Impact of Automation in Aircraft Painting and Paint Removal

João Pedro Ferreira
joaopsferreira@ist.utl.pt

Instituto Superior Técnico, Universidade de Lisboa, Portugal

November 2018

Abstract

Globalization has boosted the use of airplane as a means of transport, which has led to an increase in the number of passengers and, consequently, the aircraft number. The airplane coating is a fundamental condition for airworthiness. However, the paint has a limited shelf life, which is required to be replaced repeatedly. In order to keep up with the growth of the aircraft industry, aircraft maintenance companies have been looking for alternatives to the old painting and paint removal methods used, mostly manual, time-consuming and costly, as well as potentially dangerous for operators. In this sense, the technological advance verified in the area of automation makes this seem like a natural solution to optimize the maintenance of the aircraft finish system. With this in mind, OGMA, an aircraft maintenance company, was associated with this study, in order to find an effective automatic solution for its activity and to be aware of the impact it would cause. Thus, during this work the knowledge of the current process is used to propose an effective automated solution for the OGMA painting and paint removal process. By idealizing the procedure for the aircraft interventions, the necessary times and resources are obtained for each one of the operations. These results are, finally, compared with the current results to determine a point of view about the impact caused by the project implementation.
Keywords: Aircraft Maintenance, Industrial Painting, Paint Stripping, Automation, Impact.

1. Introduction

The airplane, as a fast, safe and modern means of transport, is one of the main drivers of globalization. Nowadays, aviation plays an essential role in society, compressing time and space, breaking boundaries and denying geography as an obstacle.

Paint is usually the first impression that is transmitted to someone when they look at an aircraft for the first time. In addition, the coating protects the structure of the aircraft, allowing it to operate safely. During the airplane life, the paint is applied and removed several times to ensure its good condition or changing in the livery.

Although in other industries the painting process has already been completely automated for more than fifty years, the aircraft's coating system maintenance continues to be mostly done manually. However, the increase of aircraft numbers and the strong competition in this sector mean that, increasingly, manufacturers and maintenance companies are looking for solutions to improve aircraft's painting and paint stripping area.

It is with this objective in mind that OGMA, a Portuguese aircraft maintenance company based in Alverca, was associated with this study for the implementation of an automatic system of painting and paint stripping airplanes and to study the impact it would have on the company.

2. State of Art

2.1. Aircraft Painting and Paint Stripping

The aircraft surface is exposed to severe and adverse conditions during the flight period. Thus, surface coating plays a preponderant role in protecting the aircraft from corrosion and abrasion. In military aviation, in addition to surface protection, painting plays a significant role in camouflage, making it more difficult to detect by enemy radars during missions. In civil aviation, securing a good aesthetic appearance of the aircraft is one of the painting functions, such as signage through security badges and the final liveries that identify the airline for which the aircraft operates. In addition to the aforementioned, the aircraft coating makes it easier to maintain and wash, giving it less vulnerability to dirt and oil.

Although proper paint application and good paint quality can increase the aircraft coat lifetime, methods and technologies currently used to paint an aircraft have a validity of less than a decade, usually 5 to 6 years. Thus, at the end of the coating life, there is a need to pick up the old paint and apply a new paint to the airplane [10, 5, 1].

Painting

Generally, the aircraft's finish system consists of three layers: surface treatment (pretreatment), primer and topcoat (Figure 1). Pretreatment is usually a chromate-based chemical compound which is applied to the metal surface forming a conversion layer (chromatization). Subsequently, the organic coatings are applied: the primer, with an epoxy resin or polyurethane base, and the topcoat, with resin polyurethane or polysulfite base. Due to safety aspects, various insignia and signs are often painted on the exterior of the aircraft. For aesthetic and advertising reasons, schemes or liveries can also be added to the topcoat to identify the company to which the airplane belongs.

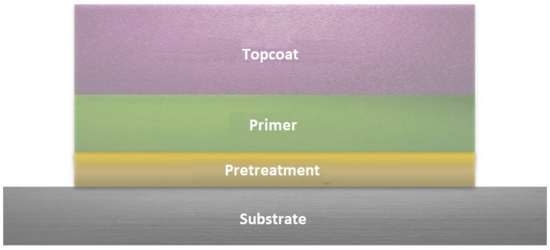

Figure 1: Finish system scheme

Normally, in aircraft painting, paint is sprayed with a 'High Volume Low Pressure' gun, due to its very thin layer of painting. However, other equipment is available to paint an airplane, such as airless and electrostatic guns [10].

Paint Stripping

The finish system removal is performed whenever it is necessary to change the aesthetic appearance of the aircraft or when it is necessary to make structural maintenance.

There are several ways to perform the process of paint stripping an aircraft. The most commonly used method is chemical paint stripping, in which chemical strippers are applied to the surface of the airplane and act until the coating is softened and can be removed using brushes [10].

Another possible method is mechanical paint stripping. The mechanical process of removing paint uses sanders or other abrasive equipment. There is also the Plastic Media Blasting (PMB), a method that uses plastic particles, projecting them at a pressure between 0.28 and 0.41 MPa, to about 30 to 60 cm of the surface which is intended to be stripped.

Finally, in the last years, the technological development allowed an optical paint removal, through laser. The laser energy is focused on the surface and is absorbed by the coating, resulting in the paint decomposition and removal, causing only a minimal increase in substrate temperature.

2.2. Industrial Automation

Industrial automation can be defined as 'automatically controlled operation of an apparatus, process or system by means of mechanical or electronic devices that replace human labor' [11]. With the advances in this area, automated systems are increasingly becoming a reality in various industry sectors. Proof of this is the data on the commercialization of industrial robots worldwide: in 2016, about 294 thousand units were installed, while in 2012 these figures were just over half, 159 thousand.

The main objectives of industrial automation can be summarized in the following points [11]:

- Improve productivity
- Reduce production costs
- Increase product quality
- Increase flexibility
- Improve the working conditions of operators
- Replace periodic inspections and manual controls

Within the wide range of applications for automated systems, the industrial painting area stands out. It is estimated that in 2023 this market will move more than 2700 million euros. Companies like Kawasaki Robotics, ABB, Fanuc, Yaskawa, Kuka Robotics and Durr Systems are some of the industry leaders in this sector.

A "Paint Robot" is distinguished from the rest due to two characteristics that, although not exclusive, are very typical of this area: they are built with explosion-proof robotic arms, so they can be used in flammable environments such as the servant by spraying paint, and have the ability to control all spray parameters, from air pressure to paint flow, contributing to the quality of the final product [4]. Paint robots bring improvements in the field of repeatability, operator safety, productivity and final product quality [3, 7].

In the aeronautic sector there are already some automatic systems of airplanes painting and paint stripping. *Lockheed Martin*, the company responsible for designing the F-16 and C-130 military aircraft, among others, has developed an autonomous painting system for its F-35 model. This system was known as *Robotic Aircraft Finishing System* (RAFS). For paint stripping, there is the case of the *Advanced Robotic Laser Coating Removal System* (ARLCRS), developed to remove the American Air Force (USAF) aircraft coatings. Finally, *LRSystems*, a dutch start-up, is developing a paint and paint stripping super robot.

3. OGMA's Painting and Paint Stripping

In OGMA, the aircraft coating maintenance mainly happens due to the need to develop maintenance work on the airplane structure. This process follows rigid internal specifications which have been carried out in accordance with the manuals and indications provided by the aircraft manufacturers. The airplane is initially stripped. After this process is carried out to the maintenance hangars where it remains several days, weeks or even months, depending on the work to be done. Finally, he returns to the painting hangar where a new coating is applied.

3.1. Paint Stripping

The paint stripping method used in OGMA is chemical removal, aided by mechanical removal when it is impossible to apply the first, or at the customer express request.

This process is lengthy and consists of several steps. When the airplane arrives at the paint hangar, work begins on the preparation of the surface for paint removal and the components sensitive to chemicals are masked. Thereafter, the stripper is applied and it is left to act. After some time (tipically one hour, but it can last for some hours), the paint that has been lifted is scraped off with brushes. Finally, the anticorrosion treatment is applied and the masking sheets removed. All this process requires the use of adequate safety equipment.

3.2. Painting

When the airplane arrives at the painting hangar, coming from the maintenance, usually comes with a dirty and greasy surface, a situation that does not favor the paint adhesion to it. Thus, the painting process begins with the airplane washing and the reapplication of anti-corrosion and chromatization treatments. After this initial stage, the airplane is masked for paint. Then the paint application begins with the primer and, after that, the topcoat. Finally, the paint is inspected and the masking material is removed.

At OGMA, paint application is done using conventional, HVLP or electrostatic spray guns. To ensure greater efficiency, the last two methods are the most commonly used. The brush for retouching is also used in areas inaccessibles to the gun.

4. Case Study: OGMA's Automated Painting and Paint Stripping

4.1. Specifications and Requirements

It is intended that, the solution implemented, in addition to the ability to paint/stripp all models of aircraft normally operated in OGMA, have the flexibility to intervene other models that may be added in the future. Moreover, the company intends that the new painting and paint stripping system present the highest level of autonomy possible and that the solution found is technologically evolved, so that it remains current if the project takes several years to be implemented. Finally, it is essential for OGMA that the quality standards defined by its internal standards be strictly accomplished. Finally, the automated solution will have to fulfill the necessary requirements to be able to be duly certified.

4.2. Automation Process

The solution to be implemented will be a mobile robot composed by an AGV platform, a simple lift structure and a robotic arm (Figure 2). This solution had already been found in a preliminary study carried out by Umberto Morelli, "*Preliminary Design of an Aircraft Automatic Painting and Paint Removal System*" [8].

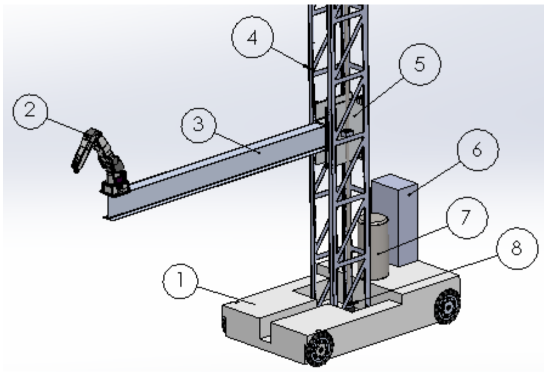

Figure 2: Robot drawing

Table 1 identifies the various components of the robot, indicated by numbers in the Figure 2.

nº	Description
1	AGV
2	Robotic Arm
3	Horizontal Beam
4	Lift Structure
5	Beam Support
6	Robotic Arm Controller
7	Paint Tank
8	Stepper Motor

Table 1: Robot's components

Despite all the components already identified, in the previous study no operating tools (equipment to be attached to the robotic arm to accomplish the task) were selected.

Tooling

The types of existing painting guns can be summarized in the categories of HVLP, Airless and Electrostatic. In the category of electrostatic guns there are Rotary-Bells, an equipment specially developed for robotic applications, which uses a high-speed rotary device to improve spray results. To maximize the level of process automation, it is necessary that the gun used by the robot has the highest possible paint transfer rate. The transfer rates of each of the gun categories mentioned are shown in Figure 3.

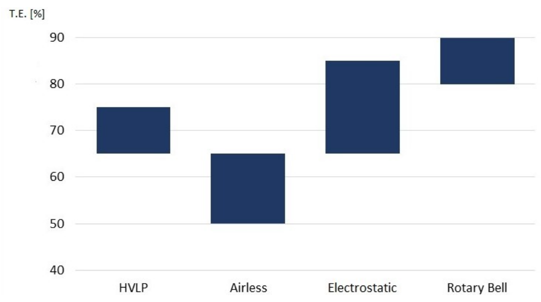

Figure 3: Guns' transfer efficiency

That said, despite the higher cost, it was chosen to use a rotary bell because of its superior efficiency rate and due to its technologically advanced features that can contribute a lot to a greater final result in the aircraft coating. After a market research, it was selected Nanobell 2, from Sames-Kremlin as the most suitable gun to use in the painting process.

On the other hand, it is more difficult to choose a method of paint stripping. Chemical stripping has the advantage of being a method already known in the company and not representing a big initial investment. However, the robot could only carry out the application of the stripper product, still requiring operators for the remaining steps [10]. PMB could be an alternative. This method has the advantage of being easily integrated into the robot. However, it represents a high initial investment and may be a risk to the aircraft surface [10]. Finally, laser removal has lower operating costs than other methods, it is an advanced technology and is easily applicable to the robot. In addition, it is "environmentally friendly" [9, 6].

After weighing the pros and cons of each method in a decision matrix, it was decided to select the laser removal method. CleanLaser provided an effective solution, the CL 600, with a pickling speed of 12 cm^2/s.

4.3. Procedure

Both in painting and paint stripping procedures, the robot moves around the airplane perimeter, starting at the front, skirting the wing and following its path till the rear of the aircraft. The standard trajectory (valid for any type of aircraft with a similar arrangement) taken by the robot is represented in Figure 4.

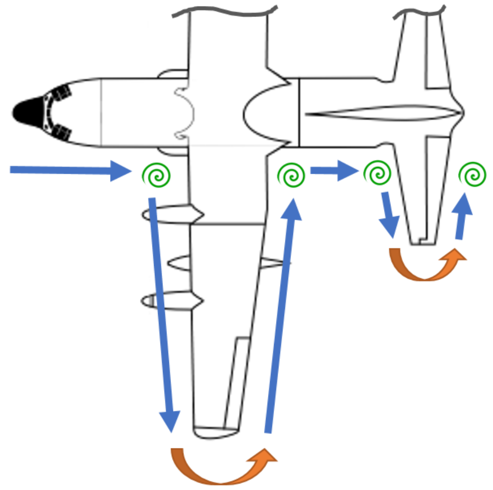

Figure 4: Robot's trajectory around the airplane

During the trajectory, the robot positions itself facing the plane and moves laterally, using its omnidirectional wheels. This movement will, for the most part, be a rectilinear movement. However, next to the airplane wing, it will be required to the robot to change direction, so it will have to perform a rotation about its center. In order to reproduce the manual work currently applied, the airplane is divided by sections of equal spacing. The robot applies and removes paint on each of the sections separately, moving to the next when it complete the job in the section before. An example of this division of the aircraft surface can be found in Figure 5.

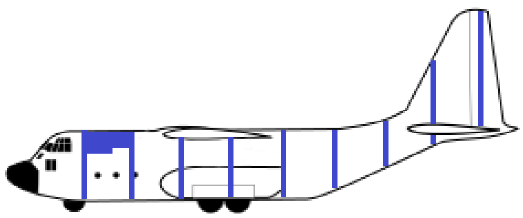

Figure 5: Plane divided into multiple sections

The sections' width will correspond to the robotic arm's maximum working envelope capacity. Therefore, the sections' width will be 1.15 m.

During the course, the AGV platform performs the lateral movement and immobilizes in the center of each section, allowing the robotic arm and the horizontal bar to perform the painting work. Because of the curved nature of the plane's surface, the platform at these times will have to move back and forth, so that the robotic arm reaches all locations without colliding with the airplane structure. During the painting process, the robot will always have to start applying paint from the top of the fuselage, due to the hangar's down-draft air system. Thus, the robot will always have to raise the horizontal bar after finishing each of the sections, so that it starts over the next one. During the spraying, the trajectory followed by the robotic arm to paint each section is represented in Figure 6.

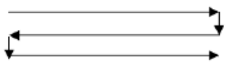

Figure 6: Spraying trajectory

It is recommended that, when painting, the gun tip moves at a speed between 0.2 and 1.2 m/s. Thus, a velocity of 1 m/s will be selected in the horizontal surfaces painting. On vertical surfaces the speed will be 0.24 m/s due to lift motor limitations.

In the paint stripping process, the trajectory will be equal to the painting process one. Paint removal by laser will also be done by using the airplane sectioning. However, in this process the robot will not need to start work at the top of the section, which will save the additional time to lift the horizontal bar. Thus, the painting process may occur in a more fluid manner, as shown in Figure 7.

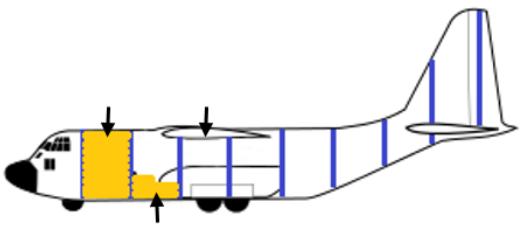

Figure 7: Airplane paint stripping sequence

4.4. Operational Times

The total time robot needs for painting an aircraft will be result of the sum of the time it takes to apply the paint on the aircraft surface and the time spent on the movements between sections. In addition to these two parameters, extra time will be added, regarding some movements that require more preparation and the time spent refilling the paint tank, if necessary.

Sections' painting will be done continuously, without stops. Thus, the time in which the robot is effectively applying paint to the plane surface can be calculated by extrapolating the time robot takes to paint a small area for the time it takes to paint the entire aircraft surface. Considering that the painting process is carried out in straight horizontal passages, with $Lvao = 1{,}15\ m$, and knowing the vertical progression by passage ($\Delta z = 20\ cm$), the painted area per passage is easily calculated ($Apass$):

$$Apass = Lvao \times \Delta z \quad (1)$$

The time this area takes to be painted will depend on the orientation of the aircraft surfaces. As already mentioned, the gun speed will be different for horizontal and vertical surfaces. Thus, a different passage time ($tpass$) will be obtained for these two types of surface:

$$tpass = Lvao \times vpass \quad (2)$$

Using the aircraft CAD model, it is estimated the proportion of horizontal and vertical surfaces (Sh and Sv). Finally, with the total aircraft surface area (A), a prediction of the time spent applying paint is obtained, using the expression 3.

$$tpaint = \frac{A}{Apass} \times [Sv.tpassv + Sh.tpassh] \quad (3)$$

For the entire operating time estimation, the time spent in paint application will be added to the time robot takes to move between the sections. To calculate the number of movements required along the fuselage of the aircraft, the length of the entire fuselage is divided by the width of each section. The same procedure will have to be done for the wing and stabilizer, this time multiplying by two, since the robot will act in both sides of these surfaces. Thus, it is known the number of sections in which the airplane is divided and, consequently, the number of movements along it.

Knowing that the maximum acceleration of the robot is 0.5 m/s^2, it is estimated that, to occur safely, the time required for the movement between two sections is approximately 4 s. However, on vertical surfaces on which the horizontal bar must be raised to the top of the aircraft, the time lost in this operation must be accounted for. This time will depend on the height of the fuselage of each airplane model and can be calculated by dividing this dimension by the raising speed of the stepper motor. The product of the number of movements by the time that takes each movement will give the final result for the time spent on the movements between sections by the robot.

In addition, the movements that require the robot's rotation (marked with the green spiral in the Figure 4) are more complex and therefore an additional minute will be considered each time the robot has to do it. During the aircraft painting, it will also be necessary to bypass the top of the wing and stabilizer (marked with the orange arrow in Figure 4), so one more minute will be added for each time this operation is needed. Finally, due to the capacity of the robot's paint tank, whenever it is necessary to replenish the robot, add 10 minutes to the total time.

The total time spent on painting the airplane will be the sum of all the times mentioned above. This final value will, however, be multiplied by a safety coefficient of 1.2 to ensure that the painting time of an aircraft is not underestimated.

For the paint stripping process, the time required will be obtained by adding the time the laser is stripping the coating and the robot needs moving between sections. As with the painting process, extra time will also be added for the same special reasons. The chosen laser strips the surface at a velocity (j) of 12 cm^2/s. Thus, knowing the airplane surface area, it is easy to calculate the time spent in this action, through the expression 4.

$$tstrip = \frac{A}{j} \quad (4)$$

In this process the robot will not have to raise the horizontal bar before starting each section. Thus, the travel time will be 4 s for all movements. The total time spent on the aircraft paint stripping will be the sum of all the times mentioned above, multiplied by a coefficient of 1.2 per security.

4.5. Cost Assessment

All components that had already been developed in the previous study had their cost identified. These values are shown in Table 2.

Component	**Cost**[€]
AGV	55 000
Robotic Arm	20 000
Lift System	4 000
Paint Tank	3 600
Lift Structure	2 000
Stepper Motor	1 000
Horizontal Beam	900
Beam Support	100
Total	**86 600 €**

Table 2: Robots' components costs [8]

Costs with tooling for painting and paint stripping processes are shown in Table 3.

Tool	**Cost**[€]
Nanobell 2	55 000
CleanLaser CL 600	280 000

Table 3: Tooling costs

For the remaining robot's control, programming and assembly costs, it was estimated that it would be spent one or two times the components of the robot structure value. Thus, one can estimate the cost of each robot (Table 4).

	Paint[k€]	**Depaint**[k€]
Structure	87	83
Tooling	55	280
Others	[87 - 173]	[83 - 166]
Total	**[228 - 315]k€**	**[446 - 529]k€**

Table 4: Robots' final costs

Finally, during the lifetime of the robots (10 years), there will be some maintenance costs (Table 5).

Year	**Maintenance cost** [€]
1 to 4	2 000
5	20 000
6 to 10	2 000

Table 5: Maintenance cost

5. Impact of OGMA's Paint and Paint Stripping Automation

Obviously, the automatic system implementation will have an impact on what is OGMA's current reality. To ensure greater insight into the impact, two of the aircraft models that are most frequently used in the company were selected to be calculated the operating times and costs with the automatic process, through the methodology discussed in the previous section. These values will be compared with the manual process values. As it is not possible to disclose the selected aircraft models, these will henceforth be designated by **Large Military Airplane** (AMGP) and **Medium-sized Executive Airplane** (AEMP).

5.1. Operation

The paint application and removal operations are only a part of the entire painting and paint stripping process. In order to obtain the perception of the robots' work relevance, the time, with the current method, involved in the accomplishment of each one of the stages of the painting and paint stripping process. These values were obtained from OGMA working papers.

In the painting of **AMGP**, the distribution of the total time of the process by the several steps that compose it is represented in the diagram of Figure 8. To **AEMP** it is shown in Figure 9 Since the robots only participate in the application stage of primer and topcoat, the new solution represents an automation rate of 29.4 % and 12.1 % to **AMGP** e **AEMP**, respectively.

Regarding the paint stripping process, to **AMGP**, the process total time distribution by the several steps that compose it is represented in Figure 10 and to **AEMP** it is shown in Figure 11. Since the robot only participates in the paint removal phase, the new solution represents an automation rate of 45.4 % and 81.6 %, respectively.

In OGMA, the time required to perform a process is measured in man-hours (MH). A man-hour is an agreed unit that measures the amount of work performed by a human operator for one hour, with no pauses or interruptions [2]. The man-hours that will be spared with the automatic system introduction in the painting process are represented in Table 6. In the other hand, the reduction of man hours in the paint stripping process can be found in Table 7.

	[HH]	[%]
AMGP	-323	-29
AEMP	-71	-11

Table 6: Man-hours' reduction with automatic system: painting

	[HH]	[%]
AMGP	-183	-26
AEMP	-486	-73

Table 7: Man-hours' reduction with automatic system: paint stripping

With the automated solution implementation proposed in this study, the material used in the airplanes interventions will be optimized. In painting there are reductions in paint consumption (Table 8) and in the masking paper currently used during the paint application (Table 9).

	AMGP [%]	**AEMP** [%]
Primer	27	26
Topcoat	38	53

Table 8: Paint reduction

	Masking paper [m^2]
AMGP	950
AEMP	400

Table 9: Masking paper reduction

On the other hand, in paint stripping it will be eliminated the cost with chemical stripper and water, which are used in the current manual method (Table 10).

	Stripper [L]	**Water** [L]
AMGP	2 000	200 000
AEMP	400	40 000

Table 10: Stripper and water reduction

5.2. Operation Costs

With the operational differences verified behind, the costs involved in the painting and paint stripping process will also present changes in relation to the costs currently supported by OGMA. To obtain these results some values were assumed:

- Typical salary of a paint technician is 1794 €/month, 10,2 €$/h$.
- Electricity price of 0,14 €$/KWh$.
- Masking paper has a value of 0,25 €$/m^2$.
- Water has a cost of 2,03 €$/m^3$.

Finally, the values considered for the paints and stripper product's cost can be found in Table 11.

	AMGP [€$/L$]	**AEMP** [€$/L$]
Primer	61,5	32
Topcoat	52,4	64,2
Stripper	7,4	8,2

Table 11: Paint and stripper's cost

For the painting of **AMGP** and **AEMP**, the difference in operational costs after the automatic system implementation is represented in Table 12.

	AMGP [€]	**AEMP** [€]
MH	-3 297	-728
Paint	-5 812	-4 447
Masking	-236	-99
Electricity	-	-
Total	**-9 345 €**	**-5 274 €**

Table 12: Difference in painting costs with the automatic process

If it is assumed that, using the automated solution, are painted and paint stripped 15 aircraft per year in OGMA, it would be possible to have cost savings in painting area of 140 182 €$/year$ if only **AMGP** were painted, 79 114 €$/year$ if only **AEMP** were painted and, finally, 109 648 €$/year$ if the proportion of **AMGP** and **AEMP** is identical.

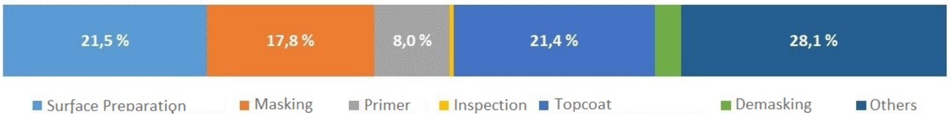

Figure 8: Temporal distribution through the various stages of painting an AMGP

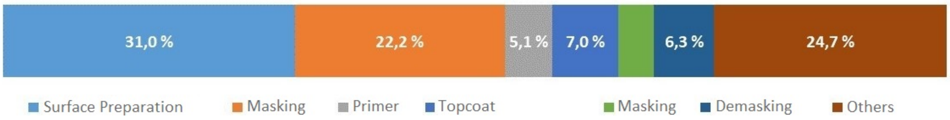

Figure 9: Temporal distribution through the various stages of painting an AEMP

Figure 10: Temporal distribution through the various stages of paint stripping an AMGP

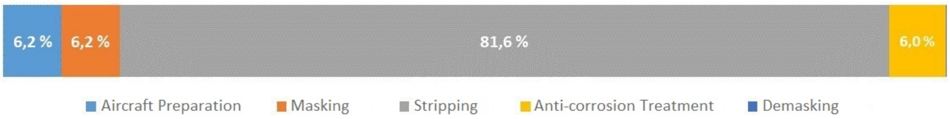

Figure 11: Temporal distribution through the various stages of paint stripping an AEMP

For the paint stripping of **AMGP** and **AEMP**, the difference in operational costs after the automatic system implementation is represented in Table 13.

	AMGP [€]	**AEMP** [€]
MH	-1 866	-4 956
Stripper	-14 800	-3 280
Water	-405	-81
Electricity	+551	+232
Total	**-16 520 €**	**-8 085 €**

Table 13: Difference in paint stripping costs with the automatic process

At the end of a year, with 15 aircraft stripped, this would mean cost savings of 247 805 $€/year$ if only **AMGP** were stripped, 121 278 $€/year$ if only **AEMP** were stripped and, finally, 184 542 $€/year$ if the proportion of **AMGP** and **AEMP** is identical.

5.3. Other Impacts

Quality, Consistency and Predictability

With the implementation of the automatic painting system some of the paint defects that lead to the rework can be avoided. In addition, it would be easier to predict costs and operating times.

Environmental Cost

Stripping through laser technology would represent the adoption of a more ecological and sustainable system. In terms of weight, laser stripping generates only about 0.3 % of the waste generated through chemical stripping. For 1 kg of coating removal, chemical stripping generates 9.1 kg of solid waste plus 165 kg of liquid waste, while laser removal generates only 0.5% kg of solid waste.

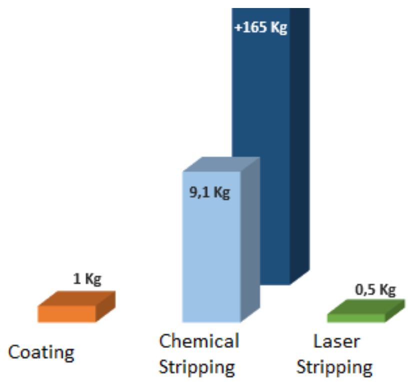

Figure 12: Waste generated [6]

This would contribute to a reduction of the company costs with waste treatment, mainly the wasted water treatment.

5.4. Automation's Viability

In order to determine the project viability, several indicators were used. First, a simple forecast was made, without considering the time value of money, to determine the number of aircraft that will have to be intervened to recover the initial investment in the equipment. In this analysis the various types of aircraft that can be operated are considered, from a sample composed only by **AMGP**, only by **AEMP** or by an identical proportion of the two types of airplane (50/50). It was also considered the minimum and maximum investment, resultant from the range of values that robots can cost.

Figure 13: Nº of aircraft that have to be intervened

Net Present Value (NPV) is an indicator that allows to evaluate a project through the sum of future cash flows' values, discounted at a certain interest rate, obtained during the lifetime of the project. NPV can be calculated from Equation 5 [2].

$$VAL = -CF_0 + \sum \left(\frac{CF_i}{(1+r)^i} \right) \tag{5}$$

In this expression, CF_0 is the initial investment value, in €; CF_i is the cash flow of year i, also in €; r is the discount rate. In the analysis of a project NPV, in order to be considered feasible, it must be greater than zero [2].

For these project's NPV calculation, the following was assumed:

- Number of project years equal to the robot's estimated lifetime, 10 years.
- Discount rate (r) of 8%, based on historical data from other projects evaluated in Portugal.
- For cash flows, it was considered that the robot has a depreciation period of 10 years and that the tax rate applied to the company is 21 %.
- It is estimated that, per year, 15 aircraft are operated. That is, 15 planes carrying out the paint stripping and painting process.

In Figure 14 it is represented the NPV variation for the project of implementation of an automatic painting and paint stripping system, according to the typology of the set of intervened airplanes. Horizontal axis begins with the point where the set of aircraft is composed only by **AMGP** up to the point at which the aircraft package involved is composed only by **AEMP**, passing through the different proportions of one and the other type, with emphasis on the situation where the proportion is identical (50/50).

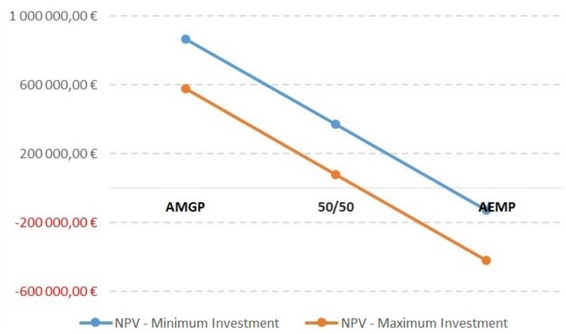

Figure 14: Project's NPV

Moving to another indicator, the IRR is the discount rate that equals the NPV of the project's cash flows to zero. In other words, it is the rate that makes the entries' updated value equal to the cash outflows' updated value. Thus, the IRR will be the solution of Equation 6 in order to r [2].

$$-CF_0 + \sum \left(\frac{CF_i}{(1+r)^i} \right) = 0 \tag{6}$$

For the analysis of the IRR results, the project is considered acceptable if the value obtained is greater than the discount rate used (in this case, r = 8%). The higher the IRR, the greater the project gain and the less sensitive it will be to potential unplanned risks. For the analysis of the IRR, it was considered that the set of aircraft to be operated is composed of an identical proportion of **AMGP** and **AEMP**. The project's NPV variation in relation to the discount rate can be found in the Figure 15 graph.

It was found that, when the investment is minimal, the IRR assumes the value of 13.76 %, whereas with a maximum investment this rate is 9.02%. In both cases the rate of return is higher than the discount rate used (r= 8%), although there is no very high margin. These values were obtained graphically.

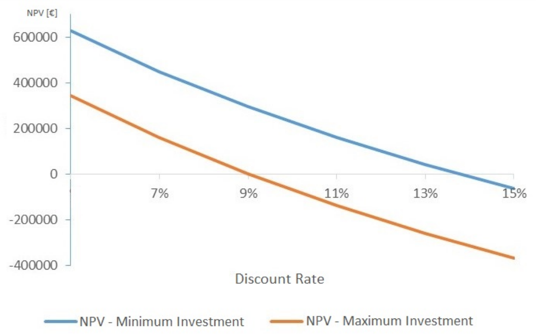

Figure 15: NPV variance in relation to r

6. Conclusions

After this work, some conclusions could be drawn from it. Maintenance of an aircraft coating is a long and time consuming process, which does not end with the removal of old paint and the application of new paint. Despite all the advances achieved in the industrial processes automation, this area remains delicate and devoid of automatic solutions with the ability to intervene in the entire process. Even so, the automation of aircraft painting and paint stripping in a maintenance company is possible. Proof of this are the meager, but real, examples of success stories such as the USAF-implemented ARLCS.

After complete some steps, the impact of the project was then calculated. Thus, it was noticed that in painting, the degree of automation achieved is very low, while in the paint stripping the influence of robots will be greater. In any case, there will be a reduction of MH required in both processes. When it comes to materials used in the interventions, reductions are achieved in the paint, masking paper, stripper product and water. With the new automatic system, paint reductions of 26 to 53 % are achieved. All of the improvements mentioned have contributed to the reduction of operating costs when compared to the manual process currently in use. In this field, it is noticed that a greater value is saved in AMGP aircraft.

Finally, several indicators were considered for a projects' viability study. It was realized that profit will be maximized if the most intervened aircraft are AMGP. It was also concluded that the investment is feasible for a period of 10 years, although only generate profit in the last years of the robots' useful life. Thus, the study is not fully indicative that the implementation of the automatic painting and paint stripping system will be a benefit to the company, although for these calculations the contributions of other impacts, such as costs for treatment of environmental waste and for defects' repair in the painting process.

Acknowledgements

I would like to thank Prof. Filipe Cunha and Prof. Paulo Peças for all the help provided during this work realization.

I also would like to thank OGMA, particularly Eng.ª Cláudia Magalhães, for the oportunity to develop this study and for all the information and assistance provided.

References

[1] *Aviation Maintenance Technician Handbook - Airframe*, volume 1, chapter Aircraft Painting and Finishing. Federal Aviation Administration, 2012.

[2] O. Blanchard and S. Fischer. *Lectures on Macroeconomics*. The MIT Press, 1989.

[3] P. S. E. Company. The pros and cons of automated robotic painting.

[4] M. Freels. Robotic paint automation for smaller industrial operations. *Robotic Industries Association*, 2008.

[5] J. Koleske. *Paint and Coating Testing Manual*, chapter Aerospace and Aircraft Coatings. ASTM International, 15 edition, 2012.

[6] Lasertronics. Financial payback overview.

[7] P. Mills. Applying robotics to your paint line.

[8] U. Morelli. Preliminary design of an aircraft automatic painting and paint removal system. Master's thesis, Instituto Superior Técnico, 2016.

[9] M. Then. The future of aircraft paint removal methods. Master's thesis, School of Systems and Logistics of the Air Force Institute of Technology, 1989.

[10] United States Air Force. *TO 1-1-8 Technical Manual: Application and Removal of Organic Coatings, Aerospace and non-Aerospace Equipment*, Março 2016.

[11] M. Wilson. *Implementation of Robot Systems*. Butterworth-Heinemann, 2015.