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EVALUATION OF PCN AND PCR PARAMETERS FOR UNPAVED AERODROMES

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ABSTRACT

About 72% of the runways registered in DECEA do not have a coating layer, and even so the ACN/PCN and ACR/PCR methods, which are parameters that indicate the bearing capacity and are mandatory for aircraft weighing more than 5700Kg, are applicable only to paved aerodromes. Considering that there are aircraft able to operate on unpaved runways that exceed this weight limit, and given the economic viability of the construction of unpaved aerodromes, this research aims to evaluate the application of these parameters in unpaved aerodromes. The objective is to compare the difference in bearing capacity, layer thicknesses and materials used, as well as the CDF obtained, for flooring with and without coating in both methods. For this, an experimental applied research was carried out, in which aircraft capable of operating on unpaved runways were selected, and thus the dimensioning of pavements with and without coating in an aerodrome located in the region of the Jequitinhonha and Mucuri valleys in Minas Gerais, through the COMFAA 3.0 and FAARFIELD 2.0 software. In view of the data obtained, it is verified that the PCN and PCR values for both situations were similar for each aircraft, with small variations. In addition, the thickness and the need to use the subbase are influenced by the presence or absence of coating, as well as the weight of the aircraft. The thickness of the base layer, for the most part, presented values close to 150mm, with slight variations. The possibility of not using a coating layer proved to be an effective strategy to reduce execution costs, ensuring the runway's bearing capacity, especially for small aircraft such as the Pilatus PC-24.

Keywords: ACN/PCN. ACR/PCR. Pavement. Airfields.

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INTRODUCTION

The air transport sector has a great importance in the global economy and logistics, enabling the rapid movement of cargo and people over long distances. To meet this growing demand, it is essential that airports have an adequate infrastructure, both for commercial and executive aviation (RENZETTI, 2018).

Regarding airport infrastructure, the 2021 Airport Projects Manual defines that every area established for the arrival, departure and movement of aircraft, whether on land or water, is determined as an aerodrome, which can be classified according to its type of use, which can be: civil, military, private or public. An airport is a type of aerodrome, classified as public, which has buildings, facilities, and equipment that provide support either in the embarkation and disembarkation of people or in the handling of cargo (MINFRA, 2021).

The physical structure of an airport is divided into two parts: the Airside and the Landside. The Landside is the public area where there is no controlled access, such as the vehicle parking lot and the entire part of the Passenger Terminal (TPS) prior to the security inspection. The Airside corresponds to the operational area of controlled access, in which we find several elements, such as the Taxiways, the Aircraft Yard, the Fire Fighting Section (SCI) and the Aircraft Supply Park (PAA). However, the highlight of this area is the Landing and Takeoff Runway (PPD), where the main aircraft movements occur (MINFRA, 2021).

In order for a Landing and Takeoff Runway (PPD) to be used, it is necessary to meet several standards established by regulatory bodies, such as the National Civil Aviation Agency (ANAC), the Brazilian Airspace Control Department (DECEA) and the International Civil Aviation Organization (ICAO or ICAO). These standards include requirements related to the length and width of the roadway, safety zoning, and above all, pavement strength (MINFRA, 2021).

From 1936 onwards, aircraft began to have increasingly larger dimensions and weights, due to the proximity of World War II, which ended up requiring more reinforced coating layers on the runways, increasing studies and the implementation of new sizing technologies. From the moment that accidents began to occur more frequently due to runway failures, the United States Army Corps of Engineers (USACE) dedicated itself to developing formalized systems that addressed resistance in relation to the thickness of each pavement, between the 1950s and 1970s (CAVA, 2021).

While some floors operated with considerably high loads, others already accommodated small aircraft, with a lower load factor, which required the creation of a

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classification standard that informed the strength of the aerodrome pavement (CAVA, 2021).

Thus, in 1981 the ACN (*Aircraft Classification Number*) and PCN (*Pavement Classification Number*) methods came into force, which indicate the resistance of paved Landing and Takeoff Runways (PPD) and are addressed in all countries, maintaining a standard aviation language stipulated by ICAO. While the ACN is directly linked to the aircraft and serves to classify them according to the effects that are transmitted to the runway, the PCN relates to the pavement and presents resistance values for a given list of aircraft (ANAC, 2020).

However, this method was developed more than 40 years ago, which makes the results outdated due to technological advances in this area. In view of this, ICAO has initiated several studies to introduce new parameters for runway design. Thus, the ACR (*Aircraft Classification Rating*) and PCR (*Pavement Classification Rating*) method emerged, which was promulgated by the ICAO council, in July 2020, through amendment 15 annex 14 of the state letter AN 4/1.2.28-20/35 (FABRE, 2020), which will be in force simultaneously with the ACN/PCN until November 2024, after that date, only the new method can be used (ANAC, 2022).

However, these methods are restricted to airfields with paved runways only and do not address the determination of the strength of unpaved runways. It is important to note that there are aircraft capable of operating at this type of aerodrome, but that exceed the established load limit, increasing the risks to operators and increasing the possibility of damage to aircraft. In addition, unpaved dirt tracks have lower construction and maintenance costs compared to paved ones. It is in this context that this work emerges as a possible solution to study the proper sizing of unpaved runways, in order to establish the necessary resistance parameters to meet the requirements of new aircraft (ANAC, 2021).

For this, an applied research was carried out at an airport located in the region of the Jequitinhonha and Mucuri valleys in Minas Gerais, in which through the improvement of the soil, the sizing of the pavement of new aerodromes without the need for the coating layer was evaluated, for the operation of aircraft that have sufficient technology for a safe operation in this type of runway.

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METHODOLOGY

This study is classified as an applied research, as it aims to expand the knowledge already developed in order to solve practical problems. For this, the pavement was analyzed with and without the coating layer, comparing their respective bearing capacities in relation to the load of the project aircraft. Thus, the research is considered experimental due to the technical procedures adopted, in which an object of study was defined and its behavior was evaluated according to the impact generated by the variables (GIL, 2002).

To achieve the objective of the research, some steps were established as methodological procedures, namely: (i) conducting a literature review, with a focus on understanding how the variables influence the pavement design; (ii) experimental program with the collection of soil samples in a region of the Jequitinhonha Valley and Mucuri, in Minas Gerais; (iii) interpretation and organization of the data from the soil characterization and compaction tests, which were provided by the company contracted for the execution of the airport. This allowed us to determine the most appropriate soil stabilization method, when necessary; (iv) determination of the design aircraft and their respective traffic volume. Then, the computational processing of the pavement data with and without coating was carried out in the COMFAA 3.0 software for the determination of the PCN and in FAARFIELD 2.0 for the definition of the PCR. Thus, the results obtained were compared in terms of bearing capacity, thickness of the layers, CDF achieved, materials used and execution price per square meter.

PCN SIZING USING COMFAA 3.0

To calculate the numerical value of the PCN, COMFAA 3.0 was used together with its Support Worksheet, following the process illustrated in the flowchart in Figure 1 (ANAC, 2020).

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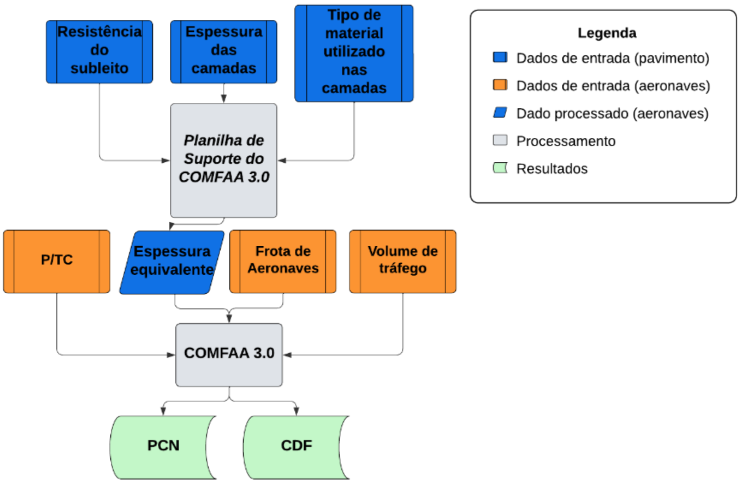
Figure 1 - Flowchart with the procedure to be performed in COMFAA 3.0



Source: The authors, 2023.

This procedure consisted of determining an equivalent thickness based on pavement data using the COMFAA 3.0 Support Worksheet. However, it is important to emphasize that unlike the current design models that consider the modulus of elasticity of the materials, the ACN-PCN method is based only on the CBR of the subgrade and correlates the materials that make up the pavement structure with the standard materials of the software.

This approach can generate possible inconsistencies, since there is no possibility to customize the characteristics of the materials that make up the layers. Because of this, the method does not allow analyzing the behavior of the mixtures tested for the base. Due to these limitations, the evaluation was restricted to pavements with and without coating for each aircraft, without the variation of mixtures.

To obtain the equivalent thickness, the pavement structure was assembled in the Support Worksheet, in which for the base layer, the material P-213 was used, determined as *Sand-Clay Base Course*, or mixture of sand and clay, since the tested mixtures had their parameters based on this material, according to the requirements described by AC 150/5370-10H.

However, the Support Worksheet does not allow the direct use of this material, requiring correlations with materials available in the interface. To carry out this process, the software provides a spreadsheet with conversion values, as indicated in table 1.

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Table 1: Information for Material Conversion

Structural Item	Description	Conversion Range for P-209	Recommended conversion factor for P-209	Conversion Range for P-209	Recommended conversion factor for P-209
P-501	Portland Cement Concrete	-	-	-	-
P-401/P-403	Hot Asphalt Mix	1.2 a 1.6	1.6	1.7 a 2.3	2.3
P-306	Concrete Lean	1.2 a 1.6	1.2	1.6 a 2.3	1.6
P-304	Cement-treated aggregate base	1.2 a 1.6	1.2	1.6 a 2.3	1.6
P-213	Sand and clay	-	-	-	-
P-220	Caliche	-	-	-	-
P-209	Britted Aggregate	1.0	1.0	1.2 a 1.6	1.4
P-208	Aggregate	1.0	1.0	1.0 a 1.5	1.2
P-211	Lime Stone	1.0	1.0	1.0 a 1.5	1.2
P-301	Soil Cement	N/A	-	1.0 a 1.5	1.2
P-154	Uncrushed aggregate	N/A	-	1.0	1.0

Source: Adapted from FAA, 2022.

However, it is worth noting that the values corresponding to the Sand-Clay material were not provided. Therefore, it was decided to consider the conversion value as 1, based on the predominantly clayey nature of the mixtures. This choice is justified by the fact that the conversion parameter varies between 1 and 2.3, and values closer to 1 indicate more granular materials.

After defining the layers that make up the pavement structure, the equivalent thicknesses for each situation were calculated through the Support Worksheet. This parameter, along with the subgrade CBR, was then introduced in COMFAA 3.0.

Then, each aircraft in the study was incorporated into the software, along with the movement previously defined for each one. In addition, a value of 2 was considered for the P/TC variable, reflecting the configuration of the lane as illustrated in Figure 2. This aerodrome has only one taxiway at one of the headlands, resulting in a total of two movements on the runway during the operation.

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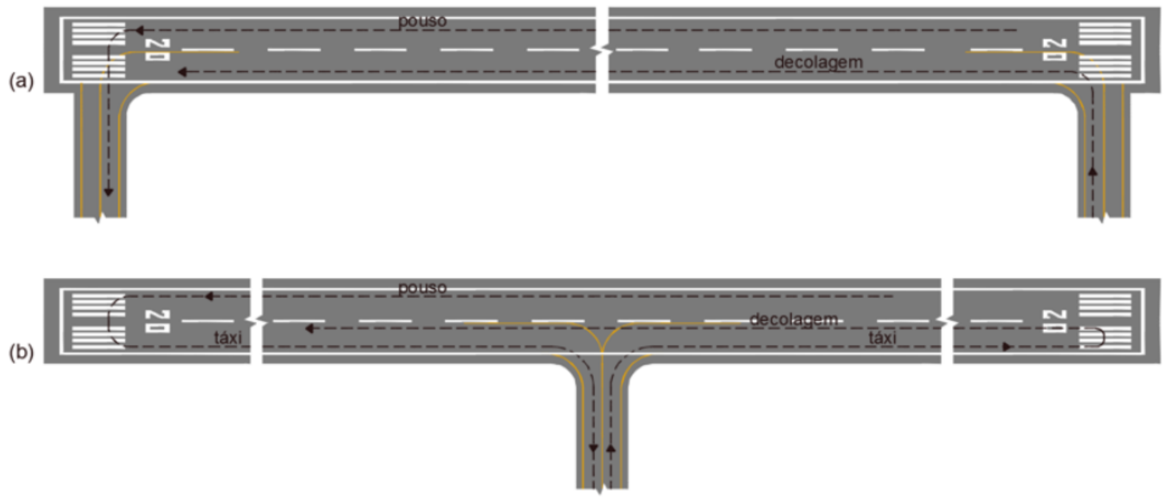
Figure 2 - Taxiways Standards Accessing PPD



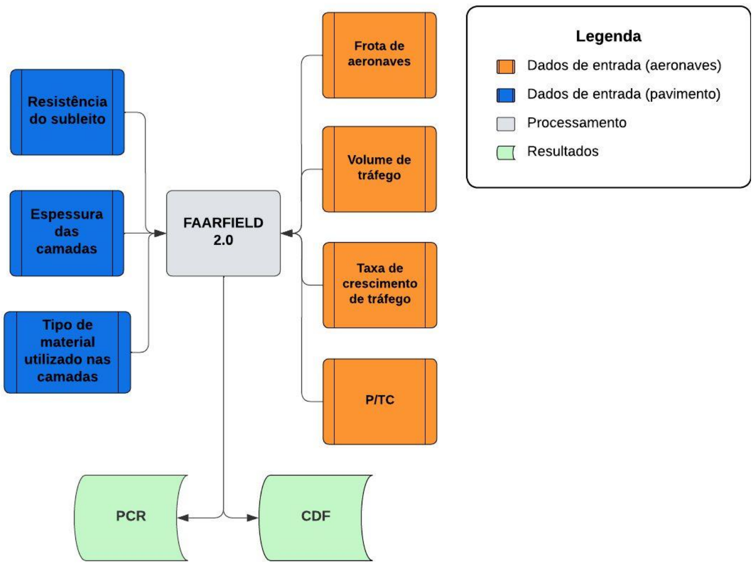
Source: ANAC, 2020.

Finally, the processing of these structure data was carried out through the software, in order to obtain a BCP that meets the aircraft's ACN and a CDF that is between 0.15 and 1, as provided by the FAA (2014).

PCR SIZING USING FAARFIELD 2.0

The process to obtain the PCR was carried out using the FAARFIELD 2.0 software, according to the procedure represented in the flowchart in Figure 3 (ANAC, 2022).

Figure 3 - Flowchart with the procedure to be performed in FAARFIELD 2.0



Source: The authors, 2023.

First, acronyms were defined to better visualize which sample is under study, which are:

- SCSR – Cement-free, uncoated;
- SCCR – Cement-free with coating;
- CCSR – With cement without coating;
- CCCR – With cement with coating.

Next, the New Flexible pavement type was selected in the software, as this model provides more freedom to modify the structure and characteristics of the road. Thus, the CBR value of the adopted subgrade was inserted, which the software converted to the modulus of elasticity using the correlation of Equation 1.

$$E=10.34*CBR \quad (1)$$

Soon after, to constitute the sub-base of the pavement structure, similar to the process in COMFAA 3.0, the material P-154 *Uncrushed Aggregate* was used, or uncrushed aggregate, as recommended by AC 150/5370-10H.

For the base layer, the customizable User defined material was used, since this model allows the insertion of the tested CBR, which is converted into modulus of elasticity by the correlation mentioned above. This customization is essential, as it is in this layer that the changes in the study will be made, using the test data carried out with soil mixtures 1 and 2.

Finally, the asphalt coating layer is represented by the material P-401/P-403 HMA Surface, or mineral aggregate and asphalt binder as recommended by AC 150/5370-10H.

With the layers that make up the pavement structure already established, the minimum thicknesses for each of them were inserted. Thus, the software reprocesses the extension of each layer through the *Thickness Design option*, or thickness design, in order to meet the ACR of the design aircraft, in addition to approximating the CDF value to 1.

After resizing the layers, the floor is properly dimensioned. This allowed the determination of the PCR for each of the lanes, using the corresponding option. As a result, the final code was generated, accompanied by a comprehensive report containing all the parameters considered for the aircraft in question.

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COST OF EXECUTION OF THE FLOORS

It is essential to evaluate the financial impact of the choices of materials used, given the large volume of earth movement required in this type of work, the cost of executing the m³ of pavement was calculated.

RESULTS

With the execution of the design using the COMFAA 3.0 and FAARFIELD 2.0 software, it was possible to obtain the necessary PCN and PCR values for each type of pavement, ensuring compliance with the 20-year project horizon and keeping the CDF close to 1. In addition, the thicknesses of the layers were determined to meet the specific operations of each aircraft.

Based on the results obtained for the floor with and without coating layer, the following analyses and comparisons were carried out:

a) PCN and PCR: The strength of the pavement in the two options was compared, that is, it was evaluated how the removal of the coating affects the bearing capacity of the structure.
b) Layer thicknesses: The thicknesses necessary to meet the aircraft demand considered were analyzed. This allowed them to determine in what proportion the presence of the coating decreases the thickness needed to serve the same project fleet.
c) Execution cost: The acquisition and execution cost to produce 1m³ of each type of pavement was compared using the data provided by the SINAPI – MG and SICRO-MG tables.

Thus, the following detailed results were obtained through the programs used.

COMFAA 3.0

The results of the PCN for the situations analyzed were obtained through data processing in the software, and are represented in the graphs in Figure 4.

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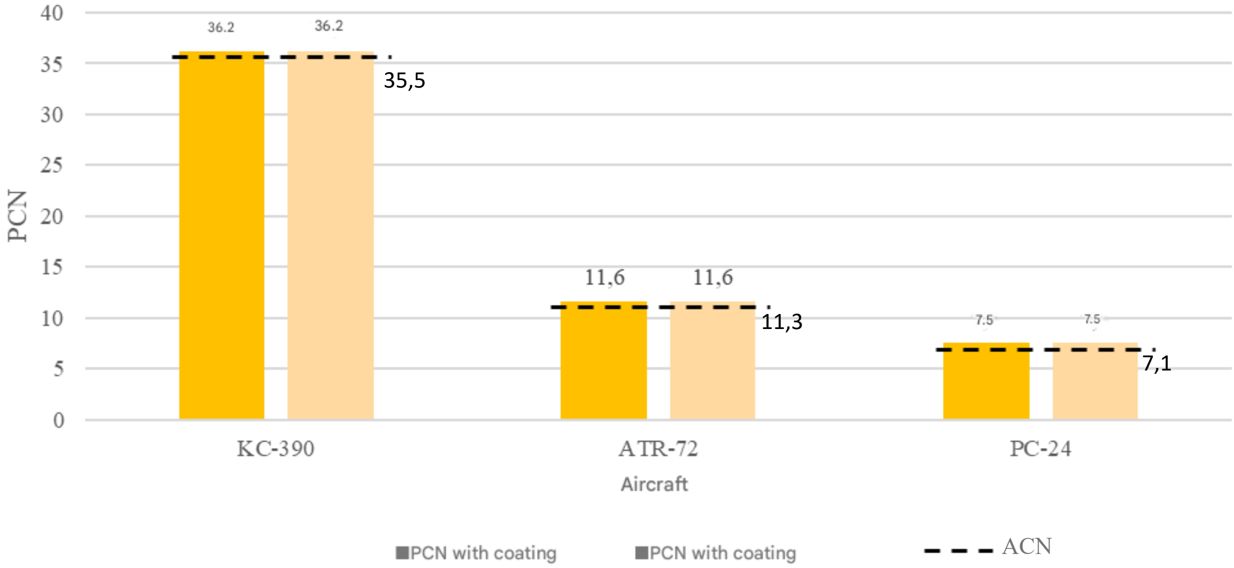
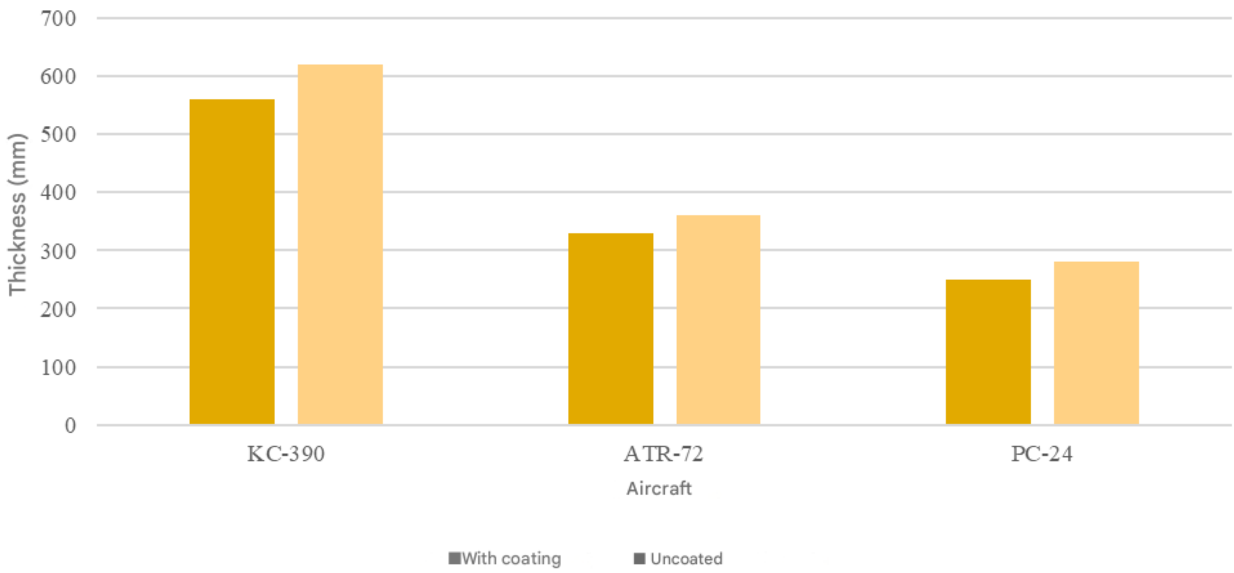
Figure 4: PCN and ACN of aircraft



Source: The authors, 2023.

As for the thicknesses (Figure 5), for the KC-390, there was an increase of 20 mm in the subbase and 140 mm in the base. For the ATR-72, the thickness of the sub-base layer of the runway did not change, remaining fixed at 180mm, while the base was modified, requiring an increase of 80mm of material in the absence of coating to meet the desired PCN. In the coating layer, only 50mm thick was required, half of what was requested for the KC-390.

Figure 5: Final runway thickness for each aircraft model



Source: The authors, 2023.

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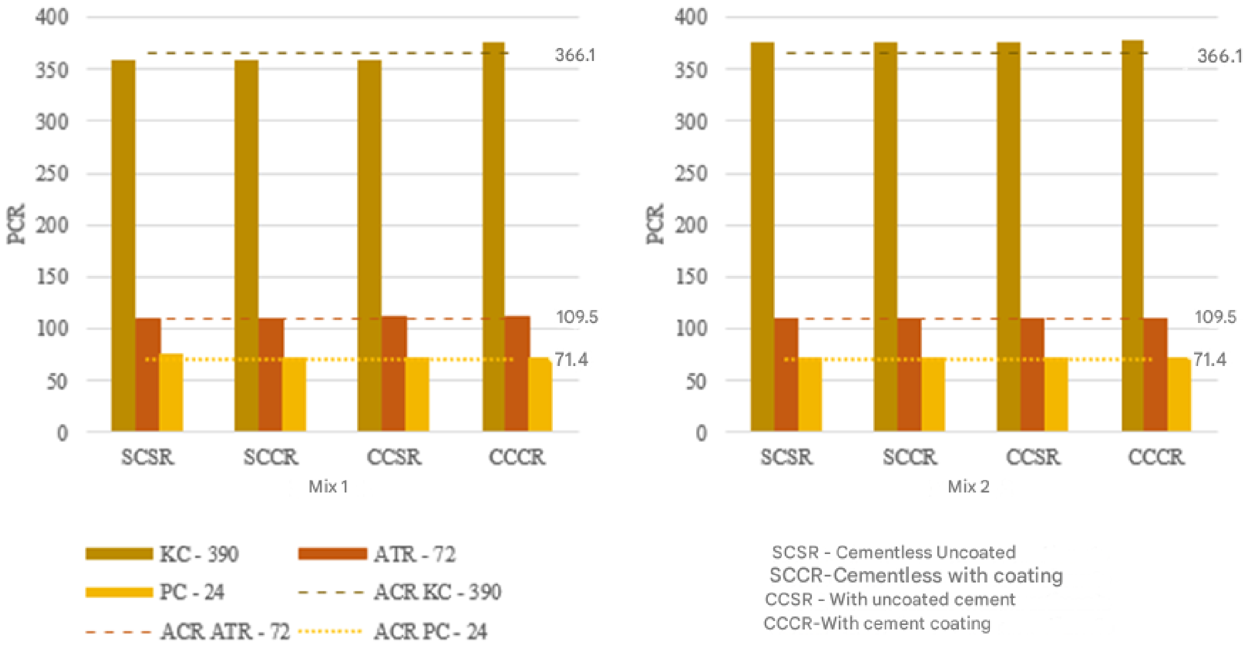
FIELD 2.0

After processing, the CRP values for each combination were obtained, according to the RCA of each model, as shown in Figure 6 below.

Figure 6: Final runway thickness for each aircraft model



Source: The authors, 2023.

COST OF PAVEMENT EXECUTION

The cost of executing the m³ of the lanes with and without coating is shown in table 2, showing the difference in values when the asphalt coating layer is used.

Table 2: Final runway thickness for each aircraft model

Aircraft		KC - 390		ATR - 72		PC - 24	
Track value (R$)	Coated	193,22		97,55		98,33	
	Uncoated	12,56		7,39		5,04	
Mixture		1	2	1	2	1	2
Value per layer (R$)	SCSR - Cementless without coating	10,89	18,79	6,99	15,67	6,18	8,79
	SCCR - Cementless with coating	13,61	23,93	9,67	19,76	6,32	11,35
	CCSR - With uncoated cement	193,78	193,78	142,95	146,64	143,41	148,33
	CCCR - With cement with coating	196,38	206,55	144,91	149,19	144,82	151,65

Source: The authors, 2023.

DISCUSSION

Considering that the CBR of the subgrade reached 9.4, being between 8 and 13, its classification is defined as medium (B), while the tire pressure is classified as high (X).

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Thus, with the results of the PCN obtained through the technical method (T), the codes presented in Table 3 were established.

Table 3: PCN code of the lanes

Aircraft	PCN Code
KC-390	36/F/B/X/T
ATR-72	12/F/B/X/T
PC24	8/F/B/X/T

Source: The authors, 2023.

It was possible to verify that the PCN for floors with and without coating obtained the same value. This is due to the fact that the only pavement parameter that COMFAA 3.0 uses for design is the equivalent thickness. In addition, during this process, modifications to the structure to meet an adequate CDF resulted in equal values of equivalent thickness for both situations, and consequently, in identical CDF values.

Given that the subgrade resilience module registered 97.22, falling between 60 MPa and 100 MPa, its classification is categorized as low (C), while the tire pressure is considered high (X). Therefore, based on the PCR results, the following codes calculated by the technical method (T) were defined, represented in Table 4.

Table 4: PCR code of the study clues

Mixture	Sample	PCR code KC-390	PCR code ATR-72	PCR code PC24
1	SCSR	360/F/C/X/T	110/F/C/X/T	76/F/C/X/T
1	SCCR	360/F/C/X/T	109/F/C/X/T	73/F/C/X/T
1	CCSR	359/F/C/X/T	111/F/C/X/T	72/F/C/X/T
1	CCCR	377/F/C/X/T	112/F/C/X/T	73/F/C/X/T
2	SCSR	377/F/C/X/T	111/F/C/X/T	72/F/C/X/T
2	SCCR	377/F/C/X/T	111/F/C/X/T	73/F/C/X/T
2	CCSR	377/F/C/X/T	111/F/C/X/T	72/F/C/X/T
2	CCCR	378/F/C/X/T	111/F/C/X/T	73/F/C/X/T

Source: The authors, 2023.

Although there is no direct mathematical correlation between the results of the ACN/PCN and ACR/PCR methods, it is noted that the PCR value is approximately 10 times higher than the PCN. This relationship is evidenced in the results, where the mean PCR for each aircraft is similar to the PCN value multiplied by 10, as shown in Table 5.

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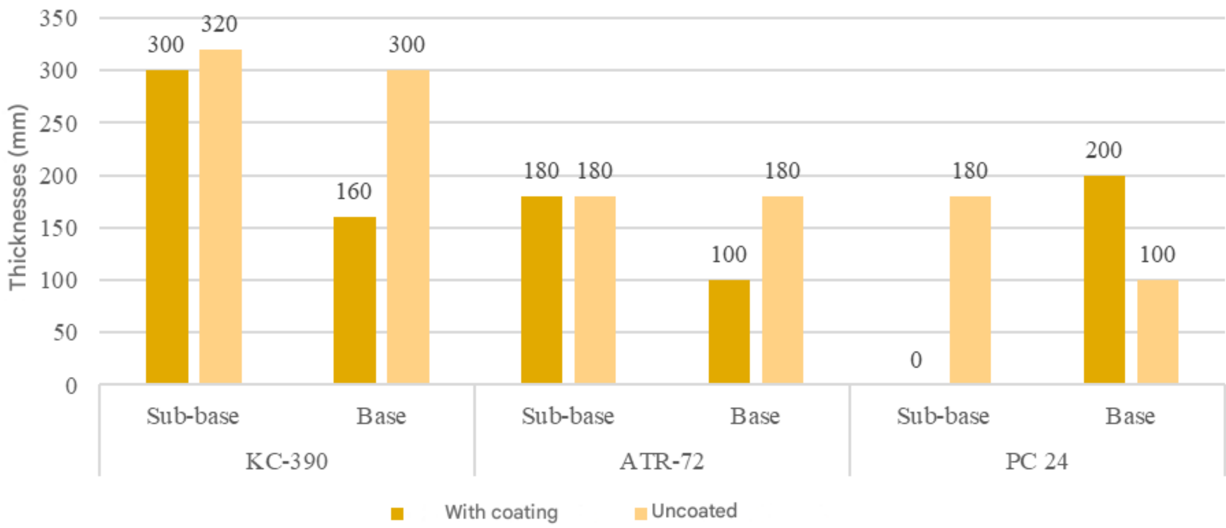
Table 5: Comparison between the PCN and PCR codes obtained

Floor	KC-390		ATR72		PC-24	
	PCN	PCR	PCN	PCR	PCN	PCR
Coated	36	373	12	111	8	73
Uncoated	36	368	12	111	8	73

Source: The authors, 2023.

Although the equivalent thickness has the same value for each aircraft, it was possible to notice significant differences in the thicknesses of the sub-base and base layers, as evidenced in the graph in Figure 7.

Figure 7: Graph of subbase and base layer thicknesses by aircraft



Source: The authors, 2023.

It is observed that the presence of the coating significantly impacts the thicknesses of the layers. The KC-390 exhibited a variation of 6.67% additional material in the subbase and 87.50% in the base, as illustrated in the graph in Figure 8. In addition, Pilatus PC-24 did not need the subbase layer when adding the coating, so when this layer was removed, a 180 mm subbase layer was added and the base was reduced by 100 mm, which generated a negative value in the graph.

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Figure 8: Graph of the percentage change of the layers when the coating layer is removed

Source: The authors, 2023.

Due to the similarities in base thicknesses, with small variations between samples, the final cost was impacted by the unit costs of the materials. Thus, sample 01 presented a lower unit cost compared to sample 02 in all scenarios, which resulted in a more economical final value.

From this, the total cost of the runway was calculated, illustrated in table 6, taking into account the measurements of 1500 m in length and 30 m in width.

Table 6: Final runway cost for cementless sample 1 for each aircraft model

KC-390 - Cementless Uncoated Mix 1			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)
1500	30	R$ 10,88	R$ 489,814.20
KC-390 - Cementless Mix 1 with Coating			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)
1500	30	R$ 193,78	R$ 8,720,176.05
ATR-72 - Cementless Uncoated Mix 1			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)
1500	30	R$ 6,99	R$ 314,613.00
ATR-72 - Cementless Mix 1 with Coating			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)
1500	30	R$ 142,95	R$ 6,432,666.75
Pilatus PC-24 - Cementless Uncoated Mix 1			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)

1500	30	R$ 6,18	R$ 278,290.80
Pilatus PC-24 - Cementless Mix 1 with Coating			
Length (m)	Width (m)	Total Unit Price (R$)	Total price (R$)
1500	30	R$ 143,41	R$ 6,453,551.25

Source: The authors, 2023.

It is observed that the aerodromes designed for the KC-390 presented the highest execution cost among the aircraft in the fleet, this is due to their high weight which in turn requires a more robust pavement structure. It is also possible to observe that in the pavements with coating, the runways designed for the PC-24 exhibited a higher cost compared to the ATR-72. This difference was due to the lack of sub-base in Pilatus, which caused the base thickness to increase and raise the price.

CONCLUSION

At the end of the studies, it is possible to point out that the ACN/PCN method, by performing an analysis based on the CBR of the subgrade and adopting characteristics of the layers according to the standards available in the program's internal library, limits the customization of the materials that make up the structure, and prevents a more accurate representation of its characteristics, according to what will actually be used in the execution.

In addition, the approach of using the equivalent thickness obtained through a conversion performed by the Support Worksheet can result in identical values of BCP and CDF for structures with different properties.

It is also noteworthy that the lack of data on the mechanical properties of the pavement layers and the absence of data for the conversion of materials within the Support Spreadsheet itself can result in inconsistencies between the analyses made and reality.

Thus, the analysis through COMFAA 3.0 resulted in 6 pavement configurations, 3 with a coating layer and 3 without this layer. It is important to highlight that both categories presented the same PCN and CDF values for each type of aircraft. To meet the ACN requirements of each aircraft in the absence of the coating layer, significant adjustments were made to the thicknesses of the base and sub-base layers.

FAARFIELD 2.0, on the other hand, is based on principles of empirical-mechanistic methods, incorporating the most recent studies in this area. Although it provides more accurate and simplified designs compared to COMFAA 3.0, its use requires testing to determine the elastic parameters of the materials. In situations where these assays are not accessible, correlations need to be used.

However, it is important to note that the use of correlations may not accurately represent the properties of the materials used in the structures. These correlations do not disqualify the use of the software, which continues to be used for sizing, following the standards established by the FAA.

Thus, the analysis of the pavements, considering mixtures 1 and 2 tested with base material, resulted in eight pavement configurations for each type of aircraft. These configurations vary in the use or not of the asphalt coating layer and the mixture used in the base. The PCR values obtained were similar for each aircraft, with minimal variations.

For the composition of the structure of the floors, it was decided to use materials recommended by AC 150/5370-10H. P-154 *Uncrushed Aggregate* was used as the uncrushed aggregate for the subbase, while mixtures 1 and 2 were formulated based on the P-213 material, identified as *Sand-Clay Base Course*, a mixture of sand and clay intended for the base layer. For the coating layer, P-401/P-403 HMA Surface was adopted, a composition of mineral aggregate and asphalt binder.

Regarding the results obtained, the CBR test indicated positive values for the subgrade, while for the use in the other layers, the need to perform a more adequate redistribution of the soil fractions is highlighted, leading to the realization of a physical stabilization based on the Sand-Clay material, and a chemical stabilization with cement.

It is also observed that, although the addition of 1.5% cement generated a strength gain in the CBR test of the mixtures, this contribution did not contribute significantly to the reduction of the thickness of the base layer. With this, it is possible to say that the addition of cement is not advantageous in terms of resistance, considering its higher cost.

Specifically, in the case of the PC24, the sub-base layer was not necessary in the presence of coating, and it was necessary to remove it to avoid an over-sizing of the structure, this caused the final price of its runway to be higher than that of the ATR-72, since the base layer is more expensive than that of the sub-base. Therefore, the thickness and the need to use the subbase are influenced by the presence or absence of coating, as well as by the weight of the aircraft.

It is also noted that the thickness of the layers presented considerable variations, and the sub-base varied proportionally to the weight of the aircraft and inversely proportional to the presence of coating in both COMFAA 3.0 and FAARFIELD 2.0. The

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thickness of the base layer remained mostly close to 150 mm, with slight variations. It is noteworthy that the sub-base layer has undergone more changes, since the software performs the sizing, mainly changing the lower layers.

In addition, both for the runways designed by FAARFIELD 2.0 and for the pavements determined through COMFAA 3.0, the 01 mix proved to be more economically viable in all the cases analyzed, costing up to 44.61% less, compared to the 02 mix.

In conclusion, the no-coating approach has proven to be an effective way to significantly reduce execution costs and ensure pavement bearing capacity, especially for small aircraft such as the Pilatus PC-24. In this context, even with the variations in the thicknesses of the layers, the difference in cost is remarkably significant, reaching differences of more than 2000%.

In addition, the execution of a track without the coating layer is notably more agile compared to the one that has pavement. It is also possible to carry out this task in more remote locations, due to the simplicity of the materials involved, avoiding the need for large displacements of trucks loaded with asphalt mass, for example. However, it is important to note that durability and maintenance parameters were not considered, which can affect the performance of the track.

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