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Evaluating Cumulative Damage Factor (CDF) of 20 Brazilian Airfield Pavement structures using FAARFIELD and BAKFAA

Análise do fator de dano acumulado (CDF) de 20 pavimentos aeroportuários brasileiros utilizando FAARFIELD e BAKFAA

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ABSTRACT

There is a growing concern regarding the structural integrity of Brazilian airport pavements. This concern arises from the fact that they were originally designed to accommodate lighter aircraft during an era of lower traffic. However, with the substantial increase in air traffic and the introduction of heavier aircraft, compounded by the aging infrastructure predominantly built between the 1950s and 1970s, these pavements are now confronted with significant challenges. This research involves collecting data on aircraft characteristics, traffic patterns, and pavement layer properties to update information on the pavement life service of existing Brazilian airfield pavements. Research involves the analysis of determine the Cumulative Damage Factor (CDF) of 20 Brazilian airport runways pavement. Backanalysis of deflection basins obtained from Heavy Weight Deflectometer (HWD) tests is conducted using the BAKFAA software. The FAARFIELD software is then employed to calculate the CDF, incorporating the latest information on aircraft mix and pavement conditions. The study reveals that 65% of the analyzed airport pavements consist of 4 structural layers, with 50% of the structures composed of cement-treated base course layers. Notably, 11 airports exhibit a CDF less than 0.01, suggesting potential overdesigned of pavements for existing aircraft movement. Boa Vista Airport/RR (SBBV) stands out with a CDF of 1.5, prompting recommendations for actions to mitigate pavement degradation. The findings offer valuable insights for future actions, maintenance strategies, and recommendations for the construction of new airports.

RESUMO

Há uma preocupação crescente com a integridade estrutural dos pavimentos dos aeroportos brasileiros. Esta preocupação surge do fato deles terem sido originalmente concebidos para suportar aeronaves mais leves durante uma época de menor tráfego. No entanto, com o aumento substancial do tráfego aéreo e a introdução de aeronaves mais pesadas, combinado com a infraestrutura envelhecida predominantemente construída entre as décadas de 1950 e 1970, estes pavimentos enfrentam agora desafios significativos. Esta pesquisa envolve a coleta de dados das características de aeronaves, padrões de tráfego e propriedades da camada do pavimento para atualizar informações sobre a vida útil dos pavimentos de aeródromos brasileiros existentes. A pesquisa consiste na análise para determinar o Cumulative Damage Factor (CDF) do pavimento de 20 pistas de pouso e decolagem de aeroportos brasileiros. A retroanálise das bacias de deflexão obtidas nos testes do Heavy Weight Deflectometer (HWD) é realizada usando o software BAKFAA. O software FAARFIELD é então empregado para calcular o CDF, incorporando as informações mais recentes sobre o mix de aeronaves e as condições do pavimento. O estudo revela que 65% dos pavimentos aeroportuários analisados são compostos por 4 camadas estruturais, sendo 50% das estruturas compostas por camadas de base tratadas com cimento. Notavelmente, 11 aeroportos apresentam um CDF inferior a 0,01, sugerindo potencial sobredimensionamento dos pavimentos para o movimento de aeronaves existentes. O Aeroporto de Boa Vista/RR (SBBV) se destaca com CDF de 1,5, gerando recomendações de ações para mitigar a degradação do pavimento. As descobertas oferecem informações valiosas para ações futuras, estratégias de manutenção e recomendações para a construção de novos aeroportos.

1. INTRODUCTION AND BACKGROUND

There is a growing concern about the structural integrity of Brazilian airport runways, which were built between the 1950s and 1970s and designed to accommodate lighter aircraft during a period of lower traffic. However, with the substantial increase in air traffic and the introduction of heavier aircraft, coupled with predominantly aging infrastructure, new challenges arise for the structural condition and expected lifespan of these structures. Nowadays, among the 29 Brazilian airports that currently handle more than 1 million passengers per year, 22 airports were opened to traffic before 1970, and their runways were constructed considering the operational conditions of that time during their planning (ANAC, 2022).

In accordance with ANAC (2022), regulatory changes in Brazil promoted the adoption of price freedom policies starting in 2001 and freedom of provision of air services from 2005, popularizing air transport and thereby causing a considerable increase in the number of landings and takeoffs. The total number of landings and takeoffs grew by 87% from 2004 to 2013 and has since maintained a certain stability, with slight variations mainly influenced by the country's macroeconomic performance, the exchange rate of the American currency, and the international price of aviation fuels. An exception to this trend is the years 2020 and 2021, during which there was an atypical and significant drop in aircraft movement due to the restrictions caused by the Covid-19 pandemic.

Due to the constant technological advancements in the aeronautical industry, the maximum takeoff weight of aircraft has increased from around 200 tons in the 1970s to up to 500 tons in the last decade (Bejan, Charles and Lorente, 2014, p. 044901). This has led to an increase in the transmitted stresses on airport pavement structures. The design of airport pavements depends on a set of variables that differentiate them from roadway pavements, including the high tire inflation pressure of aircraft, the various arrangements of tires in landing gears, the substantial loads applied by tires on the pavement, the frequencies of load repetition, and others.

Brazilian airport pavements are traditionally designed according to guidelines and methods developed by the North American aviation regulatory agency, the Federal Aviation Administration (FAA), such as the FAA Method - AC 150/5320-6G. In 1995, the FAA conducted studies on the use of concepts from the elastic layered theory for the design of airport pavements, resulting in the development of the Linear Elastic Design Federal Aviation Administration (LEDFAA) software. Since then, the practice shifted from adopting a critical design aircraft to considering the contribution of all aircraft in operation at the airport in pavement design, applying Miner's (1945) hypothesis of fatigue due to cumulative damage.

Furthermore, the use of the elastic modulus was adopted to replace the California Bearing Ratio (CBR) as an indicator of the load-bearing capacity of pavement layers. Subsequently, in 2009, the FAA made further modifications to its guidelines, and the LEDFAA software was replaced by the Federal Aviation Administration Rigid and Flexible Elastic Layered Design (FAARFIELD) software, which is widely used in Brazil. This software applies the Theory of Elastic Layer Systems for the design of flexible pavements (FAA, 2021, pp. 1-1), and is utilized for both the design of new airport pavements and for rehabilitation or reconstruction of existing pavements. The released program included significant modifications to both rigid pavement and flexible pavement design models, while adds new features to improve the user experience (Brill and Kawa, 2017, p. 92). Currently, FAARFIELD 2.0 replaces all previous versions of FAARFIELD software (FAA, 2023).

In order to investigate the structural condition of Brazilian airport pavements, the research aims to survey the current mix of aircraft in operation, their main characteristics, the number of landings and takeoffs, as well as the properties of the layers of existing pavements on the runways of Brazilian airports. Using backanalysis from the data collected by Heavy Weight Deflectometer (HWD) tests conducted at Brazilian airports, this study aims on determining the elastic modulus of each layer of the existing pavement structures using the BAKFAA software. With the assistance of the FAARFIELD software, the Cumulative Damage Factor (CDF) of the airport pavement structures will be determined. The scope of this research is limited to the analysis of pavement structures and the current aircraft traffic mix of 20 Brazilian airport runways that integrated the 6th round of federal government concessions.

2. FAA PAVEMENT THICKNESS DESIGN

For the design of flexible airport pavements, to which the object of this study is restricted, the FAARFIELD software uses the maximum vertical shortening deformation at the top of the subgrade and the maximum horizontal elongation deformation in the lower portion of the asphalt layer as design criteria. FAARFIELD software provides the necessary thicknesses for all pavement layers to support a mix of aircraft during the project's design life with the existing subgrade.

Thus, the structural condition of the runway pavement is determined by its remaining life. The design life refers to the structural life, that is, the period during which the airport pavement is subjected to the landings and takeoffs of the mix of aircraft before experiencing structural failures. This concept differs from the service life, which is the period during which the pavement can maintain an adequate level of functionality, and it may even be longer than the design life.

Regarding the loads generated by aircraft on the pavement, the FAARFIELD software uses the maximum takeoff weight and the distribution of weight between the wheel sets of the landing gears as provided by the manufacturers. According to FAA (2021, pp. 3-12), using the maximum takeoff weight allows for a conservative design and accommodates changes in the use and traffic of operations. The tire inflation pressure varies according to the aircraft weight, tire size, and landing gear configuration.

The traffic volume typically used for airport pavement design considers the number of annual takeoffs for each type of aircraft and includes all aircraft that will use the pavement. According to FAA (2021, pp. 3-13), the number of landings is disregarded in the design because, generally, the weight of aircraft during landing is much lower than during takeoff due to fuel consumption. In some cases, such as when there is no refueling service available at the aerodrome, aircraft land and take off with the same weight. Therefore, the design in the FAARFIELD software should consider twice the number of takeoffs to indicate the number of times the pavement is subjected to that load.

Unlike the design of road pavements, which starts with the load of a standard axle and determines the number of passes of that same equivalent axle for other vehicles, the design of airport pavements considers the entire mix of aircraft in operation at the airport. This applies the hypothesis that structural failure occurs due to the accumulation of damage caused in each landing or takeoff operation over the design life. The so-called Cumulative Damage Factor (CDF) is the amount of structural fatigue that a pavement in use can withstand that has already been consumed (FAA, 2021, pp. 3-14) or the ratio between the number of applied loadings and the total number of loadings that the pavement can withstand until failure. When the cumulative total damage reaches 100% at the end of its design life, the pavement is expected to experience fatigue cracking within the wheel path of a certain aircraft (Kosasih and Fibryanto, 2005, p. 29).

CDF for aircraft is a value between 0 and 1 which states the contribution to pavement failure from the number of movements projected for each type of aircraft using pavement. CDF analysis can then estimate the remaining age of the runway pavement. According to Miner's law, a traditional theory that estimates the amount of usage to pavement failure, to determine the value of CDF in a particular plane is determined by Equation 1 and Equation 2 below:

$$CDF = \frac{(\text{annual departure})\ \text{x}\ (\text{life in years})}{\left(\frac{\text{pass}}{\text{coverage ratio}}\right)\ \text{x}\ (\text{coveraged to failure})} \quad (1)$$

$$CDF = \sum \frac{n_i}{N_i} \quad (2)$$

where n_i is the number of coverages applied to a pavement by aircraft and N_i is the number of coverages to failure for aircraft.

The FAARFIELD software determines the effects of damage caused by each aircraft listed in the traffic mix, considering the specifics of their landing gear, weight, and wheel location in relation to the center of the runway. The software then calculates the total Cumulative Damage Factor (CDF) for each 0.25 m strip in the central 20.8 m of the runway. The design CDF is the highest CDF value obtained among all the 0.25 m strips. This is because, in considering the cumulative effects of damage caused by each aircraft for the design of airport pavements, the effect of lateral movement of aircraft during landing or takeoff maneuvers must also be analyzed. According to FAA (2021, pp. 3-15), aircraft wheel wander follows a normal distribution. With the movement of the aircraft along a runway, it may be necessary for the aircraft to make multiple passes in a specific section of the pavement for a single coverage. This coverage is the one that produces damage equivalent to the maximum loading produced by a particular aircraft.

The ratio between the number of passes required to apply a coverage to a unit area of the pavement is expressed as Passes per Coverage (P/C). For flexible pavements, coverages are a measure of the number of repetitions needed to achieve the maximum deformation at the top of the subgrade produced by a specific aircraft. To determine the CDF, the software also considers the concept of effective tire width, which, as mentioned, in flexible pavements is defined at the top of the subgrade. Figure 1 illustrates the effective tire width for flexible pavements used in the calculations.

The number of passes for each type of aircraft on a runway is obtained through simple observation and by collecting records from airport operators. The resulting number of coverages from the operations of a particular aircraft, in turn, is a function of the number of passes, landing gear configuration, wheel contact area width, lateral variation of the wheel path in relation to the center of the runway, and is mathematically determined in the FAARFIELD software.

Obtaining a unit value for the total CDF indicates that the pavement has used its entire service life over the established design life for the considered conditions of aircraft movement and pavement structure. The design-established service life is usually set at 20 years. CDF values below 1.0 indicate that the pavement still has some remaining service life, while CDF values above 1.0 do not necessarily imply that the pavement will not withstand traffic loads. However, it suggests that the pavement may be in a state of structural failure, in accordance with design guidelines. In cases where a CDF value above 1.0 is obtained, it is considered appropriate to assess the need to adopt measures that mitigate accelerated pavement degradation, such as conducting preventive maintenance. These measures may include restrictions on the number of landing and takeoff operations or limitations on operations of aircraft that significantly contribute to the increase in the total CDF value (ANAC, 2020, p. 15).

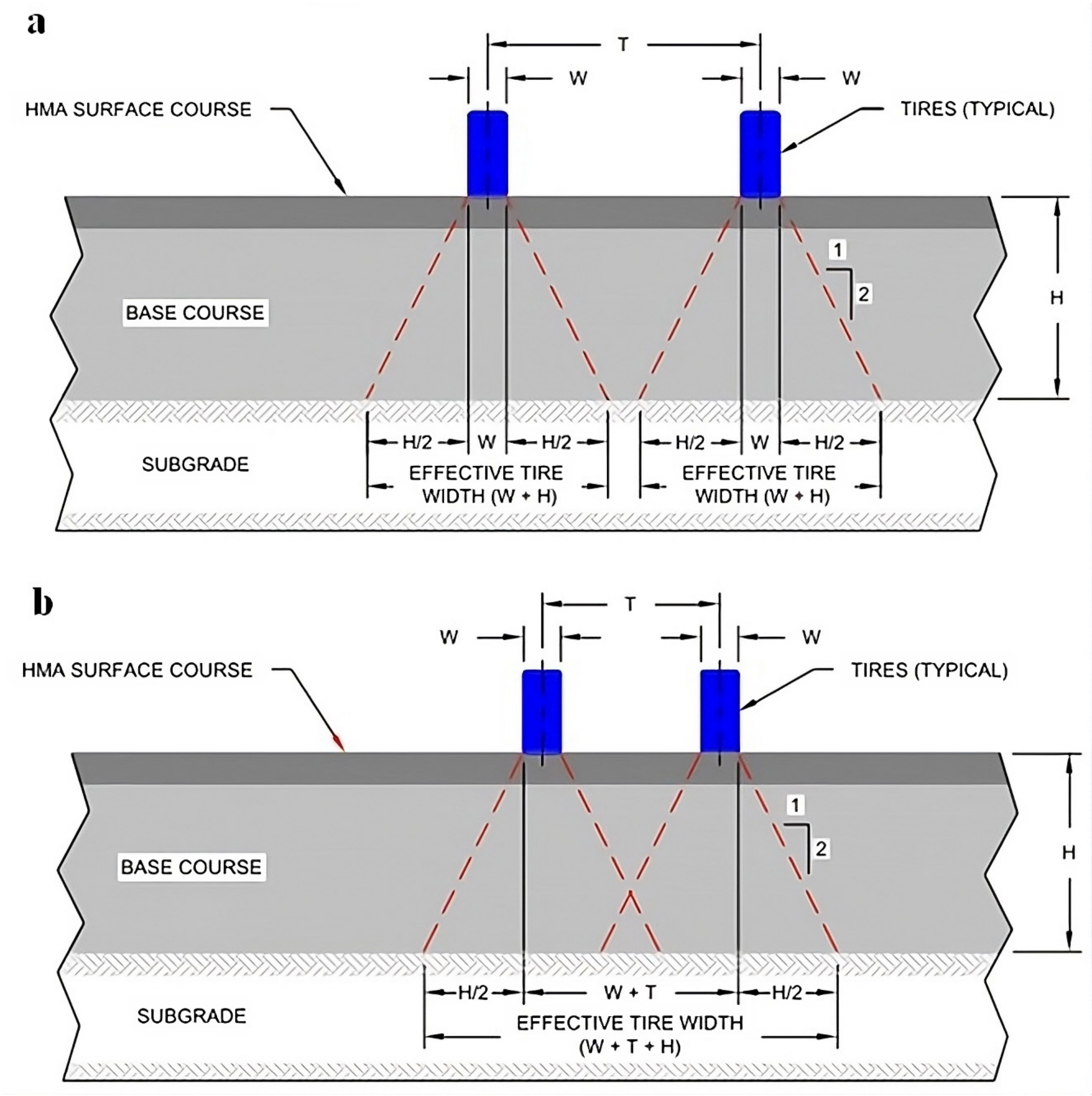

Figure 1. FAARFIELD effective tire width for flexible pavements: (a) no overlap; (b) overlap. (FAA, 2021, pp. 3-16).

3. METHODOLOGY

3.1. Brazilian Aircraft Mix determination

The FAA's airport pavement design method is currently widely used in Brazil. The U.S. regulatory agency provides the FAARFIELD software, whose pavement design process considers the entire mix of aircraft in operation at the airport. Therefore, the first stage of the present study involved collecting traffic data, including the number of landings and takeoffs, aircraft models, and their physical characteristics such as weight, landing gear configuration, tire contact area with the pavement, distribution of loads between landing gears, among others.

For the present study, 20 airports were considered, located in Manaus/AM, Tabatinga/AM, Tefé/AM, Rio Branco/AC, Cruzeiro do Sul/AC, Porto Velho/RO, Boa Vista/RR, Goiânia/GO, Palmas/TO, Teresina/PI, Petrolina/PE, São Luís/MA, Imperatriz/MA, Curitiba/PR, Foz do Iguaçu/PR, Londrina/PR, Curitiba (Bacacheri)/PR, Navegantes/SC, Joinville/SC, and Uruguaiana/RS. The basic physical characteristics of the aerodromes under study, such as location, PCN (Pavement Classification Number), dimensions, and orientation of the runway, were obtained from the publications of Aeronautical Information of Brazil (DECEA, 2023), as well as satellite images.

The survey of the aircraft mix and the number of movements (landings and takeoffs) at airports was conducted using the database of the National Civil Aviation Agency (ANAC) and the National Civil Aviation Secretariat of the Ministry of Ports and Airports. This data was made available to those interested in participating in airport concession processes. The obtained data cover the total quantity of landings and takeoffs, broken down by the years 2014 to 2018, and by the model of aircraft operating at the airports under analysis. The decision was made not to use more recent data due to the restrictions imposed by the Covid-19 pandemic, which led to a reduction in airport movements worldwide since December 2019. Therefore, only larger aircraft with a significant number of movements were consolidated in the aircraft mix to be used in this study. Small private-use aircraft, helicopters, sports and training aircraft, and those with very low annual movements were disregarded. Thus, aircraft whose contribution is irrelevant to the structural analysis of the pavement were excluded.

The physical characteristics of the aircraft in operation, necessary for the pavement design and structural assessment process, were obtained from the Manufacturers' Manuals, generally referred to as ACAP - "Airplane Characteristics for Airport Planning" (Boeing Commercial Airplanes, 2022; AIRBUS S.A.S., 2022; EMBRAER S.A., 2021), and with the assistance of the existing database in the FAARFIELD software.

The aircraft mixes of the airports under study, as well as the number of annual landings and takeoffs, were consolidated. Table 1 provides the collected data, referring to the aircraft mix in 2018. Figure 2 presents a box plot of the volume per aircraft type.

Table 1: Aircraft mixes in 2018. Adapted from ANAC (2021).

Aircraft	Landing and Take off in 2018 - Airport (ICAO)									
	SBBI	SBBV	SBCT	SBCZ	SBEG	SBFI	SBGO	SBIZ	SBJV	SBLO
Aero Boero 115	3994									
Airbus A318			44				12			
Airbus A319			2863		741	634	1927	144	934	622
Airbus A320		1208	10577		3065	5216	7651	1644	962	1882
Airbus A321			3607		3438	1592				
Airbus A330-200			190		826					
ATR-42-300										
ATR-72-600			4276			420	2577		1183	2644
Beechcraft Baron	822			356		273	2108			1088
Beechcraft King Air	1615						3377	238		
Beechcraft King Air B350										
Beechcraft Super King Air	1248									
Boeing 727-200			876		244					
Boeing 737-300			99		68		894			
Boeing 737-400			109		838		66			

Table 1: Continued...

Aircraft	Landing and Take off in 2018 - Airport (ICAO)									
	SBBI	SBBV	SBCT	SBCZ	SBEG	SBFI	SBGO	SBIZ	SBJV	SBLO
Boeing 737-700		34	5774	192	130	736	1513		502	900
Boeing 737-800		688	9685	606	7669	4976	3734		728	1944
Boeing 737 Max 8					220					
Boeing 747-400			146		334					
Boeing 747-8			66		84					
Boeing 767-300			193		1851					
Cessna 152	3857						1836		151	3484
Cessna 182 Skylane										
Cessna 206 Station Air		474		68						
Cessna 208 Caravan		1233		202						
Cessna 210 Centurion		168								
Cessna Citation Excel		34								
Cirrus SR22	1551									
Embraer 135					124					
Embraer 170					50					
Embraer 175					36					
Embraer 190			3016		423	562	2227	28	162	116
Embraer 195		292	17062		3716	3092	10000	627	566	2148
Embraer Phenom 100			611							
Embraer Phenom 300										
Piper Cheyenne 2	839									
Piper Cheyenne 3	621									
Piper Cherokee Arrow				30						
Piper P28A Tupi	1649									862
Piper P28B Dakota				156						
Piper PA-32 Cherokee				2837						
Piper Seneca	3201			543		393	4624	246	270	
Aircraft	**Landing and Take off in 2018 - Airport (ICAO)**									
	SBNF	**SBPJ**	**SBPL**	**SBPV**	**SBRB**	**SBSL**	**SBTE**	**SBTF**	**SBTT**	**SBUG**
Aero Boero 115										
Airbus A318										
Airbus A319	1273	87		94	32	294	412			
Airbus A320	3275	1552	2066	1620	927	3074	3514			
Airbus A321					70	2020				
Airbus A330-200										
ATR-42-300								42		
ATR-72-600		1440						398		398
Beechcraft Baron			92		170			28		
Beechcraft King Air		706	98				693		112	28
Beechcraft King Air B350										
Beechcraft Super King Air										24
Boeing 727-200										
Boeing 737-300						201	406			
Boeing 737-400						40	72			
Boeing 737-700	1732	470	32	52	406	306	516			
Boeing 737-800	4602	1489	570	2786	2048	2863	2287			
Boeing 737 Max 8				22						
Boeing 747-400			32							

Table 1: Continued...

Aircraft	Landing and Take off in 2018 - Airport (ICAO)									
	SBNF	SBPJ	SBPL	SBPV	SBRB	SBSL	SBTE	SBTF	SBTT	SBUG
Boeing 747-8										
Boeing 767-300										
Cessna 152										
Cessna 182 Skylane										
Cessna 206 Station Air										
Cessna 208 Caravan			248	2781	629			1584	624	
Cessna 210 Centurion		362							14	
Cessna Citation Excel										
Cirrus SR22	578		86				285			14
Embraer 135										
Embraer 170										
Embraer 175										
Embraer 190	1370	392	80	28		36	6			
Embraer 195	3836	1340	1212	3157		4749	1748	322	708	
Embraer Phenom 100	428									
Embraer Phenom 300										12
Piper Cheyenne 2										
Piper Cheyenne 3										
Piper Cherokee Arrow									142	
Piper P28A Tupi										
Piper P28B Dakota										
Piper PA-32 Cherokee					488				96	
Piper Seneca	519	795	170	633	767	769	1236	104	90	

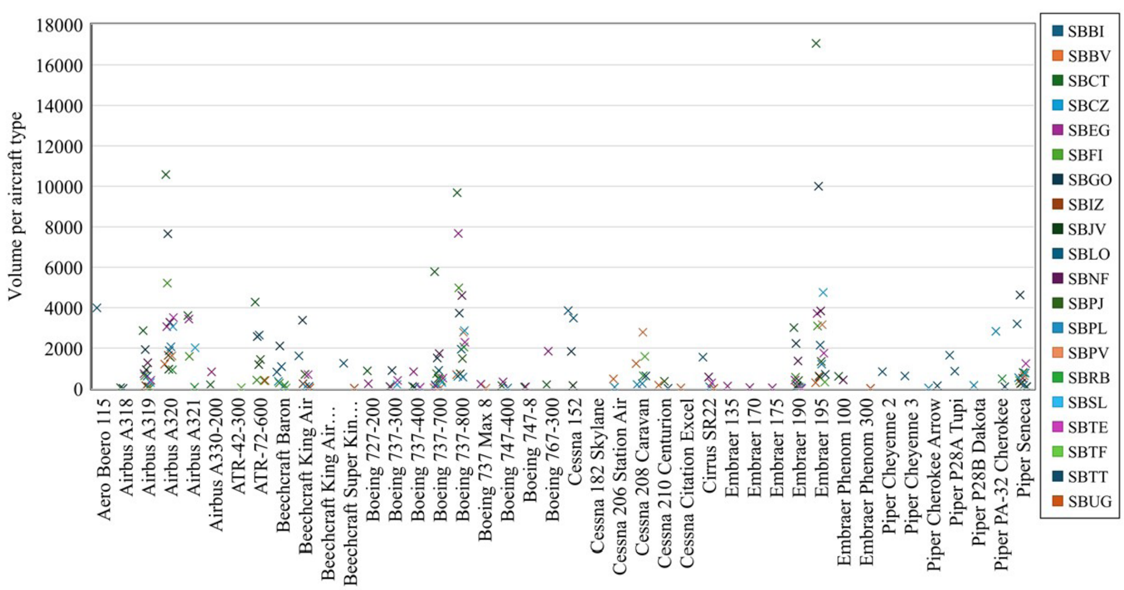

Figure 2. Box plot of the volume per aircraft type.

3.2. Properties of the Brazilian Airfield pavement structures

In the second stage of the research, a survey was conducted on the properties of the layers of the pavements on the runways of Brazilian airports, as well as the thicknesses of the constituent layers. The collection of information regarding the construction characteristics of the runways of 20 airport pavements was carried out through geotechnical test reports (Brasil, 2022) provided by the Brazilian Ministry of Ports and Airports.

Among the geotechnical test reports are: standard penetration tests (ABNT, 2020a), excavation of inspection trenches (ABNT, 2016a), California Bearing Ratio (CBR) tests in accordance with (ABNT, 2016b), particle size distribution of soils tests (ABNT, 2018), liquid limits (ABNT, 2017) and plastic limits tests (ABNT, 2016c), compaction tests (ABNT, 2020b), and Ground Penetrating Radar analysis (ASTM, 2020). This information allowed for obtaining the characterization of materials and the respective thickness of each layer of the airports pavements. These details were gathered from reports obtained from the airport managers. It is important to note that these sections were defined based on average thickness values, considering data from various inspection pits. Variations in both layer thicknesses and the type of constituent material along the length of the runways were not considered. Table 2 presents the collected pavement characteristics.

Table 2: Airfield pavement thickness and subgrade classification obtained for this study.

Airfield (ICAO)	Thickness (m)				Subgrade Predominant Material
	HMA Surface	Cement-Treated Base	Granular Base	Granular Subbase or soil	
SBBI	0.080	0.155	-	0.200	A-7-5
SBBV	0.150	-	0.300	-	A-6
SBCT	0.220	-	0.160	0.230	A-7-5
SBCZ	0.210	-	0.220	-	A-2-4
SBEG	0.290	0.140	-	0.200	A-7-5
SBFI	0.240	0.230	-	0.230	A-7-5
SBGO	0.280	-	0.170	0.310	A-4
SBIZ	0.200	0.230	-	-	A-2-4
SBJV	0.150	-	0.250	0.500	A-7-5
SBLO	0.160	0.250	-	0.200	A-7-5
SBNF	0.170	0.290	-	0.100	A-3
SBPJ	0.100	0.296	-	-	A-2-4
SBPL	0.180	0.260	-	0.360	A-4
SBPV	0.287	-	0.439	-	A-7-5
SBRB	0.150	-	0.340	-	A-7-5
SBSL	0.060	-	0.250	0.200	A-4
SBTE	0.110	-	0.240	0.350	A-4
SBTF	0.170	0.130	-	0.120	A-4
SBTT	0.175	0.108	-	0.120	A-7-6
SBUG	0.160	-	0.260	-	A-7-5

3.3. HWD Back-calculation

Precision in estimating the elastic modulus of pavement layers is crucial when assessing the condition and load-bearing capacity of an airfield pavement. The deflections of the pavement surface, obtained through a heavy weight deflectometer (HWD) test, serve as a widely adopted non-destructive testing method to determine the elastic modulus of the pavement layers. This approach encompasses a back-calculation procedure. The precision of the back-calculated modulus relies on the accuracy of both the forward calculation method and the iteration technique.

For the current study, data from HWD tests conducted by airport operators along the entire length of the runways at the 20 brazilian airports were obtained. The tests were conducted following the specifications of DNER-PRO 273/96 (DNER, 1996), adapted in accordance with the guidelines in the Airport Pavement Management System Manual – SGPA (ANAC, 2017). These adaptations relate to aligning the pressure applied by the HWD testing equipment with the pressures generated on the pavement by the tires of the largest aircraft in operation at the airport. Table 3 presents the adjustment of the load used in the HWD tests. The positioning of the test stations in lines parallel to the runway axis was obtained with a longitudinal spacing of 20 m between each station and transverse spacing of 3 m and 6 m between the longitudinal lines.

Table 3: Adjustment of the load used in HWD tests. ANAC (2017).

Aircraft	Tire pressure (kPa)	LWD - Ø 15 cm Equipment pressure (kPa)	FWD - Ø 30 cm Equipment pressure (kPa)	HWD - Ø 45 cm Equipment pressure (kPa)	Equipment test load (kN)
Citation II	896	849	212	94	15
B727-200	1020		566	252	40
E195	1062		1132	503	80
A320neo	1220		1698	754	120
A321-100	1358			1006	160
Learjet 45	1386			1258	200
B737-800	1407			1509	240
B777-300ER	1503			1761	280
A380-800	1503			1761	280
A350-900	1662			2012	320

Figure 3 presents the backanalysis procedure of the deflection basins obtained from the HWD tests resulted in determining the modulus of elasticity for each of the constituent layers of the pavement. This data is crucial for understanding the mechanical behavior of the runways' pavements. Therefore, the decision was made to perform the back-calculation using the BAKFAA software provided by the Federal Aviation Administration. This program, developed by the U.S. civil aviation regulatory agency specifically for processing airport pavements, is freely accessible and enables the processing of deflection basin data captured by a wide range of testing equipment.

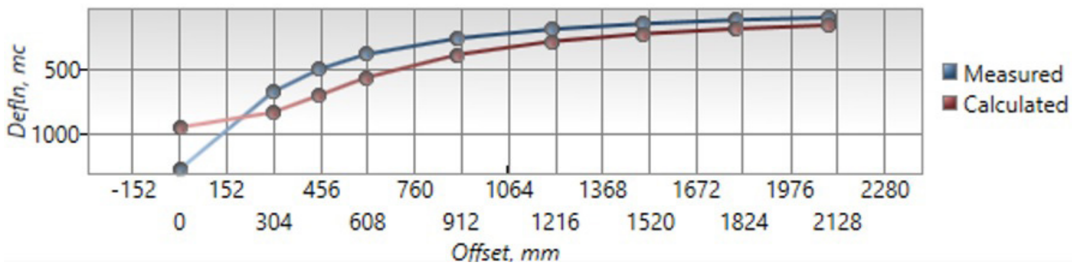

Figure 3. Deflection basin in the BAKFAA software for SBBV Airport – Boa Vista/RR.

The values of the modulus of elasticity for each layer of the Brazilian runways' pavements, obtained after backanalysis, have been consolidated in Table 4. It is important to note that these are average values, considering the back-calculation procedure of deflection basins has a significant variability of results. Overall, results demonstrates that, among 20 Brazilian airport pavements, 65% are composed of 4 structural layers. Also, 50% of the base course layers are cement-treated, while 45% of the subbases are composed of treated soil.

Table 4: Results of elastic modulus from back-calculation for Brazilian airport pavement structures.

Airport (ICAO)	Elastic Modulus (MPa)					Temperature (°C)	
	HMA layer	Cement-treated base	Granular Base	Granular Subbase	Subgrade	Air	Surface
SBBI	2006	391	-	251	80	14	16
SBBV	3000	-	300	-	170	not obtained	
SBCT	2168	-	892	300	148	18	19
SBCZ	1647	-	530	-	275	27	29
SBEG	1019	4335	-	3785	422	not obtained	
SBFI	8467	363	-	589	165	19	22
SBGO	5289	-	1022	516	134	19	23
SBIZ	3052	1193	-	-	198	26	30
SBJV	5760	-	2166	304	49	22	23
SBLO	1403	676	-	247	155	17	18
SBNF	3389	388	-	117	64	22	24
SBPJ	5117	958	-	-	285	35	41
SBPL	5137	420	-	169	163	22	24
SBPV	2338	-	135	-	398	not obtained	
SBRB	2055	-	438	-	77	not obtained	
SBSL	1783	-	784	561	216	27	29
SBTE	3560	-	1549	5439	159	33	41
SBTF	1265	559	-	315	67	not obtained	
SBTT	1519	447	-	346	181	not obtained	
SBUG	3832	-	706	-	107	16	19

3.4. Cumulative Damage Factor (CDF) results

The fourth stage involved determining the Cumulative Damage Factor (CDF) for the airfield pavements evaluated in this study, considering the characteristics of the aircraft mix (Table 1) and the structural characteristics of the pavements (Table 2). Table 5 presents the results of the CDF values for each brazilian airport pavement. Figure 4 depicts graphic of the cumulative value curve, i.e., the sum of the effects of all aircraft in the mix, as well as individual curves for SBGO – Goiânia/GO.

As observed in Table 5, a total of 11 airports presents a CDF less than 0.01. This indicates that the pavement is overdesigned for the existing aircraft movement. Three factors, either individually or combined, have a stronger influence on these low CDF values: (I) The runway pavement has a subgrade with a high elastic modulus, as is the case with SBCZ (275 MPa), SBPV (398 MPa), SBIZ (198 MPa); (II) The runway pavement has a thick asphalt cover layer, such as SBGO (280 mm), SBCT (220 mm), SBFI (240 mm); and (III) The airport has little or no movement of large aircraft, as is the case with SBLO, SBBI, and SBJV.

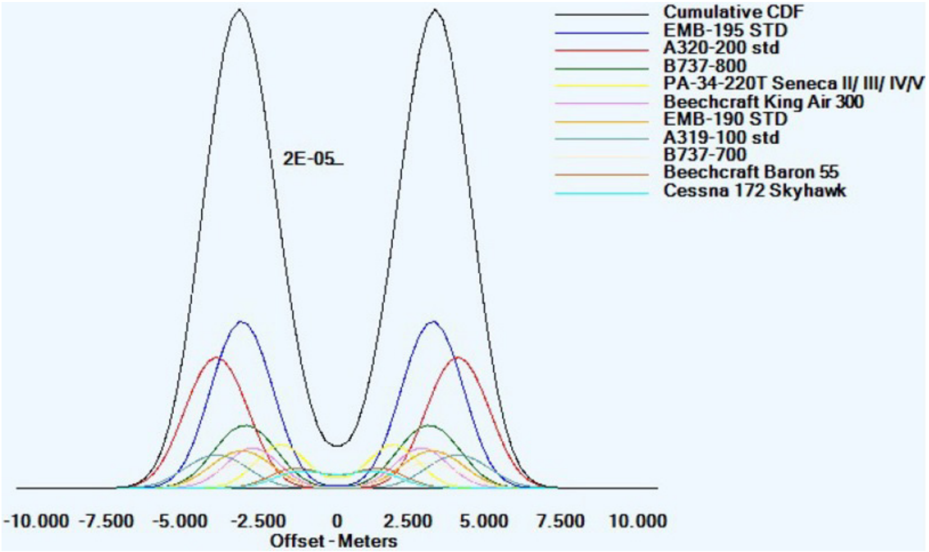

Figure 4. Cumulative value curves for SBGO – Goiânia/GO.

Table 5. Cumulative Damage Factor (CDF) results.

Airport	Runway	CDF
SBEG – Manaus/AM	11/29	0.18
SBTT – Tabatinga/AM	12/30	0.16
SBTF – Tefé/AM	15/33	0.19
SBRB – Rio Branco/AC	06/24	0.27
SBCZ – Cruzeiro do Sul/AC	10/28	< 0.01
SBPV – Porto Velho/RO	01/19	< 0.01
SBBV – Boa Vista/RR	08/26	1.5
SBGO – Goiânia/GO	14/32	< 0.01
SBPJ – Palmas/TO	14/32	0.21
SBTE – Teresina/PI	02/20	0.02
SBPL – Petrolina/PE	13/31	< 0.01
SBSL – São Luiz/MA	06/24	0.32
SBIZ – Imperatriz/MA	07/25	< 0.01
SBCT – Curitiba/PR	15/33	< 0.01
SBFI – Foz do Iguaçu/PR	15/33	< 0.01
SBLO – Londrina/PR	13/31	< 0.01
SBBI – Curitiba /PR	18/36	< 0.01
SBNF – Navegantes/SC	07/25	0.74
SBJV – Joinville/SC	15/33	< 0.01
SBUG – Uruguaiana/RS	09/27	< 0.01

Four airports, which do not operate large aircraft such as A319/320 or B737, can be considered regional airports - SBBI, SBTF, SBTT and SBUG. Despite having pavement structures with a total thickness smaller than the average, the results indicate that their are also overdesigned. However, they are more sensitive to the operations of medium aircraft, such as Embraer 195, which influenced the increase in the CDF of SBTF and SBTT.

Instead, among the 20 airports, only Boa Vista Airport/RR (SBBV) had a CDF above 1.0. In this situation, ANAC recommends taking actions. Among actions to mitigate accelerated pavement degradation, ANAC (2020) recommends either impose restrictions on the number of landing and takeoff operations, restrict operations of aircraft that have a significant contribution to the damage, or evaluate the need for pavement reinforcement.

3. CONCLUSIONS

This research presented analyses of the cumulative damage factor for 20 Brazilian airport pavements, providing information on the geotechnical properties of the airfield pavement layers and an update on the aircraft mix. Overall, results demonstrates that, among 20 Brazilian airport pavements, 65% are composed of 4 structural layers. Also, 50% of the base course layers are cement-treated, while 45% of the subbases are composed of treated soil.

Using the BAKFAA software, an extensive analysis was performed on the backanalysis of deflection basins acquired from Heavy Weight Deflectometer (HWD) tests. Contrary to the expected regarding the structural integrity of Brazilian airport runways, 11 pavement structures evaluted in this study presented a CDF value less than 0.01, indicating that the pavements are overdesigned for the existing aircraft movement. Among the 20 airports analyzed, only Boa Vista Airport/RR (SBBV) showed a CDF of 1.5, situation in which, the ANAC recommends actions to mitigate accelerated pavement degradation.

The information and analyses presented in this study update the information on the pavement life service of existing Brazilian airfield pavements, while can be used for future actions and recommendations for the construction of new airports.

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