm^2$ area with a thickness of 30mm, distributed in two separated radiators or a single one in the shape of a *u.* They also explained that the radiators must be at least 20mm distant from the exhaust system that passes through the midplane. Finally, regarding the prototype's usability, they explained that the ducts must be removed quickly to work freely on the bike.

Regarding the exhaust system has the shape of a *y* and passes below the engine and on the sides of the swingarm, we agreed that the fairing has to stay distant from it to avoid burns. Also is closed enough to the engine not to represent a problem regarding the MotoStudent dimensions constraint that imposes 100mm between the ground and the fairing.

During the meeting, we also briefly brainstormed about connecting the fairing and the snorkel to the chassis in the best possible way. Figure 13 shows the message sent at the meeting ended as a recap of all topics.

Carene 2023
RIUNIONE POWERTRAIN PETROL:
- SNORKEL:
Lo snorkel deve trovarsi sul punto di maggior pressione sulla carene.
La bocca sarà ellittica, circa della dimensione di quella attuale, con la possibilità che sia poco più grande.
L'ingresso della bocca dello snorkel invece di avere un gap tra la superficie esterna della carena e lo snorkel stesso avrà un ingresso simile al barrel con un quarto di ellisse in modo da ridurre la turbolenza in ingresso, lasciando la prima parte dello snorkel solidale alla carena.
La carena verrà simulata con la prima parte dello snorkel incluso e lo snorkel con la parte anteriore del muso.
La sezione sarà il più costante possibile, è possibile che abbia delle convergenze e divergenze e può essere curvo tra l'ingresso e l'airbox.
Oltre questo lo snorkel potrebbe essere sdoppiato verso l'airbox passando fuori dal telaio, ma è più probabile che si sdoppi solo intorno al perno di sterzo passando attraverso il cannotto.

- RADIATORI:
includere i radiatori nella progettazione della carena dall'inizio.
Massa radiante: 65cm2 con 30mm di spessore - 55cm2 con 48mm di spessore.
Inclinandoli più di 20 gradi iniziano a lavorare male a meno che le lamelle non siano inclinate ad hoc.
Possono essere distanti tra loro e l'ingresso dell'acqua può essere anche nella parte inferiore. Possono essere sia due separati che uno unico a U o a U rovesciata.
Durante la progettazione della paratia anteriore ai radiatori considerare di convogliare l'aria sulla massa radiante, chiudere al meglio intorno ai radiatori ma permettendo il passaggio di aria verso la coppa dell'olio.
Considerare di progettare una paratia posteriore ai radiatori per guidare il flusso d'aria verso fuori in modo ordinato, verso la parte inferiore della carena o sui fianchi della carena. é importante che entrambe le paratia possano essere montate e smontate a prescindere dal montaggio dell'avantreno e dei radiatori.
Per iniziare la progettazione della carena prendere in considerazione i radiatori in una posizione canonica e iniziare con il disegno della carena. Solo successivamente si passerà a provare di ruotare i radiatori.
Realizzare un parafango come quello della sciura, che indirizza il flusso verso i radiatori.
é importante che durante il posizionamento dei radiatori si lasci almeno 20-30mm di spazio con lo scarico. Evitare di posizionare i radiatori dietro lo scarico per evitare che prendano aria calda.

- SCARICO:
Sarà sdoppiato e sulla parte bassa della moto, passando dentro il puntale e di fianco al forcellone.
Stare lontani dallo scarico per evitare di bruciare la carena.
Accertarsi che la posizione dello scarico e del puntale permetta la realizzazione della parete posteriore obbligatoria per contenere i 2,5L da regolamento.

Figure 13 - Telegram message regarding Petrol Powertrain meeting

The meeting with Chassis&Dynamics

The meeting with the Chassis&Dynamics was the second one. This meeting was attended by the department head, the two students developing the chassis of each prototype and a technical director. Since the chassis is a primary component, the goal was not to make a trade-off between the components, but rather the goal was to understand the limitations imposed by the chassis and the front suspension system regarding dimensioning, movement, optimization of the chassis shape and junction between fairing and chassis. The meeting didn't focus on the swingarm since the fairing hardly gets close. More critical is the area near the electric motor where the transmission is. The topics for this meeting were the following:

- **Petrol chassis**: joint between the fairing, snorkel and chassis, radiators assembly and dynamic dimensioning,
- **Electric chassis**: joint between fairing and chassis, battery pack cooling system, radiator joint and transmission carter dimensioning,
- Dynamics regulations.

Both chassis will be manufactured in milled aluminium and welded using a jig to position the parts correctly, a new production method with respect to the one used in the previous edition, as shown in Figure 14. The elements present holes to fix them to the jig that stays visible after the welding. In particular, these holes are visible on the chassis side beam and the front part. Because of this, the students designing the

Figure 14 - The comparison between 2021 (left) and 2023 (right) chassis and swingarms

chassis have proposed attaching the fairing side, exploiting them and avoiding adding other holes representing stress concentration points. The petrol chassis is designed to house the snorkel that connects to the tip of the fairing. The previous petrol prototypes connected the fairings to the chassis through a 3D-printed *quick releaser* on the chassis side and a geometrical constraint on the snorkel, as shown in Figure 15. Since the fairing has to be easy to remove, this is an acceptable solution as long as it is stable, preventing the fairing from falling on the track. Moreover, since the new petrol prototype has a smaller but more performant engine and the exhaust system reaches the sides of the swingarm, there are no other issues other than the dynamic regulations and relative movement.

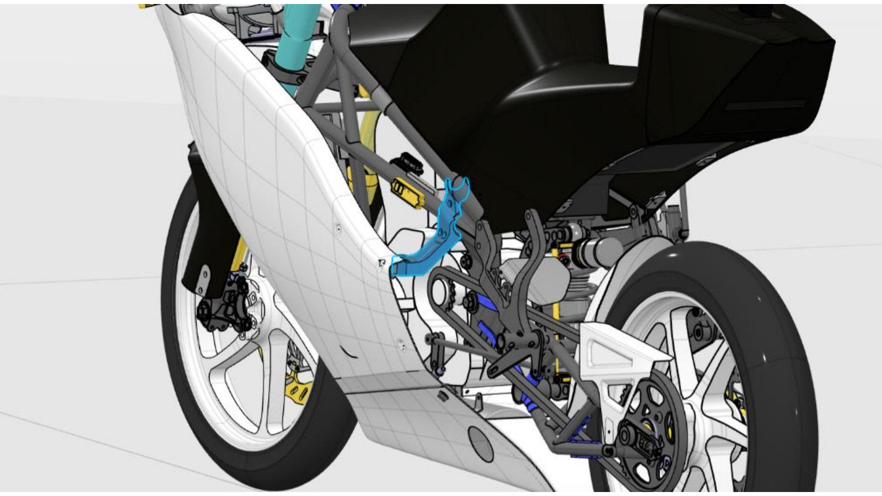


Figure 15 - The 2021 fairing-to-mainframe support

On the contrary, the electric prototype represents an issue regarding encumbrance distribution. Since the new electric prototype mounts a more powerful engine with liquid refrigerant, the battery pack is more prominent, and the chassis has to house a radiator. Also, the new prototype has a shorter swingarm and chassis, a characteristic that reduces the overall space of the *mainframe*. Another crucial encumbrance is given by the transmission, as shown in Figure 16, which occupies a significant area on one side. It is also hazardous due to the rotation speed; because of this, it must be surrounded by a carter and quickly accessible independently from the fairing. A similar solution is displayed on the 2021 electric prototype. The difference with the previous prototype is that the engine is upside down, so the transmission is on the right side while the chain is on the left side; this solution requires a rotating beam to go through the chassis adding criticalities. This issue means the fairing has to be large enough to house the transmission, and since a carter is necessary, the fairing can be fixed to it instead of the chassis. The transmission doesn't require any cooling system. A second carter will be mounted on the left side of the chassis containing electronic components that must be easy to access and isolated from heat and humidity. The fairing will be connected to the chassis through structural support because no snorkel will be designed for the electric prototype.

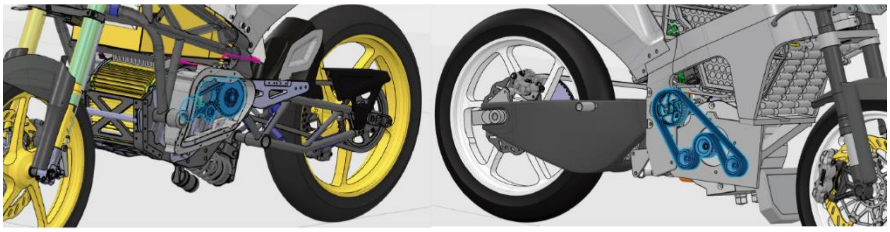


Figure 16 - The comparison between 2021 (left) and 2023 (right) electric transmission

During the meeting, we discussed the application of aerodynamics. These components exert localized stresses, requiring structural support directly connected to the chassis to avoid ruptures. In this scenario, the front support will be designed for both prototypes to reduce the snorkel structure's stress. In addition, students of the Chassis&Dynamics department suggested exploiting jig holes to attach the fairings on the electric prototype. Figure 17 shows the message sent on the Telegram channel with a recap of all topics.

Carene 2023
RIUNIONE TELAIO:

TELAIO ELETTRICO:
Attacchi carena a telaio: sul longherone il fianco si attacca ai fori della dima - ci sarà un foro sulla parte inferiore della piastra e altri fori per montare un telaietto anteriore sul cannotto per carene, dash e componenti elettronici. Muso: va fissato a un telaietto anteriore portante e se ci sono ali anche loro vanno fissate nello stesso punto.
Angolo di sterzata: 25 gradi
Corsa delle forcelle: 120mm
Corsa mono: 45mm
Ingombri:
Fianchi: il motore è verso destra dove c'è una lastra e la trasmissione -> che avrà bisogno di un carter - fianco sinistro: al momento non c'è nulla ma dovrebbe esserci: batteria low voltage ed elettronica -> sia trasmissione che elettronica è possibile che abbiano bisogno di raffreddamento.
Paratia interna alla carena: va fissata al telaio e divisa in due parti perchè l'ingombro della ruota non lascia spazio con il telaio.
Raffraddamento bacco batterie: da capire, non c'è spazio per lo snorkel.
Problema: distanza troppo risicata tra puleggia e piede del pilota.
Al momento a zero il mainframe è a 200mm dal pavimento.

TELAIO PETROL:
Attacchi carena a telaio: sul longherone il fianco si attacca ai fori della dima - ci sarà un foro sulla parte inferiore della piastra e altri fori per montare un telaietto anteriore sul cannotto per carene, dash e componenti elettronici. Muso vincolato allo snorkel e telaietto anteriore.
Angolo di sterzata: 25 gradi
Corsa delle forcelle: 120mm
Corsa mono: 45mm
La paratia sarà fissata ai radiatori e i radiatori al telaio in modo solidale.
Lo snorkel dovrà essere strutturale.

Figure 17 - Telegram message regarding Chassis&Dynamics meeting

The meeting with Powertrain Electric

Finally, the meeting with powertrain electric took place last and helped to solve some issues raised during the meeting with the Chassis&Dynamics department. This meeting was attended by the department head working on the battery pack and the student in charge of the cooling system. This meeting aimed to make an update on the design choices, limitations and constraints of both departments. Unfortunately, most of the electrical powertrain components were missing from the complete CAD assembly at the time of the meeting. Figure 18 shows the updated powertrain, almost complete. For students with less experience, it was challenging to visualize missing elements that impacted their projects. Because of this, students design primary components without considering missing ones; as a result, the project is not integrated, and one must choose the least worse solution. The topics for this meeting were the following:

- Electronics: encumbrance and placement of boards
- Radiators: dimensions and position
- Battery pack: sizes and cooling system

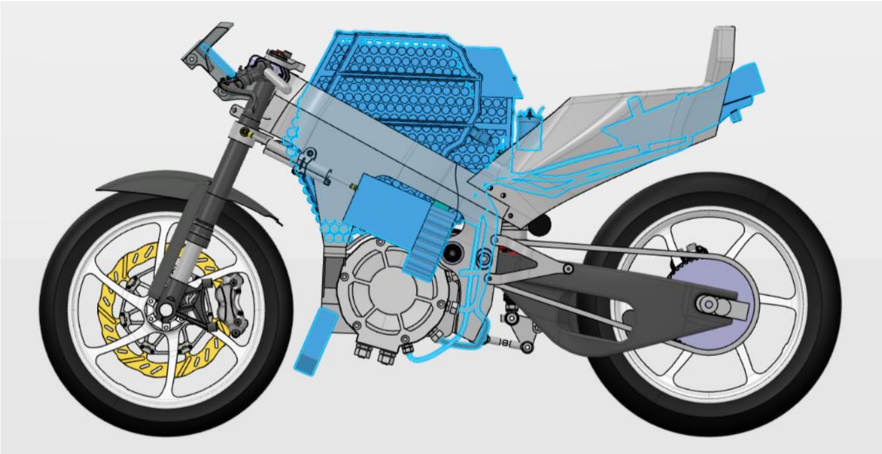


Figure 18 - Electric prototype powertrain components

During this meeting, we shared updates and criticalities learned from Chassis&Dynamics and invited powertrain students to share more information with Chassis&Dynamics. The meeting started with a warning from us to powertrain about all missing components inside the CAD assembly. To have a more accurate CFD simulation results it is relevant to have the correct encumbrances for a. The primary problems were the electronics and the motor cooling system. Moreover, boards, radiators and the pump were missing.

Regarding the radiators, we updated the powertrain department's members about the ideal position we considered and asked for the minimum size, equal to 270 mm^2 area with a thickness of 40mm. Figure 19 shows the best location found. We also agreed on the necessity of avoiding the hot air of the radiator impacting the electronics inside the left carter. Finally, we discussed the battery pack cooling system's design and insulation. The powertrain students suggested the use of a dynamic intake with a snorkel. Still, encumbrances weren't enough to develop a linear channel. Hence, we brainstormed different possibilities to build an intake that permits enough air to reach the cells while avoiding water entering the pack. Furthermore, the battery pack must be insulated entirely because of the rain test performed on the electric prototype; during the test, water is sprayed on the prototype in all directions while turned on, and it must not shut down. During the discussion, various ideas came out, like using a syphon-like shape to create an intake to stop water from entering the battery pack.

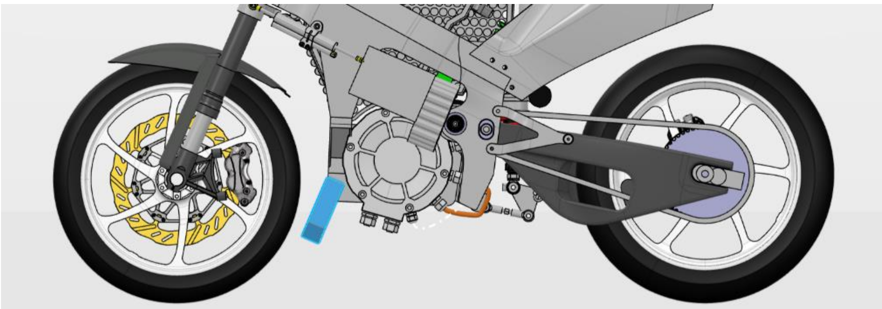


Figure 19 - Electric prototype radiator location

At the end of the meeting, we agreed to update each other frequently about missing components and the battery pack cooling system. Figure 20 shows the message sent with a recap of all topics.

Carene 2023
RIUNIONE POWERTRAIN E:

INGOMBRI DI ELETTRONICA:
Al momento mancano le schede e il cablaggio che verrà aggiunto a breve.
Una parte delle schede si troveranno sulla parte del dash (cruscotto anteriore), altre si troveranno nell spazio vuoto al posto del carter sinistro.
Fungo d'emergenza: è possibile che is troverà ancora sulla coda ma si possono levare le schede da quella zona.
Queste schede NON possono avere una fonte di calore addosso o vicina perchè potrebbe danneggiare le saldature.
INGOMBRI RADIATORE:
Il radiatore al momento ha una massa radiante leggermente sovraddimensionata di: 270mm2 (270mmx100mmx40mm)
é molto lungo per cui tutta la massa non entra nella come pezzo unico dovuto a quanto sporge sul lato, in caso di caduta potrebbe rompersi. Per cui è possibile che sia necessario che venga diviso in più parti ma l'aria calda che esce dovrà essere convogliata verso l'esterno e non verso la trasmissione o l'elettronica.
é possibile che una parte del radiatore vada nel puntale.
Manca nell'assieme anche la pompa del radiatore.

CARTER:
TRASMISSIONE:
é necessario un carter chiuso che protegga il piede del pilota.
è possibile che necessiti raffreddamento.
Deve essere protetto in caso di caduta e deve essere apribile.
LATO SINISTRO:
ELETTRONICA E POMPA RADIATORE:
ci saranno dei componenti di elettronica sul lato sinistro che deve essere isolata dal caldo del radiatore e protetta in caso di caduta e deve essere apribile.

PACCO BATTERIE:
INGOMBRI DEL PACCO:
Il pacco è soggetto a modifiche, le celle potrebbero diminuire ma è possibile che vengano distanziante le celle tra esse in modo da far passare più aria tra le celle.
Alcune celle verrano spostate in modo da posizionare l'elettronica del pacco nello stesso punto in cui si trova il bms della nyx.
Al momento la distanza con la ruota anteriore nella peggior condizione di affondamento forcelle e asola è di 20mm, per cui il telaio verrà modificato.
é necessario lavorare sulla cover del pacco per capire di quanto si possa salire con le celle.

RAFFREDDAMENTO DEL PACCO:
Il pacco andrà raffredato con delle ventole e un sistema anteriore a presa d'aria che può essere uno snorkel o un sistema sulla parte anteriore del pacco.
Problemi:
assolutamente proibito che entri acqua o condensa.
Lo strato limite tra le celle è pari alla loro distanza quindi il flusso si ferma durante l'attraversamento del pacco. Per risolvere questo va aumentata la pressione e/o velocità o la distanza tra le celle.
Stefano Oselin: lavorerà allo sviluppo di un sistema che permetta l'aria di entrare dalla parete frontale del pacco evitando l'ingresso delle gocce sia nebulizzate sia eventuale pioggia.

Figure 20 - Telegram message regarding Powertrain Electric

Final debriefing and translation of the result in morphological decisions to be applied to the design of the fairing set

A debriefing followed the meetings to discuss constraints and requirements from *parents components*. Such conditions helped set geometrical rules to be applied during the design of the fairings. Moreover, the debriefing promotes comparison with previous prototypes' solutions.

During the debriefing, three kinds of constraints emerged:

- Constraints imposed by MotoStudent competition,
- Constraints and requirements coming from related components,
- Internal to the department requirements pertinent to aerodynamics and ergonomics.

The project must comply with MotoStudent rules; otherwise, the motorcycle is disqualified. Modifications of *parents components'* constraints are hardly possible, while requirements permit a trade-off. The third kind of requirement comes from the Aerodynamics&Ergonomics department project evolution. Such requirements come from a long-lasting workflow aiming to enhance the performance of the fairing set since 2015.

MotoStudent's constraints regarding the fairing set are the following:

- Article B.2.1.2. says that the minimum tilt angle must be 50°.
- Article B.2.1.3 says that the minimum distance between the prototype in the upright position and the road surface must be at least 100mm.
- Articles B.2.1.4 and B.2.1.5 state that no prototype element shall protrude from the front vertical line drawn tangentially to the external circumference of the front and rear tires.
- Article B.2.1.8 states that the fairing's maximum width shall be 600mm.
- Article B.4.1.1 states that all edges of the fairing must have a minimum radius of 1mm.

- Article B.4.1.2 states that fairing cannot cover the rider sideways except for the forearms.
- Article B4.1.3 states there are no restrictions regarding the manufacturing material of the fairing.
- Article B.4.1.4 states that it is allowed to install any aerodynamic device protruding from the fairing or bodywork, if they do not exceed the maximum dimensions stated above.
- Article B.4.1.5 states that the aerodynamics appendices' minimum radius must be 2,5mm
- Article B.4.1.6 states that any aerodynamic device's maximum deflection will be 10mm at any point when a 50N vertical load is applied in the downward direction.
- Article B.4.1.7 states that mobile aerodynamic elements are allowed.
- Article B.4.2.1 states that the lower fairing must contain a minimum of 2.5 litres of liquid in case of an accident.
- Article B.4.3.1 states that front and rear mudguards are compulsory.

The following subsections will be dedicated to the outcome of the debriefing in the form of a trade-off between related components and fairing requirements. Such results will be divided by the fairings areas.

The new set of constraints for the upper fairing:

The upper fairing is one of the bike's most critical parts regarding aerodynamics; it is one of the first elements to be hit by the incoming airflow. The upper fairing aerodynamic behaviour affects the slipstream of the entire bike. Therefore, the shape must follow specific considerations to avoid *flow separation*. In addition, such a component interacts with other areas, like the chassis, the front suspension and mudguard, the radiators, and the semi-handlebars. The chassis and the radiators are part of the mainframe, and there is no relative motion between them; the interaction with such components is related to aerodynamics and assembly. Differently, mudguards, suspensions and handle-bars move relative to the upper fairing; They move along the suspension direction and around the steering pivot. Because of such relative motions, the upper fairing design must consider enough space to avoid contact. Finally, one of the most important relationships is with the rider; the upper fairing shields the rider from the incoming airflow by frontally covering his silhouette.

The team has developed a design approach for the upper fairing. First, it is relevant to clarify that CAD modelling happens in the complete assembly and with a mannequin for the rider. During such modifications, students in charge shape the element using two main views on the CAD: the *Right* and *Front views*. The Right view helps modify the length and height of the part, the profile close to the hands and head. Most importantly, such a view helps to determine the *central curvature* on the upper fairing. This curvature modifies the behaviour of the slipstream along the rider's back, drastically reducing flow separation. Moreover, the shape determines the pressure behaviour on the bike. Finally, students use aerodynamic profiles to draw the profile of such a line to develop a correct behaviour. Regarding the Front view, students use the rider profile to regulate the shape. The shape of the upper fairing doesn't fully cover the rider's profile; it leaves a part uncovered. The front profile is used to guide the air towards the rider, reducing flow separation to avoid enlarging the slipstream. Furthermore, the shape of the entire fairing starts with analysing former prototypes. Such prototypes followed the design guidelines of the *Intermedia* fairing. Both *BM0* and *FM04* fairings had a long tip, closer to the vertical tire constraint than Moto3 fairings. Figure 21 shows both 2021 fairings overlaid, showing how the different geometries interact with the rider's profile. In addition, both had a highly pronounced central curvature. A significant distinction between them was the amount of the mannequin profile covered on the Front view.

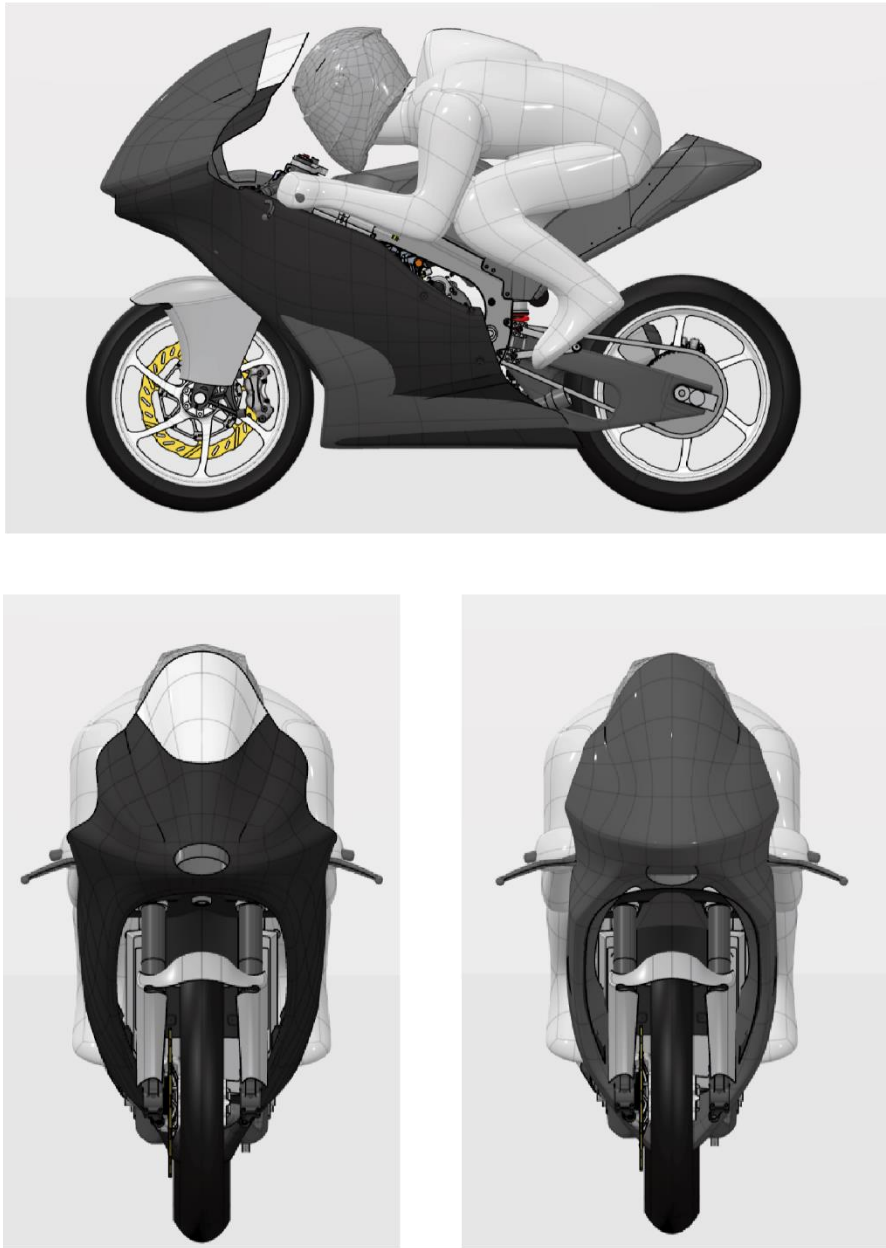


Figure 21 - Comparison between petrol and electric 2021 fairings. The development is performed using a parallel view, not considering any perspective

BM0 covered most of the hands and arms, leaving a part of the helmet visible. On the contrary, the *FM04* fairing shielded only partially hands and arms. Another significant difference was related to the airbox inlet; the *BM0* had a rounded tip to house the intake, while the *MF04* had an edgier tip.

Finally, thanks to the previous analysis and the meeting with the team, the fairing work group decided on the following morphological constraints. First, the shape must consider all encumbrances and relative movement. Both the *Right* and *Front profiles* must follow the rider's profile to reduce flow separation. Regarding the tip, the design split for the two prototypes. The petrol fairing will house the inlet, so the tip will be rounder than the electric one that shows no tip. Moreover, since the Regulation permits actuated appendices, it is relevant to consider their application during the initial phase of the upper fairing development.

The new set of constraints for the fairing sides:

Fairing sides cover the chassis and the engine sideways. Such components modify the aerodynamic behaviour of the central part of the bike; they aim to reduce flow separation on the rider's leg towards the rear wheel. Moreover, such elements impact the radiator's efficiency and its outlet.

Fairing sides interact with the chassis, the engine, the radiator and the exhaust system; on the electric prototype, instead, they interact with the motor, the battery pack and the transmission. The Fairings&Aerodynamics department thanks to its experience, understood the sides' critical aspects. First, the *frontal side edge* shape determines the pressure points and the incoming airflow behaviour towards the radiators and the leg. On previously designed fairings, the *frontal side edge* differs significantly from one to another. For example, the *BM0* fairing had a short round edge, while the *MF04* had a long edgy line; it was long enough to reach the motor guiding airflow towards it. Moreover, the *horizontal curvature* determines the airflow behaviour from the frontal part toward the leg. Once again, the BM0 and the MF04 showed different solutions. The former covered most leg's profile with a wide shape; the latter had slimmer curvature, designed to point towards the inner part of the leg. The MF04 solution showed an improvement in the airflow around the calf. The third critical aspect is the surface closing around the chassis side. Such surface ventilates slow inner airflow down instead of towards the torso.

Regarding new prototypes, the workgroup decided to follow different paths for each prototype due to the inner mainframe encumbrances. The aim will be to reduce flow separation as much as possible. On the petrol prototype, the team decided to implement venting ducts and horizontal edges to improve downforce and slipstream.

The new set of constraints for the lower fairings:

The lower fairing is situated at the same height as the wheels and the brake calliper, 100mm above the ground. Such a component receives turbulent airflow from the front wheel, so streamlines are more likely to separate in this part of the fairing. Such a part impacts the overall aerodynamic performance. Its impact can vary from neutral to positive or negative depending on the *horizontal curvature* inherited from the fairing side and its frontal encumbrances. The goal set for this component will be to avoid flow separation and keep a fast airflow below the feet and exhaust system.

The new set of constraints for the inner airflow:

Inner airflow design is crucial for the PMF aerodynamic goal; it takes a significant percentage of the overall performance. Therefore, the bikes will have inner walls surrounding the radiators, guiding airflow through them and outside the prototype in a controlled way; this helps to clean internal airflow, avoiding provoking unwanted turbulences. In particular, a simulation with exhaust radiator ducts will be performed on the petrol prototype to analyze the airflow behaviour with such a solution implemented. Figure 22 shows the geometry of the 2021 inner duct from surrounding the radiators and guiding the incoming airflow.

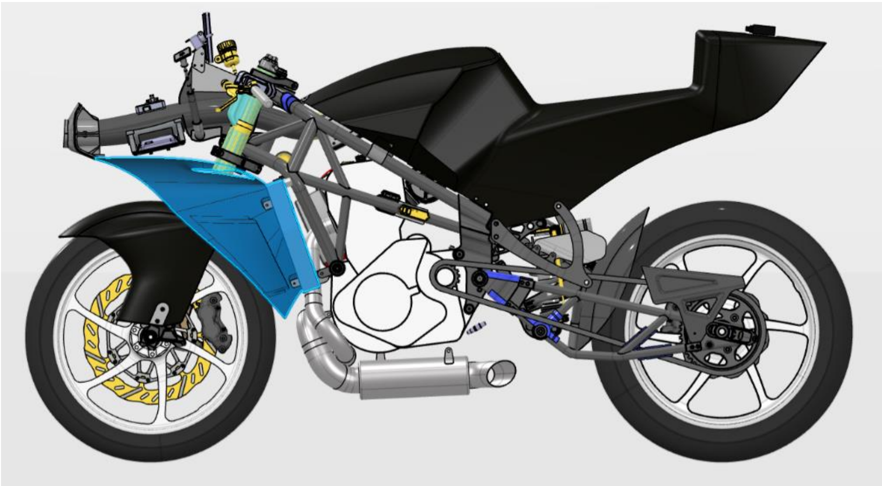


Figure 22 - 2021 inner duct and radiator

Insights and next steps

In conclusion, thanks to the meeting, it was possible to make different constraints impacting the fairing set design and optimization explicit for all workgroups. Furthermore, thanks to the applied approach, it was possible to set the ground for further interdepartmental communication and regular updates. In addition, such discussion permitted frame components relationships. The following part will describe the outcome of such an application, focusing on optimising the fairing set for both prototypes. It is relevant to underline that the fairing development has been structured as a collaborative project. A group of students participated, and I held both the project leader and designer roles. I worked on the petrol fairing CAD and as a facilitator for the students working on the electrical fairing. My role was aimed to show the design process making considerations about CFD results and how to translate such reviews on the fairing geometry. Moreover, the CFD simulations have been performed by students with an aerodynamics engineering background.

Chapter 10
The new fairing sets design and development

This chapter describes the process implemented to design and develop the 2023 fairing sets, implementing design constraints resulting from previously described meetings. Such constraints are used to build and optimize the fairing shape translating the requirements into morphological aspects. Since the fairing interacts with most main components, its form has to reflect all considerations taken during the debriefing.

The Fairings&Aerodynamics optimization process

Historically the Fairings&Aerodynamics department developed five sets aimed at improving aerodynamics performances without affecting other components' geometry, for the department was hardly possible to impose constraints outside their field. However, during the ongoing cycle, it became clear that this design process wasn't sustainable. The new methodology applied during the development of the new fairing sets helped improve communication to achieve an integrated project.

Previously the fairing was perceived as a skin surrounding other prototype components. In other words, the fairing was designed considering the whole bike, including the rider, while other workgroups developed their parts without considering the fairing. The new methodology implemented aimed to shift the balance by giving more space to the fairing project—such a method leverage interdisciplinary communication without undermining the design method internal to the department. This chapter will briefly explain the design and optimization method implemented with the new methodology to show the development outcome of the new fairing sets.

The department design method implements the knowledge of students coming from different backgrounds, such as product design, aerodynamics and mechanics. The mixture makes it possible to have a complete project view since the department must consider various aspects while designing its components. For example, the workgroup considers the rider in the saddle development and the fairing optimization. Because of this, design students with knowledge about user experience and ergonomics are helpful. Moreover, aerodynamics students bring knowledge about computational analysis and simulation settings to the team.

During the optimization process, design students work alongside aerodynamics students. The former use their project experience to

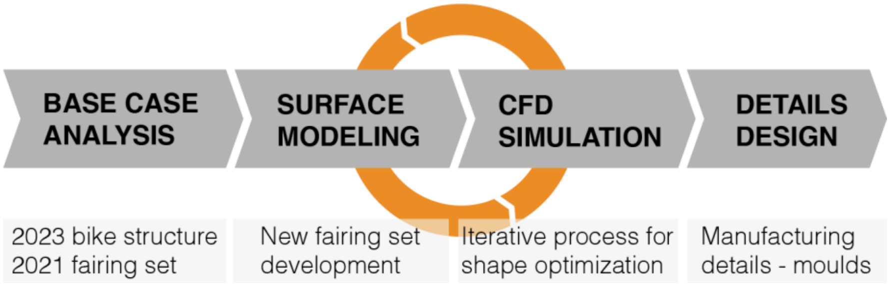


Figure 23 - The iterative process involved in the design and optimization of the fairing set

model fairing parts using surface CAD tools that reflect aerodynamic requirements suggested by aerodynamics students aiming to make a trade-off between such conditions and manufacturing one. The latter is in charge of supporting the design process and building the CFD case, the mesh and boundary conditions. Figure 23 shows the iterative optimization, including CFD simulations, analysis and brainstorming about results and CAD modelling to implement modifications to the fairing concept.

CFD simulations and base case

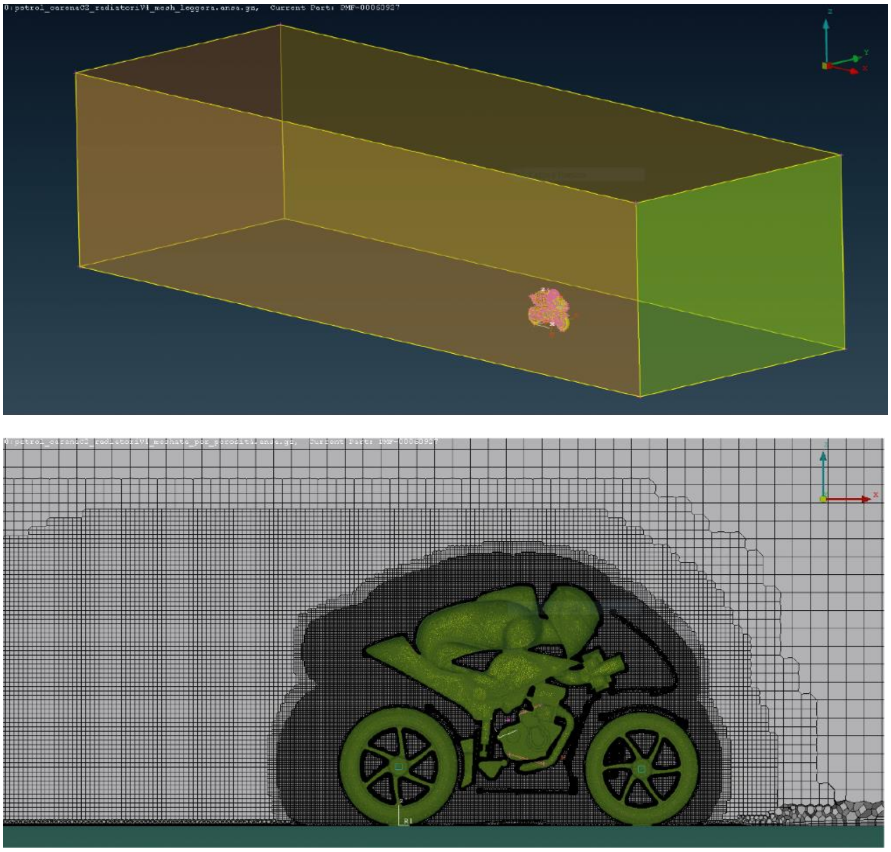
Computational fluid dynamics is an analytical tool in which computers are used to solve problems involving fluid flows; the governing equations of the physical phenomenon are solved to represent synthetically real conditions. In the computational simulation, a set of equations derived from Navier-Stokes equations are iteratively solved until convergence is obtained (Jayanti, 2018).

The software used are part of BETA CAE suits, such as ANSA for pre-processing and META for post-processing. The calculations have been done using OpenFoam V.9 open-source software, using the finite volume method to discretize the domain.

Because of the high cost of CFD simulations in terms of computational resources and time, some simplifications are necessary to solve real engineering problems (Yeoh, H., & Liu, 2018). In this case, the fluid flow is considered to be steady; thus, the CFD model uses Reynolds-averaged Navier-Stokes equations coupled with a turbulence model to solve the fluid flow around the bike.

The department builds the case by recreating real-life conditions. Hence, the motorcycle-plus-rider model is placed inside a virtual wind tunnel representing the calculus domain. Boundary conditions are accordingly set on the different surfaces and walls to replicate the correct fluid behaviour. To have more accurate results, the bike suspensions are set to replicate the correct position of the motorcycle by using telemetry data obtained from track tests.

Figure 24 - Above: virtual wind tunnel. Below: CFD mesh generate using ANSA software



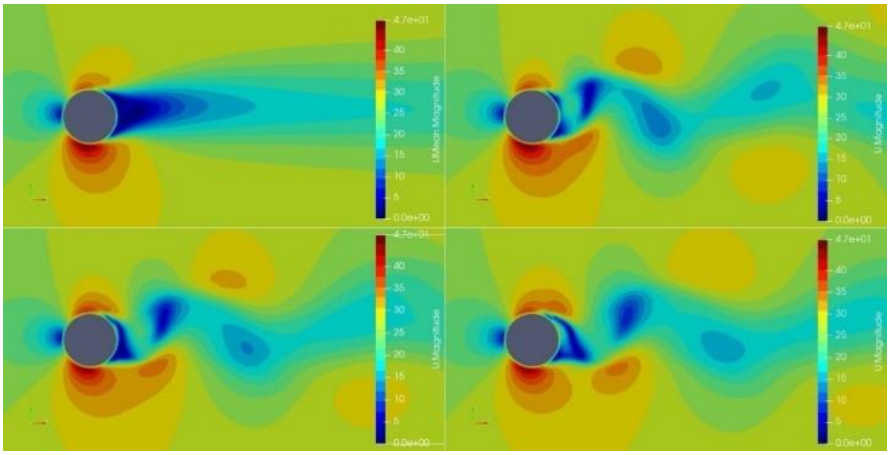


Figure 25 - The behaviour of the wake on a bluff body, the left top image shows the average result, while the other three show single iterations

Finally, bike assembly and virtual tunnel are meshed together, refining the mesh closer to the bike to have more accurate calculations without wasting computational power.

Because of the complexity of the simulated case, validation is necessary. Wind tunnel experimental results are used for validating the CFD model implemented. In Figure 24, the computational domain previously described is displayed; below, a detail of the mesh discretization is presented, and it is possible to see the refinement regions used to improve accuracy.

Surface 3D modelling using IMA and ICEM

In the Fairings&Aerodynamics department, the 3D modelling of components is mainly approached through the surface's method. However, most of the department's parts have complex tridimensional shapes with high complexity continuity. In addition, such components are manufactured in composite materials through wet lamination. Hence, team members learn to model using the *style method* of intersecting surfaces trimmed with each other. On the 3DEXPERIENCE software, such a method is possible using *ICEM Shape Design* and *Generative Shape Design* applications, among others. These apps permit a wide variety of controls on curves and surfaces, giving the possibility to achieve a high quality even in high-complexity shapes, such as the saddle.

On the other hand, though, the style method has limitations when the goal is building a complex surface with no intersecting surfaces, completely tangent. For example, the department has chosen a different approach to build the fairing surfaces because its goal is to improve aerodynamics. Such a goal is better achieved if the fairing surface doesn't present any interruptions or sudden geometry changes; for example, two intersecting surfaces with a small round between them could provoke a flow separation. Moreover, the fairing project has to occupy a small time window of two months. During this period, the workgroup must develop the fairing, the radiator's duct, the mudguards and the tail. Consequentially, only the fairing surface body is built through the freestyle modelling method of the *Imagine and Shape* application. Such a method uses *vertices* and *control points* to model a net of connected surfaces. The more the division of the surface, the worst the surface quality; it is better to add divisions only when required from the shape complexity. The freestyle method permits high-complexity shape guaranteeing tangency through the whole body with the advantage of being easy to modify. However, these surfaces have downsides because they work on one feature instead of building a feature tree; it is crucial to work on different revisions to avoid losing previous work. The overall quality gives another negative aspect if the surface is not corrected frequently. Indeed, this method does not permit the creation of *Class-A* surfaces.

Focus box: Class-A surfaces

Class-A is a term used in automotive design; it describes the highest surface quality level that can be achieved. Class-A modelling process starts with a fully developed design, clay or CAD. Since the vehicle's design is set, the designer can take more time to build surfaces of the highest quality standards, ready for production. The challenge is to put together tangency continuity, final product highlights, engineering requirements and production constraints, like flanges and tolerances. The designer must achieve tight tolerances of G0 (contact between surfaces), G1 (tangency given by the first derivative), G2 (continuity provided by the second derivative) and G3 (surfaces connection representing the third derivative) continuity through the whole surfaces. *ICEM Shape Design* application of 3DEXPERIENCE is used to achieve such quality; *Imagine and Shape* use a different modelling method.

The reason why the team uses the freestyle method for such a significant component is given by time restrictions imposed by the project. Finally, the fairing surfaces' main goal is to improve aerodynamics, even sacrificing the body's aesthetic equilibrium.

The following section will describe the design process used for the Petrol fairing set and inner duct, describing the primary iteration of the entire design process's 3D modelling and aerodynamics simulations. It is essential to highlight that I have worked as a designer of such surfaces, modelling and analysing CFD results in terms of the images that will appear. Furthermore, I have used the such activity to transmit the historically used method to the rest of the workgroup to build and optimize these surfaces. The Electric fairing set has been designed and developed by two students who entered last year in the team. The design and analysis process was achieved through group brainstorming and not as a solitary activity. The base case and the CFD simulations have been cured and performed by team members with aerodynamic backgrounds.

Main iterations and design considerations

The new design process starts with the base case simulation, including the new bike structure and the 2021 aerodynamics set. Once such CFD is analyzed, it is possible to have a starting point for comparison and modifications. Consequentially, the first fairing is designed and simulated with 2021 mudguards and the tail set. This year's project aims to improve internal and external aerodynamic behaviour; hence fairing, inner ducts, and radiators have been optimized together. Furthermore, all components have been named using internal software revisions to maintain constancy.

Focus box: Collaborative Lifecycle and Revisions

The 3DEXPERIENCE has applications dedicated to managing components' maturity and collaboration since the software permits them to work simultaneously inside shared assemblies. For example, the *Collaborative Lifecycle* application permits such management. Moreover, such an application helps manage components' revisions. A revision is a copy of the part that keeps the same name, changing a letter representing the revision. For example, the first component is revision A.1, and the second is B.1. It helps to keep the chronological time steps of the model easy to recall and correlate with each other.

First CFD simulation: the base case with 2021 aerodynamics set

The mesh for the first CFD simulation included the new bike structure and the 2021 fairing set. The new bike is small than the previous one making the fairing look too large on the sides. As a result, the slipstream is long and wide, as shown in Figure 26. On the rider's bike, the airflow separates on the upper part. However, the fairing has a slight pressure point on the tip, visible in Figure 27 and reaches a good slipstream quality at 0,8 m from the ground. The 2021 fairing has wide sides with a curvature that enlarges towards the rider's leg; because of this, the fairing receives laminar airflow from the front because it is larger than the front wheel and braking calliper. In addition, the sides' shapes partially cover the front wheel, channelling the airflow inside rather than outside its profile. The upper fairing has a long tip with a horizontal curvature towards the rider profile. On the vertical midplane, the upper fairing has a curvilinear profile that should join with the helmet, though because of this bike dimension, such alignment is missing. Moreover, the first simulation was performed without the radiator's duct because not compatible with the new bike.

Risultati	**Cd (-)**	**Cl (N)**
BM0	0,527	-0,077

For a simplified lecture and for the aim of this thesis, it was chosen to display only data regarding the drag coefficient (i.e. Cd) and the lift (i.e. Cl)

In conclusion, it was decided to build the first 2023 set closer to the bike, with a shorter upper fairing aiming to expose part of the rider to maintain a faster airflow around the bike and the rider. Main simulations have been performed considering the prototype in acceleration. In addition, the positions of braking and cornering are implemented during the detail stage.

Figure A
Pressure

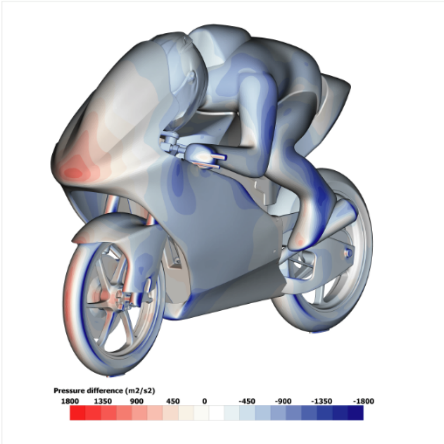


Figure B
Streamlines on
the midplane

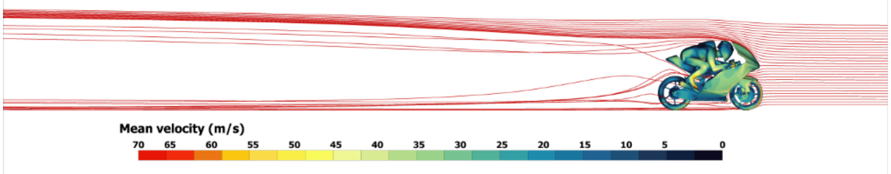


Figure C
Mean velocity on
the midplane y.0

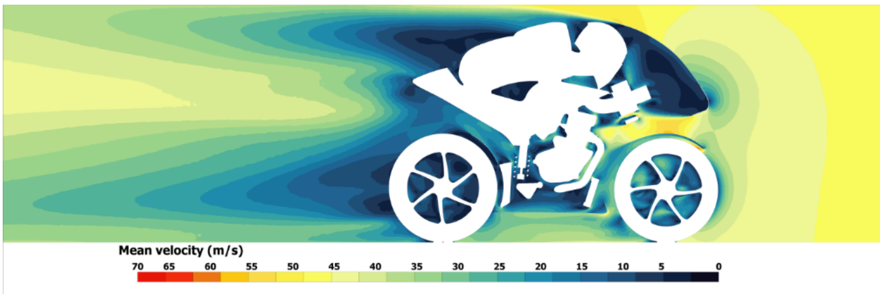


Figure 26 - Base case pressure, streamlines and mean velocity

Figure A
Mean velocity on
the vertical plane y.1

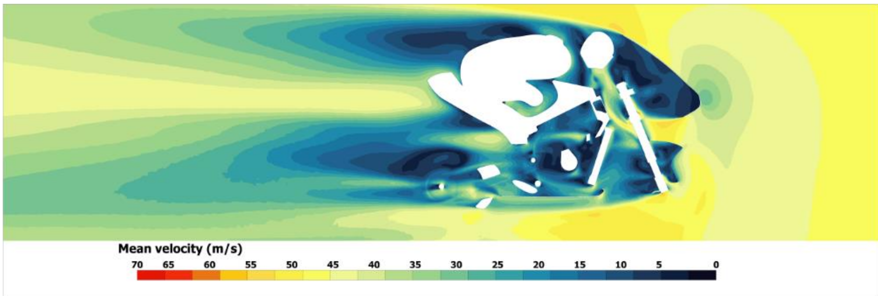


Figure B
Mean velocity on the
horizontal plane 0.8

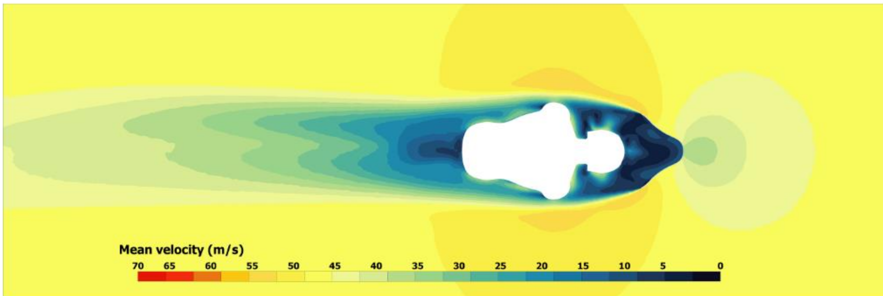


Figure C
Mean velocity on the
horizontal plane 1.0

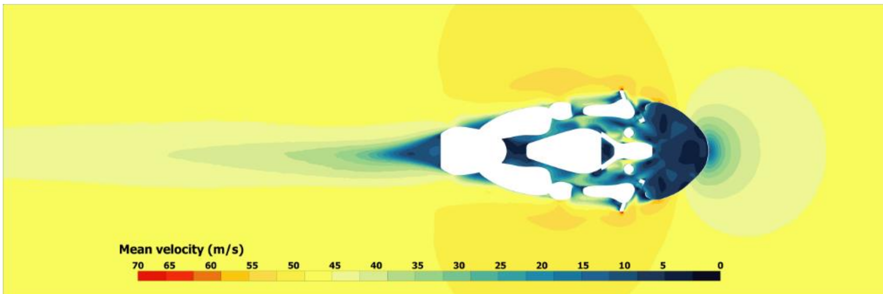


Figure 27 - Mean velocity shown on different slices

First 2023 fairing concept, revision A.1

The first sketch was modelled using the 2021 fairing for comparison. The goal was to try a shorter tip and a slighter front profile; sides curvature and midplane profile had an average shape. As a result, the upper fairing was too wide and didn't expose the rider's profile correctly. Figure 28 shows the streamlines on the vertical plane that separate from the upper part of the rider's back. The slimmer sides expose the leg partially, but the airflow generates turbulences behind them. Moreover, at hand height, the airflow follows the shape of the bike, though, at the shoulders' height, the wake doesn't follow the rider's profile, as shown in Figure 29.

At this point, optimizing the shape and including the inner radiator's duct to clean internal airflow was possible.

Revision	**Cd (-)**	**Cl (N)**
A.1	0,475	-0,057

Figure 28 - Revision A.1 streamlines on the midplane

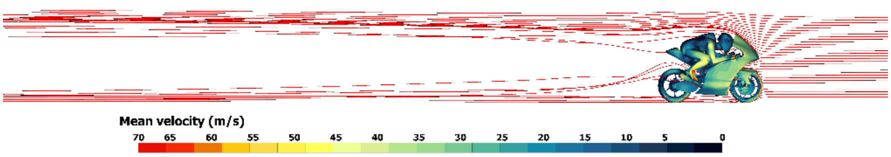


Figure A
Mean velocity on
the midplane

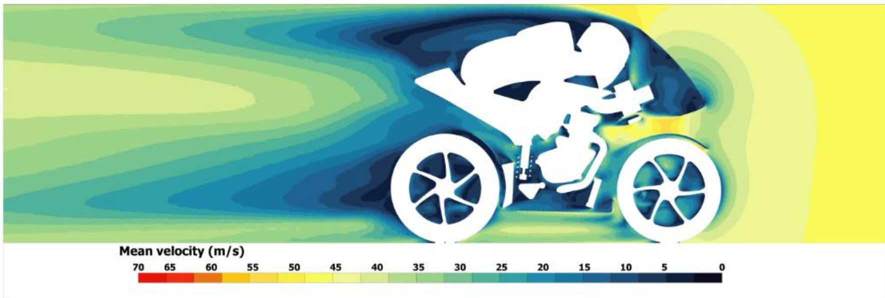


Figure B
Mean velocity on the
horizontal plane 0.8

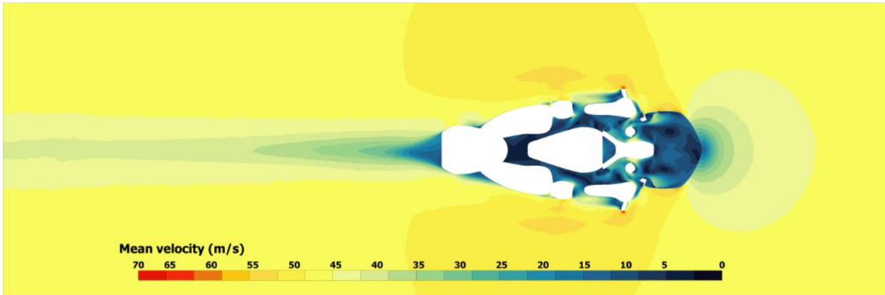


Figure C
Mean velocity on the
horizontal plane 1.0

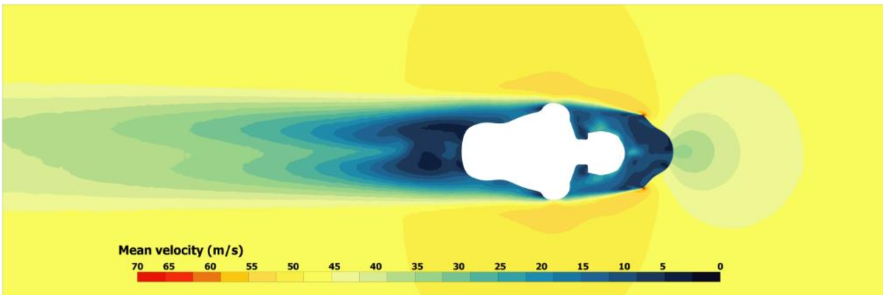


Figure 29 - Revision A.1 mean velocity on different slices

Second fairing revision B.1

The behaviour of the B.1 revision drastically changes the overall prototype slipstream. On the vertical planes shown in Figure 30, the airflow follows the rider's back almost to the tail; on the shoulder, the airflow separates too early because of the upper fairing side shape. As a result, the images show the mean velocity on the rider's shoulder, which is too slow. Moreover, Figure 31 shows how the airflow separates on the areas of the lower fairing at 0,3-0,4 m height and above the hands. In the lower part, the separation is due to the wheel and the calliper. At the same time, the upper part is provoked by the fairing shape that enlarges the flow around the shoulders and head. Additionally, this simulation included the radiator's duct revision A.1. Due to the pack of porosity on the radiator, the airflow entering the fairing follows a path to exit it on the lower part worsening the airflow and reducing the velocity on the fairing sides.

Revision	**Cd (-)**	**Cl (N)**
B.1	0,433	-0,015

The first inner duct was modelled following the same concept as the 2021 one. The surface is built using ICEM Shape Design to create surfaces surrounding the radiators. The front edge of the duct has no G0 tangency with the fairing to avoid slowing down the incoming stream; instead, there is a small gap.

Figure A
Streamlines on the
midplane

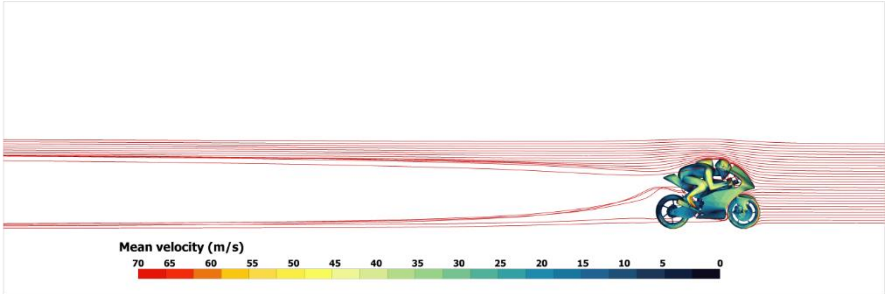


Figure B
Mean velocity on the
midplane

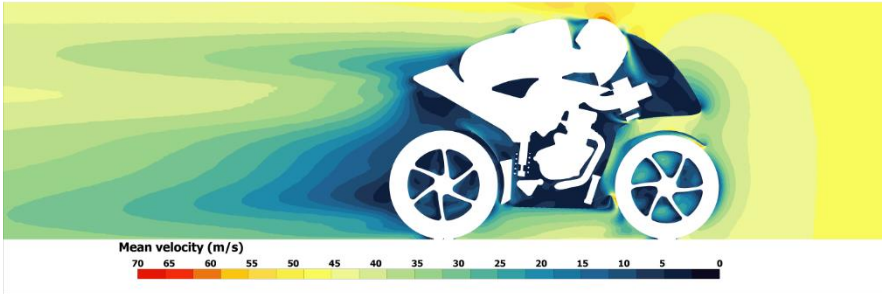


Figure C
Mean velocity on the
vertical plane y.01

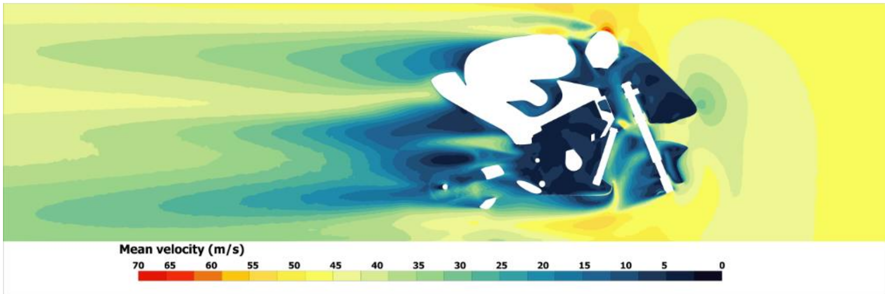


Figure 30 - Revision B.1 mean velocity on vertical planes and streamlines

Figure A
Mean velocity on the
horizontal plane 0.3

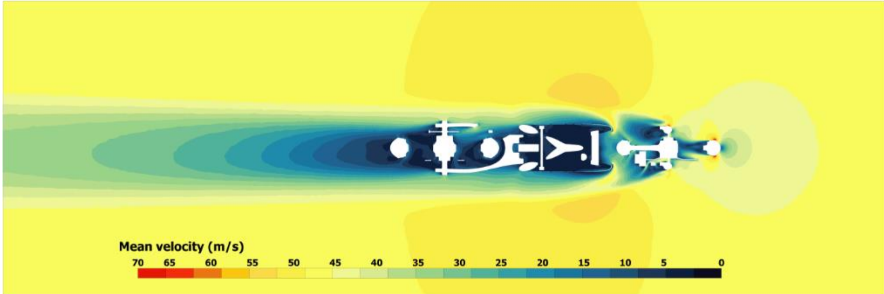


Figure B
Mean velocity on the
horizontal plane 0.8

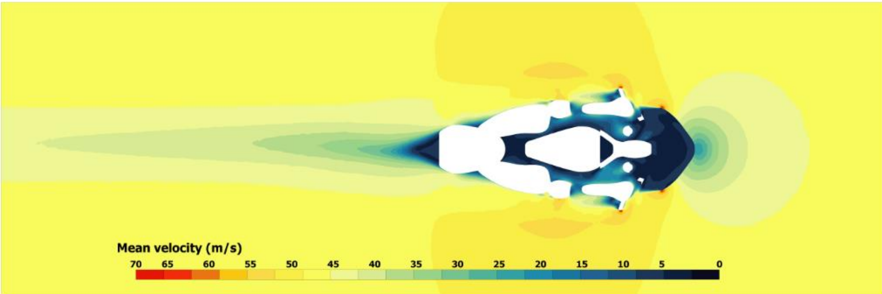


Figure C
Mean velocity on the
horizontal plane 0.9

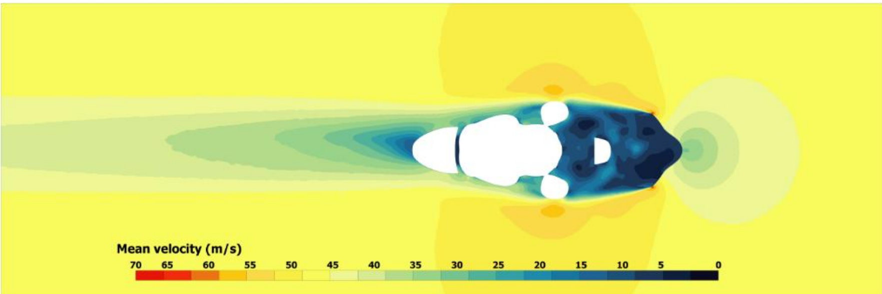


Figure 31 - Revision B.1 mean velocity on horizontal slices

Third fairing revision C.1

During the C.1 revision creation, the porosity on the radiators was implemented, and their shape changed, occupying more space. As a result, the airflow on the lower part of the fairing improved significantly. On the contrary, from 0,7 m height and above, airflow worsened. Furthermore, since the upper fairing curvature increased, the airflow created a bubble around the rider. The shape of the upper fairing had to change on the midplane because of manufacturing constraints. The central curvature of C.1 fairing is flatter because of thermoforming limitations. Such modification altered the airflow's behaviour impacting the helmet and down the back. On the contrary, the velocity on the sides is higher.

The inner airflow also improved significantly with the implementation of the porosity. Regarding front suspensions, the holes where the air comes in through the ducts must be closed to enhance streamlines quality.

Revision	**Cd (-)**	**Cl (N)**
C.1	0,402	-0,058

Furthermore, during the analysis of the C.1 revision, a new thesis started regarding an active aerodynamic braking device aimed to be connected to the fairing sides. Such a device should improve braking time opening during the braking phase before turns. Because of this device, revision D.1 will implement modifications to house the new aerodynamic appendices.

Figure A
Streamlines on the
midplane

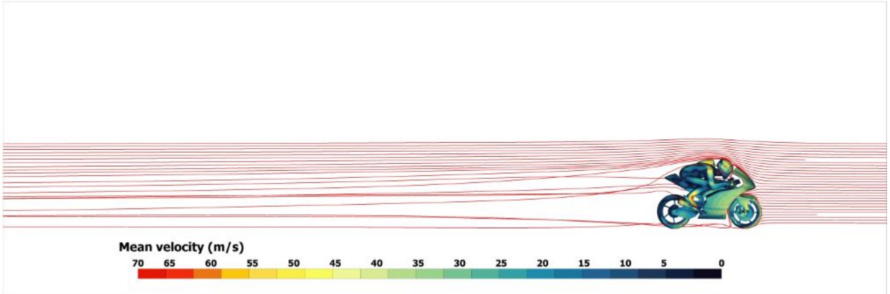


Figure B
Mean velocity
on the midplane

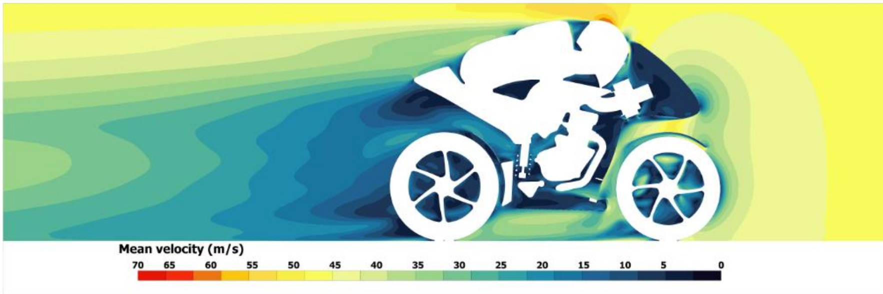


Figure C
Mean velocity on the
vertical plane y0.1

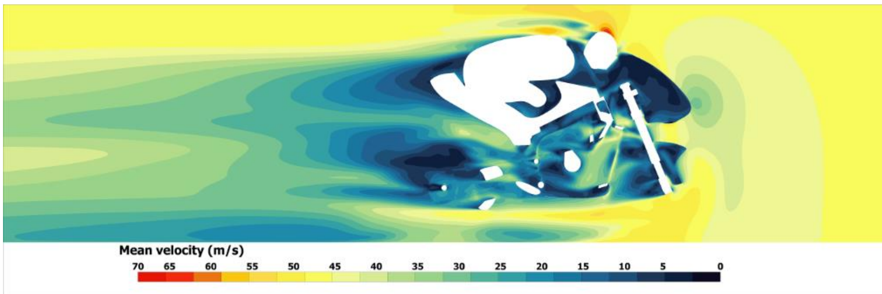


Figure 32 - Revision C.1 mean velocity on vertical planes and streamlines

Figure A
Mean velocity on the
horizontal plane 0,5

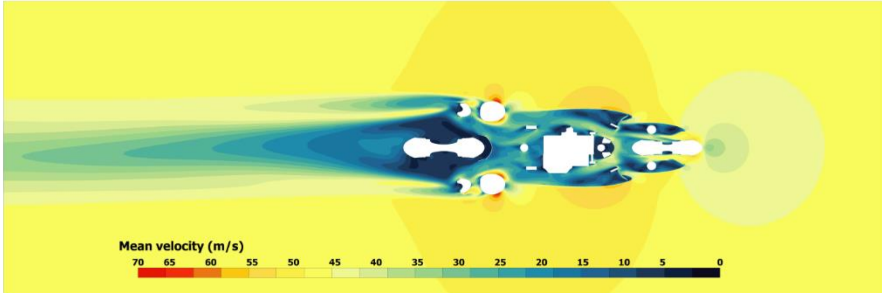


Figure B
Mean velocity on the
horizontal plane 0,8

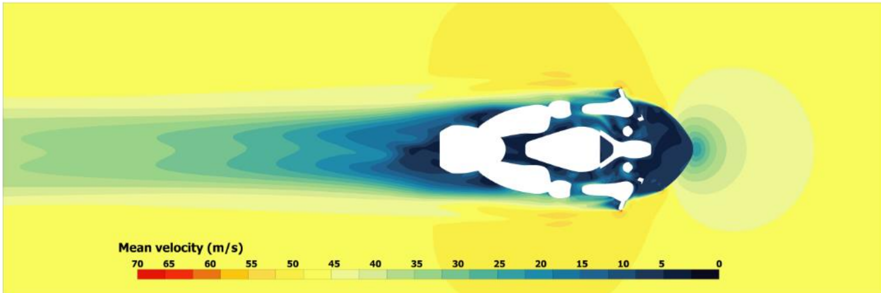


Figure C
Mean velocity on the
horizontal plane 1,0

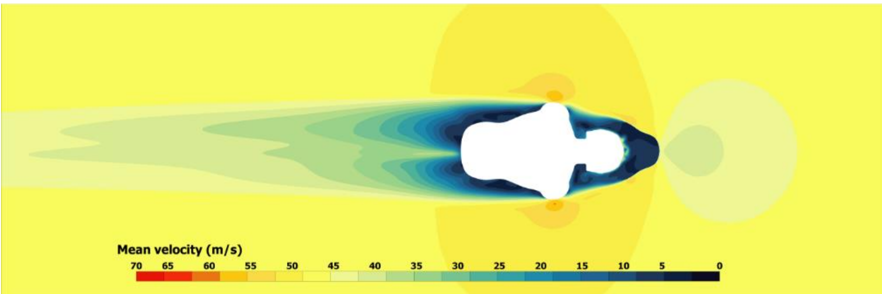


Figure 33 - Revision C.1 mean velocity on horizontal slices

Fourth Fairing revision D.1

Revision D.1 shows a fairing significantly different from the previous one. The overall fairing shape has been modified to guide streamlines correctly around the prototype as shown in Figure 34. The two main sections that have received modifications were the upper and the lower fairings. The upper fairing shows a much straight central profile following the frontal rider silhouette. As a result, the wake on the back and shoulders does not separate till the tail, as shown in Figure 35. Moreover, the hands' area fully covers the hands guiding the streamlines around the rider. At 0,8 m from the ground, the slipstream has a short and slim area of low velocity. Regarding the lower fairing, the geometry has been significantly modified to create a slimmer front view profile wheel width that enlarges towards the exhaust system visible in Figure 36. The aim was to shield the exhaust from the incoming airflow. It was impossible to cover the feet because the airbrake imposed constraints on the fairing sides. Moreover, this fairing has also been simulated with the close airbrake to retrieve data about the internal streamlines. As a result, having an exhaust radiator's duct cleans the internal airflow reducing the drag coefficient without provoking separation of the fairing sides.

Revision	**Cd (-)**	**Cl (N)**
D.1	0,344	0,026

Figure A
Pressure

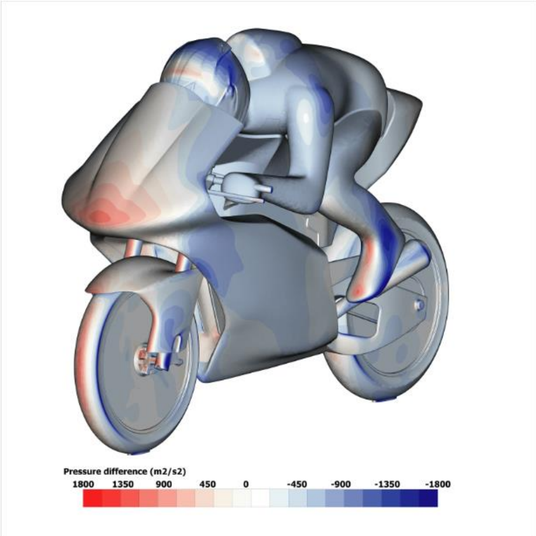


Figure B
Streamlines on the
vertical midplane

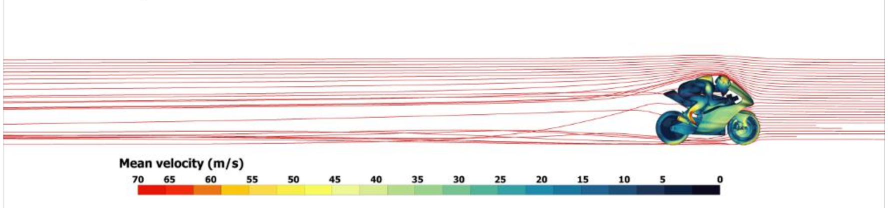


Figure 34 - Revision D.1 showing pressure (above) - and streamlines on the midplane (below)

Figure A
Mean velocity on the
vertical midplane

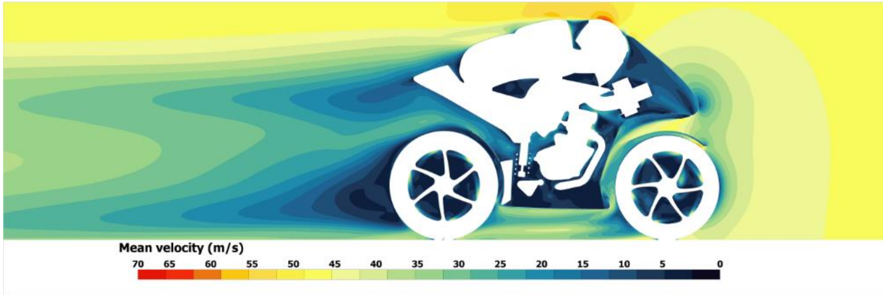


Figure B
Mean velocity on the
vertical plane 0,2

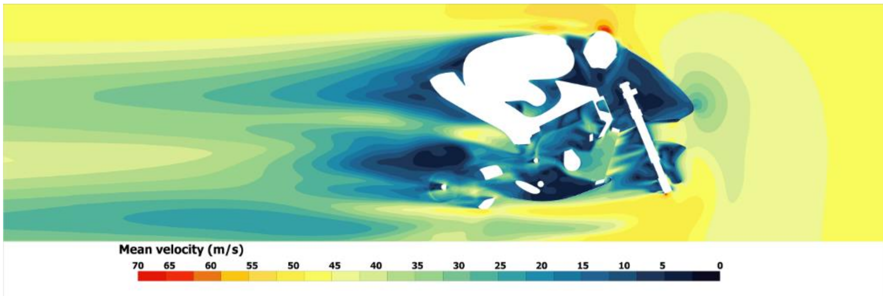


Figure C
Mean velocity on the
horizontal plane 0,8

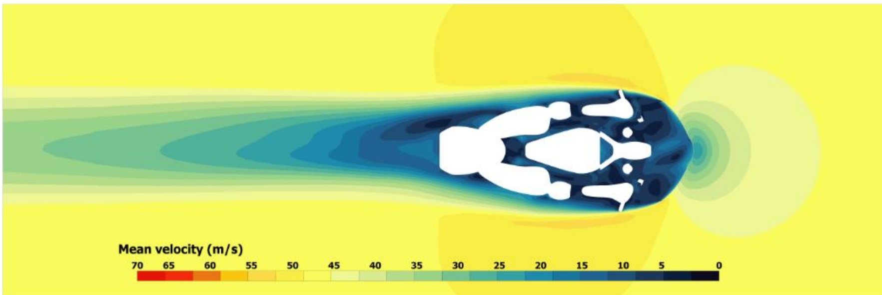


Figure 35 - mean velocity on vertical plane 00 and 0,1 m and on the horizontal slice at 0,8 m

Figure A
Mean velocity on the horizontal plane 0,5
without the airbrake and radiators exhaust

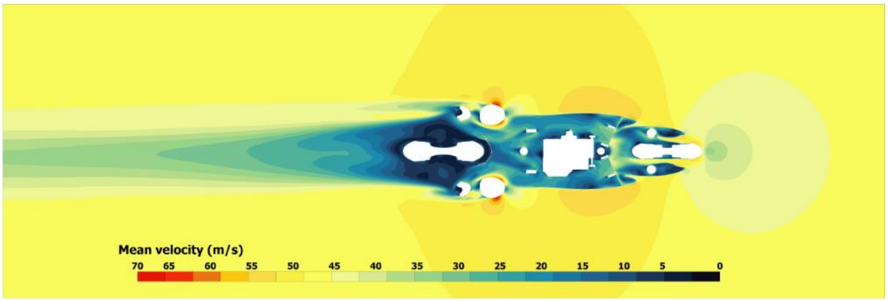


Figure B
Mean velocity on the horizontal plane 0,5
with the airbrake and radiators exhaust

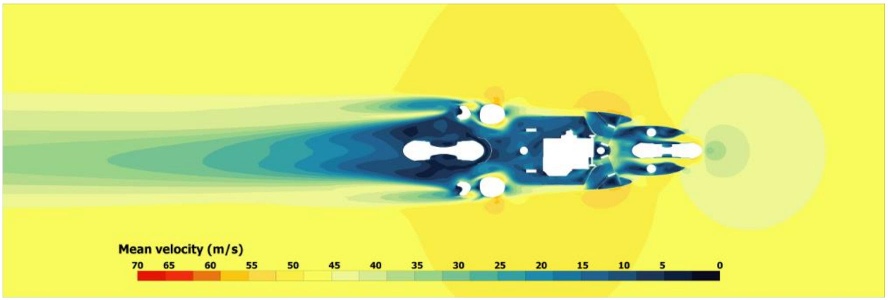


Figure C
Mean velocity on the
horizontal plane 0,2

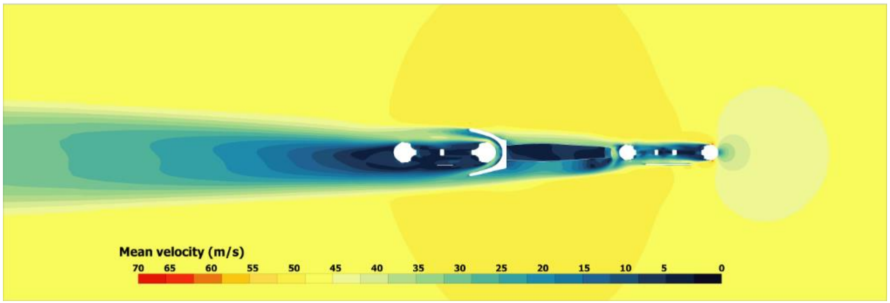


Figure 36 - Mean velocity at height 0,5 and 0,2 m. Figure B shows the simulation with the airbrake and the radiators exhaust ducts

Design process conclusive analysis

Even though the fairing development didn’t end, it is possible to appreciate the evolution of brainstorming. For the first time, the aerodynamics optimization included the radiators and a complex active system to enhance the prototype performance on the entire track, not just on the straight but also during cornering. The brainstorming opened the possibility of enriching the project from the concept. This year, the aerodynamic pack have reached high complexity regarding the project and the morphological aspects. Moreover, the project was quickly adapted to the new air brake project to develop both projects together to have a better global result instead of two independent projects.

Regarding the specific component goal, each was different and even in contrast with the other. For example, the fairing is optimized to reduce the drag coefficient and improve track straight's performance. On the other hand, the air brake aims to increment the drag coefficient by augmenting the prototype frontal area with two moving spoilers. Such air brake works at the end of the straight while braking, reducing braking distance. Consequently, the workgroup doubled the simulations to retrieve data during acceleration, with the spoiler closed and during braking, with the spoiler opened. As a result, the optimization process doubled the time to improve the fairing design, radiators, ducts and air brake design.

In parallel with aerodynamic optimization, the workgroup developed the joining parts between fairings, chassis and air brakes. In addition, the workgroup developed components integrated with the project to enhance joint quality, reduce assembly time and guarantee rider safety. Differently from the previous years, after last year's track days and races, it was decided to connect all parts of the fairings independently from each other to the chassis. The goal is to avoid removing the whole fairing for minor activities, simplifying mechanics’ work in the box and pitlane. Hence, the workgroup developed a set of carbon fibre supports to assemble all fairing parts and the whole air brake system to the chassis.

In the previous design process, no appendices were developed with the fairing due to organizational complications between different departments. For example, the collaboration between the Fairings&Aerodynamics department and the Dynamic department was never efficient enough to develop appendices optimized to improve the dynamics in cornering and braking.

In conclusion, the fairing project acquired a leading role during the design and testing phases. Thanks to the implementation of an explicit meeting approach, the fairing project could set constraints upon critical components, a characteristic that hardly ever happened before. Usually, the fairing was dependent on other components, but the relationship was one way. The creation of dependency maps helped students, both internal and external, to the fairing development, building an overview regarding constraints and opportunities surrounding the fairing element. Such overview permits the start of interdepartmental brainstorming since the early stages of dependent components development. For example, thanks to the implementation of such structured meetings, two petrol powertrain students have adopted the fairing as part of the development of the airbox and the exhaust system. Consequently, they frequently meet with the fairing workgroup to stay updated and solve common issues. Maintaining an active communication channel permitted the development of integrated solutions instead of isolated elements.

In conclusion, having an overview of related element constraints helps to improve the team’s collaborative aspect, which is the key to developing a high-complexity project by dividing the project into small tasks and milestones assigned to different workgroups. Furthermore, implementing components mapping and boundary objects during the structured meetings helped contextualize and frame the shared design aspects. Inside a team where multiple components are developed in parallel, framing components' context help to refine the constraints setting phase, which is essential to achieve production maturity in a shorter time window. Regarding the fairing development, the implementation of an explicit meeting structure helped to develop the fairing, the inner duct, the radiators and the airbrake in parallel. Moreover, the fairing project included, from the early stages, the design of component use during track days, where mechanics had to work fast on the prototype, reassuring reliability and safety in components' joints.

Part 4: Conclusion

Chapter 11
General Discussion, limitations and conclusions

The following chapters are dedicated to a retrospective view regarding answering the research questions. It will be considered how research and methodology have supported the answers and what paradoxes have been found. Moreover, the sections will highlight the encountered limitations and future developments regarding implementing the new methodology and its application to the constructive learning workgroups lacking a guiding figure.

General discussion

This thesis has been built using extensive initial research to describe and analyse the Polimi Motorcycle Factory context. The study aims to make explicit the relationships formed between team members and between team members and the prototypes, subject/subject and object/subject. In particular, the research leverages the role of the prototypes in building knowledge and linking project cycles over time. By putting together the concepts of *boundary objects* and *fetish objects*, it was possible to map the *material culture* the team builds around the bikes and how this culture influences the project approach and the passage of knowledge through cycles. Moreover, thanks to the research, communication problems impeded achieving common goals through related components, reducing overall project quality.

Furthermore, the research displayed communication methods used in a *constructive learning* group where the *guiding figure* of the teacher is missing. The students use boundary objects to create interdisciplinary communication channels to compensate for their lack of experience and competencies due to their learning nature. The peculiarity of this case study is the high-complexity project held by a team of students with no professional guidance.

As a result, the questions aimed to make explicit the team's collaboration method to leverage the communication quality during brainstorming and meetings.

. How can component-to-component and component-to-time relationships help identify collaboration touchpoints between workgroups developing related components of a high-complexity prototype?

The research highlights how students who lack experience struggle to approach brainstorming on an abstract plane. The use of implicit boundary objects to establish better interdepartmental communication was familiar but without any method. Using objects and representations as *boundary objects* moves the power from that object back to the subject, reducing the *fetish power*.

> *. Starting from the collaboration touchpoints, how can a structured method of defining shared objectives and constraints leverage the collaboration between workgroups developing related components?*

It is possible to explicit objects' materiality through mapping, showing the correlation between components. Furthermore, it highlights the parts' creation and evolution stages and how they relate. Such relationships, mapped, represents the relationships between workgroups. The identified touchpoint are nodes of collaboration to stress brainstorming. Making explicit such nodes helps to have an overall understanding of the common goals across related components.

Mapping components' relationships mirror workgroup relationships through a material infrastructure given by the prototype. The method developed for this thesis is a subtle change using already-known tools such as the prototype and meetings to focus on such relationships. The goal was to reduce individual component development and promote a broad view of the context around each component. The project results show a better-integrated process regarding considerations, parallel components design and complexity. Instead of existing as a covering skin, the aerodynamic pack is integrated with the prototype design at different levels and in different phases. The fairing is moulded around the bike and the rider, aiming to enhance the slipstream, house an active appendix and reduce time wasted during box work.

It was necessary to visualize the dependencies to map the components' relationships. A fast way to demonstrate such dependencies was by using the completed CAD assembly, making visible only the parts the fairing set depends on and dividing them by departments. Fairing design criticalities become more evident thanks to this visualization, showing the importance of considering other components' constraints since the early design stages—such mapping show how most of the bike is affecting the fairings. However, different components of the same department affect the design at different stages and degrees.

The fairing set depends on primary components, such as the chassis, and less critical components, such as the braking handle. Such an intricate tree of relationships relates to the state-of-the-art aerodynamics optimization required. More accurate simulations require ready-for-production parts and fully assembled CAD; such requirements directly impact the design dependencies. However, such conditions mean postponing fairing development until all other components are ready for production and a significant computational capacity to run a simulation with such a complex mesh. Due to the impossibility of closing the project so soon, a trade-off between accuracy and quality must be accepted—such trade permits more in-depth analysis of the dependencies to optimize components' quality. The fairing set depends on many elements at different design stages. For example, to start with the aerodynamic optimization phase, the chassis is not required to reach the ready-for-production deadline; it would be enough to know the manufacturing method. On the contrary, the radiators must be designed together with the fairing and can hardly be modified after the fairing enters the production phase.

Previously shown maps are a graphical representation of relationships and connecting points between a group of components. The maps help to draw collaboration lines between workgroups using their parts as starting points.

The graphics help visualize the context around each component, showing how parts affect each other. In design projects, having the object's context in mind helps to have an overall view of the project. Such a view is helpful to avoid creating hermetic components in high-complexity projects. In other words, having a broad view helps components' integration by designing the prototype as one and not as an addition of single parts. Students working on one piece will be more inclined to consider other parts' requirements during their brainstorming. Such visualization is helpful in collaborative learning contexts where the teacher's guiding figure is missing. The graphics work as tools that make a component context explicit. Such a tool help students have a less abstract view of the whole project. The maps organize tasks and problems to be solved by planning design relating to other components' stages. For students with little experience facing high-complexity projects, such graphs can substitute the guiding figure by working as a project explicit visualization. Moreover, the acknowledgement of components' dependency relationships promotes communication between workgroups. In addition, *dependencies maps*, used during interdepartmental meetings, have encouraged the definition of common goals and requirements because students are more inclined to look for *collaboration touchpoints* between their projects.

Furthermore, in interdisciplinary meetings used as study cases, implementing a communication structure helped to leverage the collaboration between workgroups by creating a contextual path guiding each meeting; instead of brainstorming on the abstract ground. In fact, during the implementation of the new methodology, it has been noticed that the meeting efficiency depends on the participants' background experience. As a result, if no contextual path and initial goals are set, the meeting outcome doesn't provide helpful information to the project.

In conclusion, the method applied during the meeting regarding the fairing set used the maps and the complete CAD assembly as *boundary objects* to improve communication between interdisciplinary subjects of different departments. The meetings were held with a previously set goal and by creating the conditions to brainstorm around a *boundary object* that performed as the focus point.

Limitations and future development

The first limit of the methodology application regards the extension of its test. The protocol has been applied only to a selected group of students collaborating to design and develop the petrol fairing set; it should be extended its use to more groups. Implementing such a protocol to the whole team during an entire cycle will help refine and improve it. To achieve the goals set for this study, it was decided to keep a controlled environment for the first application attempt. Moreover, for extended use of the methodology, it would have been necessary to train the management board to obtain more data. Such training would produce study cases without my presence as an active participant during the activities but only to record data, to analyze the meeting outcomes based on my experience. Since my presence could take the shape of a guiding figure in the application of the new methodology, retrieving data gathered without my help will open the path to autonomous use, which would be the ultimate goal of the new method.

Another limitation regards the extension of the fairing project. Due to a lack of compatibility between my thesis schedule and the team's deadlines, the fairing development didn't reach production maturity yet. The assembly between fairing and related components would have represented the objective outcome of this project. That is because most parts are developed together. Even in the details design phase, critical decisions about joints and connections are possible, leaving the communication channel open through diverse workgroups until production maturity is reached.

Last, during the final development steps, another design student started his thesis regarding the application of an active aerodynamic device. Such a device aims to reduce braking periods on track. It is part of the aerodynamic pack and will be mounted on the fairing sides. It would have been interesting to consider such a high-complexity project since the protocol implementation to achieve common ground for both projects, enriching the final overall outcome.

Concluding remarks

In conclusion, a few topics have emerged through this thesis development. First, constructive learning contexts inside the university doesn't always are supported by a guiding figure. Such contexts give space to groups of students to develop competencies and project awareness without the safety of the teacher. The missing figure generates an autodidact process inside the team where members acquire knowledge through resolutions of problems and collaborative work.

However, they miss the process awareness necessary to apply that knowledge strategically to reduce the trial-and-error factor. Moreover, interdisciplinary collaboration is given for granted, which means there is no active process of building personal competencies, so the design process does not exploit such relationships at best.

Last, in these self-directed projects, subject's relationships are often strongly supported by objects, used as infrastructure to establish complex communication channels. The more the subjects struggle to communicate, the more the object is helpful to focalize the brainstorming. Hence, it would be interesting to expand the method application to analyse the possible shift in the interdepartmental relationship and how they reflect on the project's decisions.

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