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RESEARCH PAPER

Prioritizing flight simulators of the brazilian air force by the analytic hierarchy process and hypothesis tests

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ABSTRACT

Goal: The purpose of the research is to apply a method of decision support to prioritize flight simulators of the Air Force Command in view of the country"s budget constraints in the defense sector.

Methodology: The research was performed with the Analytic Hierarchy Process (AHP), associated with hypothesis tests to define the preference or equivalence relationships between the simulators. Data collection involved the support of 32 Air Force specialists with extensive experience in the chosen simulators.

Results: The T-27 Tucano simulator was preferred, followed by the C-95M Bandeirantes and the C-105 Amazonas, which obtained statistical similarity to each other. In fourth place was the A-29 Super Tucano simulator. The two simulators that had the least preference were the F-5M Tiger II and the A-1 AMX, which achieved results that were statistically close to each other.

Limitations: Any multicriteria decision aid technique embeds its features and limitations. This is not exclusive to AHP, although the consistency ratio is a differential in relation to other methods. The expert sample also reflects the preferences of a group, with reservations to the generalization of the results.

Practical implications: The findings of this research can be used in practice, by assisting the Brazilian Air Force in applying its scarce financial resources to prioritize flight simulators.

Originality / Value: The research is unique to the Brazilian Air Force, in particular to the Center that oversees flight simulators, and is also relevant in including hypothesis testing to AHP results.

Keywords : Flight simulators. Brazilian Air Force. AHP. Hypothesis test.

1. NTRODUCTION

Effective pilot training is a critical component of aviation (Mavin, Kikkawa and Billett, 2018; Junior and Garcia, 2021). Flight simulators can bring significant safety benefits and save defense resources, by eliminating the risk of fatal accidents and by reducing high costs compared to the use of aircraft for actual training (Bent and Chan, 2010; Emre, 2016; Vidakovic et al., 2021). Thus, the Brazilian Air Force (FAB) established in its Strategic Guidance (Air Force 100 DCA 11-45), the highest level document of the Air Force Command (COMAER), guidelines that include the use of simulators to improve its operational capacity (Brazil, 2018a). As a result, the 2018 – 2027 Military Aeronautics Strategic Plan (PCA 11-47) established, in the "Force Preparation" macro-process, the need to improve the training of its crews by increasing the use of flight simulators (Brazil, 2018b).

COMAER has a wide portfolio of simulators for different aircrafts to optimize the preparation of pilots, distributed throughout Brazil. To avoid a gap in training activity, financial resources are

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needed for the maintenance of systems and logistical support in general. However, the budgetary difficulties to meet the needs of the Forces are verified, as explicit in the FAB"s own strategic conception (Brazil, 2018a).

Between 2010 and 2018, the decrease in budgetary resources allocated to National Defense, in relation to the Union budget, was evident. The share of GDP was reduced by 14% and, even at times when the Union Budget was growing, the Defense budget kept falling, both in relation to primary and total expenditures (Silva, 2019).

During the meetings held at the Congress" Committee on Foreign Affairs and National Defense, which were attended by the Minister of Defense and the three Secretaries of the Armed Forces, the lack of resources was central in the debates. In the 2021 budget, the Ministry of Defense estimated R$16.5 billion to cover discretionary expenses (R$7.8 billion) and priority projects (R$8.7 billion). With the cuts in the Budget Law, the amount dropped to R$8.4 billion, representing a reduction of 49% (Rodrigues, 2021).

In this context of budget constraint, reality imposes a realignment of priorities in Force spending (Ellman et al., 2016; Brazil, 2018a). PCA 11-47 projects a scenario of long-term budgetary limitations, even in the face of an eventual recovery of Brazilian economy, which directly impacts COMAER projects (Brazil, 2018b). Thus, the following research question was formulated: how to prioritize COMAER flight simulators in face of budgetary restrictions in the Defense area? The answer is a solution that allows ranking the simulators, directing financial resources that are not enough to cover all systems, to the better options.

To address this problem, the research was designed with the goal of analyzing a decision support method capable of ranking the simulators. The following intermediate objectives guide the process: (1) describe COMAER flight simulator designs; (2) explain the decision support method that fits the problem; (3) select criteria and sub-criteria that support decision making; (4) propose a ranking of simulators to prioritize the use of available resources.

2. FLIGHT SIMULATORS OF THE BRAZILIAN AIR FORCE

Research about Air Force flight simulators has drawn the attention of professional journals and academic events. The theme is recurrent, both because of technological advances and because of logistical, operational and technical reasons (Mendes, Brandao-Ramos and Mora-Camino, 2014; Bezerra et al., 2020; Silva et al., 2021; Sá, Vieira and Cunha, 2022). The Brazilian Air Force uses six flight simulators to train pilots: A-1 AMX, A-29 Super Tucano, C-105 Amazonas, C-95M Bandeirantes, F-5M Tiger II and T-27 Tucano. Table 1 presents their main characteristics.

Table 1 – Flight simulators

Type / Feature	A-1 AMX	A-29 Super Tucano	C-105 Amazonas	C-95M Bandeirantes	F-5M Tiger II	T-27 Tucano
Manufacturer	EUA - Sym Systems	Israel - Elbit	Canada – CAE	Brazil – Aeronautics Computing Center at São José dos Campos (CCA-SJC)	Israel – Elbit	Brazil – CCA-SJC - 2019
Start of operation	2000	2004	2011	2019	2007	2020
Aircraft	Single jet engine	Single engine turbo propeller	Twin turbo propeller		Jet twin engine	Single engine turbo propeller
Structure	Carbon fiber with dimensions similar to aircraft			Real aircraft cockpit	Carbon fiber with dimensions similar to aircraft	Real aircraft cockpit
Flight instrument layout	Same aircraft layout					
Simulation systems	Electric, hydraulic and fuel, which can simulate normal, abnormal and emergency conditions					
Type of force simulation on joysticks and pedals	Electric control loader capable of simulating the forces applied to the joysticks and pedals		Electric control loader, capable of synchronizing the joystick between pilot and copilot		Electric control loader capable of simulating the forces applied to the joysticks and pedals	
Sound simulation	Engines, skid, ground impact, attention and emergency alerts, unlocked landing gear alerts, overspeed, stall and maximum G reached		Engines, skid, ground impact, attention and emergency alerts, unlocked landing gear alerts, overspeed, glide slope, 200ft before reaching height and autopilot disconnect		Engines, skid, ground impact, attention and emergency alerts, unlocked landing gear alerts, overspeed, stall and maximum G reached	
Field of vision	Uncollimated with three screens and approximate field of view of 170° horizontal x 70° vertical	Uncollimated with three screens and approximate field of view of 170° horizontal x 60° vertical	Collimate with continuous screen and 180° horizontal x 40° vertical field of view	Uncollimated with four 70-inch televisions and 240° horizontal x 40° vertical field of view	Uncollimated with three screens and approximate field of view of 170° horizontal x 60° vertical	Uncollimated with five 70-inch televisions and 225° horizontal x 85° vertical field of view
Procedure simulation	GPS, VOR, DME and ILS		RNAV (GPS), VOR, DME, NDB and ILS	RNAV (GPS), VOR, DME, NDB and ILS	GPS, VOR, DME and ILS	VOR, DME, NDB and ILS
Scenario Simulation	Not allowed to include new aerodromes of interest and the scenarios represent the west coast of the USA	Visual scenery has aerodromes of interest to the FAB				

Type / Feature	A-1 AMX	A-29 Super Tucano	C-105 Amazonas	C-95M Bandeirantes	F-5M Tiger II	T-27 Tucano
Instructor Station	Start the flight wherever you want, move the aircraft, adjust height, speed and direction, configure atmospheric conditions and enter abnormal and emergency situations	Monitor the student"s instrument panels (CMFD), start a flight wherever you want, move the aircraft, adjust height, speed and direction, configure atmospheric conditions and enter abnormal and emergency situations	Monitor the student"s instrument panels (CMFD), start a flight wherever you want, move the aircraft; adjust height, speed and direction; configure atmospheric conditions, enter abnormal and emergency situations, and enter and change operational scenarios	Monitor the student"s instrument panels (CMFD), start a flight wherever you want, move the aircraft, adjust height, speed and direction, configure atmospheric conditions and enter abnormal and emergency situations		Start a flight wherever you want, move the aircraft, adjust height, speed and direction, configure weather conditions and enter abnormal and emergency situations

Source: information collected at the Aerospace Science & Technology Department (DCTA - Brazilian Air Force)

3. METHODOLOGY

The research was carried out in five steps. Initially, the literature was reviewed to survey methodologies used in similar problems to choose the decision support algorithm. The defense sector, driven by the growing need to use increasingly advanced systems in an environment of budgetary constraints, requires the use of a project prioritization tool, based on technical criteria to efficiently employ scarce resources (Arnaut et al., 2012; Stromgren et al., 2018; Janzwood, 2021). In fact, the purpose of the research is to apply a method of decision support to prioritize flight simulators of the Air Force Command. Thus, the search in the literature focused on multicriteria decision making methods (MCDM) that support this research objective and does not fit properly in the search for a research gap.

In Step 1, it was found that several authors applied MCDM to prioritize solutions in the defense area. Matos et al. (2018) explored a limited budget scenario and developed a model that allowed choosing which projects would be the object of intervention based on a multi-criteria analysis using the Analytic Hierarchy Process (AHP). Camilo, Gavião and Kostin (2020) and Silva, Belderrain and Pantoja (2010) also used the AHP to prioritize strategic aerospace projects for the Brazilian Air Force, given a similar context of economic scarcity and increasingly frequent budget cuts in the country. Salgado (2021) identified a sample of ships for polar research and their respective capacities to the construction of a new Brazilian Antarctic research vessel. He explored a hybrid model AHP-TOPSIS and PBC as a benchmarking methodology, proposing the improvement and simplification for the acquisition of naval assets. Santos et al. (2021) also considered the scenario of budgetary constraints to select a medium-sized warship to the Brazilian Navy, by AHP. Bimo et al. (2022) used AHP to select amphibious aircraft models to the Indonesian navy. In Hamurcu and Eren (2020), the authors proposed a methodology based on AHP and TOPSIS to evaluate unmanned aircraft (UAV) alternatives for a selection process. In the Portuguese Navy, the AHP was explored for the prioritization of naval projects (Simplício, Gomes and Romão, 2017). The AHP stands out among the various methods that support the multi-criteria decision, due to its logical and calculation simplicity, being indicated by Abastante et al. (2019), Agápito et al. (2015), Balusa and Gorai (2019) as one of the most adopted methods for solving problems of this nature. In the area of project or portfolio selection, AHP is also widely used (Agápito et al., 2019; Goswami, Behera and Mitra, 2020; Souza et al., 2022).

In Step 2, the hierarchical structure of the problem was built. The top is the objective to be solved, followed by evaluation criteria and sub-criteria, ending with possible alternatives to the problem. This structure follows the AHP model (Saaty, 1980; Wind and Saaty, 1980). Fig. 1 illustrates this hierarchical structure. The general objective seeks to prioritize flight simulators, from the point of view of the defense sector and considering the country"s budget constraints. In this hierarchy, the 1st level is composed of criteria selected from the attributes listed by the specialists, which consider technical aspects, the demand for training from FAB and the maintenance costs of the simulators. The 2nd level is composed of the technical sub-criteria considered in the research. The 3rd level is the simulators to be prioritized. In AHP, this hierarchical tree is similar to the traditional decision matrix of other MCDM methods, because it indicates the criteria, subcriteria and the alternatives of the problem. However, the evaluations that complete this matrix are different, as they derive from peer evaluations, rather than the isolated performance of each alternative in each criterion.

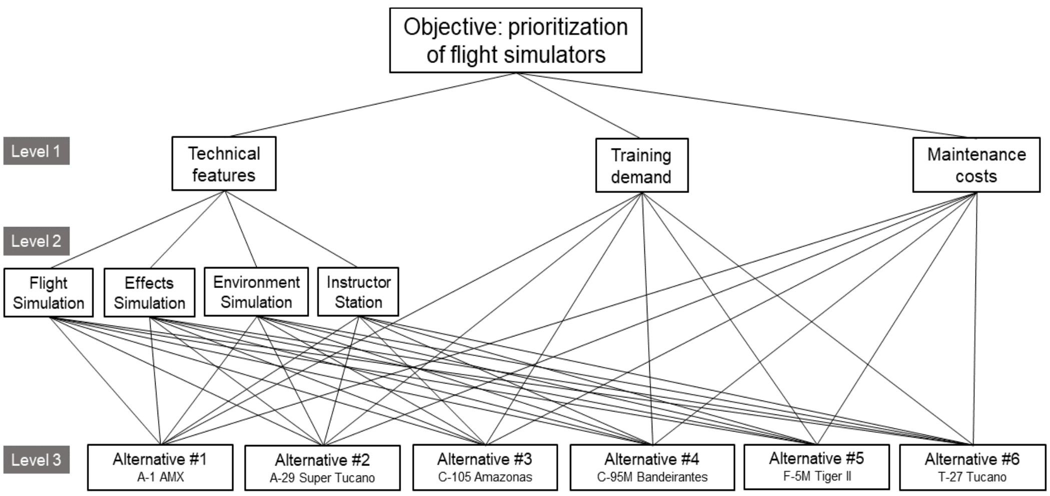

Figure 1 – Hierarchical structure

The 1st level of technical criteria were obtained from ICAO (2015) (Bass, Clements and Kazman, 2003; Zheng et al., 2009). The criteria "Training Demand" and "Maintenance Costs" derive from DCA 11-45 (Brazil, 2018a) and PCA 11-47 (Brazil, 2018b). These guidelines encourage the use of simulation devices to improve the operational training of pilots, including effective logistical support, preventive and corrective maintenance. The criteria and sub-criteria used in the modeling are presented in Table 2.

Table 2 - Description of the criteria and sub-criteria

Criteria	Sub-criteria	Description	Research question
Technical features	Flight simulation	This sub-criterion involves four aspects: the structure and layout of the flight deck, the flight modeling (aerodynamics and engine), the aircraft systems and the flight controls and forces. The layout of the flight cabin involves its physical structure, internal environment, instrument presentation, controls and crew seats. Flight modeling (aerodynamics and engine) involves the mathematical models and associated data to be used to describe the aerodynamic and propulsion characteristics needed to be modeled in the flight simulator. Aircraft systems include hydraulic, fuel, electric power, among others. Modeled systems will allow normal, abnormal and emergency procedures to be carried out. Flight controls and forces are the mathematical models and associated data that describe the required dynamic characteristics that have been modeled in the flight simulator.	Which simulator has the best technical features?
	Effects simulation	This sub-criterion involves two aspects: sound effects and visual effects. Sound effects are related to sounds generated outside the cabin environment, such as sounds from aerodynamics, propulsion, road noise and weather effects, and those internal to the cabin. Visual effects encompass the projection system used to display an image outside the cockpit (eg collimated or non-collimated) and the field of view (horizontal and vertical) that must be seen by pilots using the flight simulator from their reference point of view. Technical requirements such as contrast ratio and spotlight details are also	

Criteria	Sub-criteria	Description	Research question
		considered. If so, the Head-Up Display (HUD) may be considered.	
	Environment simulation	This sub-criterion involves three aspects: navigation, weather conditions, and aerodrome and terrain modelling. Navigation represents the simulated navigational aids, systems and networks with which flight crew members are required to operate, such as GPS, VOR, DME, ILS or NDB. Weather conditions can be simulated, from ambient temperature and pressure to storm modeling, etc. The aerodrome and terrain modeling should detail its characteristics and include such items as generic aerodromes versus custom aerodromes, visual scenery requirements, terrain elevation and Enhanced Ground Proximity Warning Systems (EGPWS) databases.	
	Instructor station	Instructors initiate exercise sessions and engage students by exposing them to variables they will experience in the real world. Options include the ability to set the time of day as well as weather conditions including fog, wind speed and direction. At any time, instructors can assist students for unexpected occurrences including weather events, obstacle loads and mechanical failures, as well as including the ability to define normal, abnormal and emergency procedures.	
Training demand	xxx	The training demand is a management criterion, arising from the number of pilots to be trained, the number of simulators available, the difficulty inherent to the type of aircraft, which need more training hours due to flight missions, among other related aspects.	Which simulator has the greatest training demand?
Maintenance costs	xxx	As the simulators are already in operation, the acquisition costs were not considered. This criterion considers the costs of spare parts, the costs of technical teams needed to repair the simulators, among other related aspects.	Which simulator has the lowest maintenance costs?

The 3rd Step focused on questionnaires to collect information from experts about the criteria, subcriteria and simulators. These assessments were used in AHP.

The 4th Step focused on choosing specialists with training and experience to assess their preferences for flight simulators. Table 3 presents the demography of the experts consulted. In addition to the qualification indicated, this body of experts is responsible for providing high-level advice on this topic in the Air Force.

Table 3 – Experts' demography

Exp	Graduation	Post-Graduation	Occupation	Prof. Experience (years)	Experience with flight simulators (years)	Best knowledge about
1	Aeronautical Sciences	Master"s Degree in Electronic and Computer Engineering; Specialization in IT Governance	Brazilian War College - Student	25	11	Training demand and maintenance costs
2	Information Systems	MBA in Business Management and Master in Technological Innovation	Information Technology Consultant and Mentor	21	2.5	Technical features
3	Logistics Sciences and Bachelor in Law	Specialization in Public and Air Force Management; MBA in Strategic Planning and Management; Master in Public Law	Air Force Command and Staff College - Student	18	5	Maintenance costs
4	Aeronautical Sciences	MBA in Public Management	Commanding Officer - Simulator Maintenance Squadron/Air Force Academy	22	20	Technical features
5	Aeronautical Sciences	MBA in Public Management	Executive Officer - Simulator Maintenance Squadron/Air Force Academy	10	5	Technical features

Exp	Graduation	Post-Graduation	Occupation	Prof. Experience (years)	Experience with flight simulators (years)	Best knowledge about
6	Computer engineering	Master in Computer Engineering	Professor at the Research & Scientific Production Department/Air Force Academy	7	7	Technical features, Maintenance costs
7	Aeronautical Sciences	Brazilian Air Force Command and Staff College	Operational IT Department - Chief	24	20	Maintenance costs
8	Aeronautical Sciences	Specialization in Information Systems Management	Infrastructure of IT Systems Division - Chief	25	7	Maintenance costs
9	Aeronautical Sciences	Public Management – Brazilian Air Force	Simulator Division/São José dos Campos Aeronautics Computing Center	22	3	Custos de manutenção
10	Computer Science	Master in Computer Science		14	14	Technical features
11	Information Systems	xxx		7.5	0.5	Technical features
12	Computer Engineering	Master in Computer Engineering	Research and Innovation Promotion Agency – Staff Officer	14	8	Technical features
13	Ciências Econômicas	Master in Computer Science	Subdivision of Application Systems Development and Maintenance – Staff Officer	35	3	Training demand
14	Aeronautical Sciences	Intermediate Officers Course – Brazilian Air Force	Development and Maintenance Subdivision/São José dos Campos Aeronautics Computing Center	22	3	Technical features
15	Computer engineering	Master in Oil & Gas	Simulator Division/São	10	10	Training demand

Exp	Graduation	Post-Graduation	Occupation	Prof. Experience (years)	Experience with flight simulators (years)	Best knowledge about
		Engineering - UFRN	José dos Campos Aeronautics Computing Center			
16	Aeronautical Sciences	Master in Computer Science	IT Governance Advisor/São José dos Campos Aeronautics Computing Center	25	3	Technical features
17	Aeronautical Sciences	Master in Systems Engineering	São José dos Campos Aeronautics Computing Center - Chief	16	16	Technical features
18	Computer engineering	Intermediate Officers Course – Brazilian Air Force	Technical Division/São José dos Campos Aeronautics Computing Center - Chief	15	5	Custos de manutenção
19	Aeronautical Sciences	Intermediate Officers Course – Brazilian Air Force	Student at the Swedish Defense University – Command and Staff College	23	15	Technical features, Demanda da FAB
20	Aeronautical Sciences	Swedish Defense University – Command and Staff College	COMPREP / Brazilian Air Force - Organization and Legislation	26	17	All criteria
21	Computer engineering	-	Simulator Division/São José dos Campos Aeronautics Computing Center	2	2	Technical features
22	Computer engineering	-		5	1.5	Technical features
23	Computer engineering	-		8	5	Technical features
24	Aeronautical Sciences	Intermediate Officers Course – Brazilian Air Force		19	9	Technical features
25	Computer engineering	Information Safety/Security		17	1.5	Maintenance costs

Exp	Graduation	Post-Graduation	Occupation	Prof. Experience (years)	Experience with flight simulators (years)	Best knowledge about
26	Computer engineering	Master in Computer Science – Modeling, Virtual Enviroments and Simulation (MOVES) – Naval Postgraduate School (NPS) – EUA		13	11.5	Technical features
27	Systems Analysis	-		10	4	Technical features
28	Information systems	-		7.5	1.5	Technical features
29	Computer engineering	-		10	2.3	Technical features
30	Technology in Business Management	Specialization in Strategic Management, Innovation and Knowledge		15	6	Technical features
31	Computer science	Systems engineering		13	3	Technical features
32	Computer engineering	Master in Nuclear Engineering		4.5	3	Technical features

The 5th Step consisted of modeling the assessments using the AHP algorithm. This process is composed of a sequence of calculations, to produce the final weights of the alternatives, whose highest value indicates the flight simulator considered preferred by the specialists. Initially, specialists" assessments need to be standardized, as each respondent chooses their reference for the assessment of the others, based on their experience and knowledge. The procedure for standardizing the assessments follows the principle of additive transitivity, as presented in Alonso et al (2008), Alonso et al (2009), Li et al (2019) e Gavião et al (2021). Thus, the number of pairwise assessments of each specialist is considerably reduced, which impacts the response time and the effort required by the specialist to answer the questionnaire. Assessments are carried out based on the nine-point scale, proposed by Saaty (1980). For the pairwise assessments, the scale indicated in Fig. 2 was used.

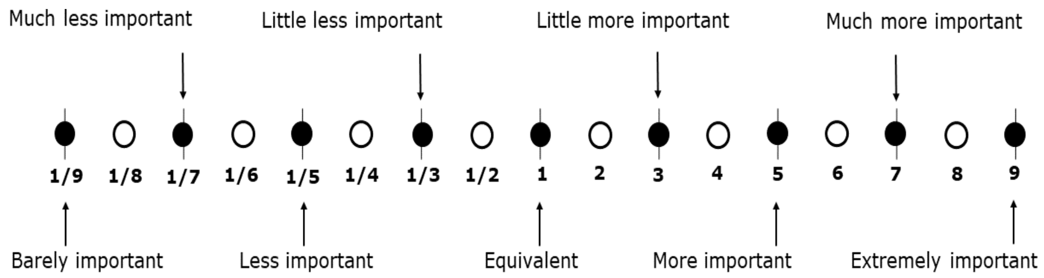

Figure 2 – Nine point scale
Source: adapted from Saaty (1980)

After completing the pairwise evaluation matrix, described in Equation (1), the sequence of Equations (2) to (6) are applied to calculate the weights of the alternatives and compute the Consistency Ratio (RC) of the evaluations. Literature records some techniques for calculating AHP weights. Here, we opted for the original model deriving from linear algebra, based on eigenvalues and eigenvectors of the evaluation matrices. The equations used were described in Liu e Lin (2016). RC indicates whether the expert"s judgments are considered logically consistent. RC values greater than 10% are considered inconsistent, requiring a new round of evaluations.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}} \quad (2)$$

$$A^s = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1' \\ w_2' \\ \vdots \\ w_n' \end{bmatrix} \quad (3)$$

$$\lambda_{\max} = (1/n)\times(w_1'/w_1 + w_2'/w_2 \cdots + w_n'/w_n) \quad (4)$$

$$IC = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

$$RC = \frac{IC}{IR} \quad (6)$$

Mathematical notations:
A: matrix of expert assessments
aij: value of the corresponding pairwise assessment on the Saaty scale
wi: eigenvector of alternatives (weights of criteria, sub-criteria or alternatives)
λmax: maximum eigenvalue of reciprocal matrix
IC: consistency index
RC: consistency ratio
IR: Random Index, based on Table 4

Table 4– Random indices of AHP

Number of variables	1	2	3	4	5	6	7	8	9
Random Index (IR)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The process was carried out for each Expert, calculating their respective final weight for the alternatives. The harmonic averages of the 32 sets of weights were calculated and adjusted to the unit sum. The use of harmonic mean has already been applied with the AHP to calculate the consistency ratio (Stein and Mizzi, 2007; Zheng and Ma, 2018). However, the use of a measure of central tendency helped define the final results, based on 32 expert responses, simplifying the decision-making process. Chakrabarty (2021) highlights the existence of seven measures of central tendency, capable of summarizing a set of data in a measure that represents them. The harmonic mean is the lowest value, when compared to the traditional arithmetic mean and the geometric mean (Vogel, 2022). Thus, it is possible to assume that the use of harmonic means reflects a conservative position for decision making, because if preferences are confirmed at the smallest differences between the results, by hypothesis tests for instance, the largest differences will also be statistically significant.

4. RESULTS

4.1 Data sample

Table 5 presents a sample of seven evaluations, due to the conciseness of the text.

Table 5 – Sample of evaluations (Standardized)

Level	Reference	E10	E11	E12	E13	E14	E15	E16	Target
1	Criterion 1	1	1	1	1	1	1	1	Criterion 1
		1	1	1/5	1	3	1/3	5	Criterion 2
		1	3	1/7	3	2	3	7	Criterion 3
2 – C1	Sub-criterion 1	1	1	1	1	1	1	1	Sub-criterion 1
		6	3	5	1	5	5	5	Sub-criterion 2
		2	1	7	1	6	3	6	Sub-criterion 3
		6	5	7	3	3	3	3	Sub-criterion 4
3 – SC1	Alternative 1	1	1	1	1	1	1	1	Alternative 1
		1	1/7	1/3	1/8	2	1	3	Alternative 2
		1/7	1/3	1/9	1/7	1/5	1/5	5	Alternative 3
		1/3	1/3	1/5	1/3	1/3	1	1/3	Alternative 4
		1	1/7	1/3	1/9	1	1	3	Alternative 5
		1/5	1/7	1/5	1/5	5	1	1/5	Alternative 6
3 – SC2	Alternative 1	1	1	1	1	1	1	1	Alternative 1
		1	1	1/3	2	1	1	3	Alternative 2
		1/7	1	1/3	1	1/5	1/3	5	Alternative 3
		1/3	1	1/5	1	1/2	1	1/3	Alternative 4
		1	1	1/3	1/2	1	1	3	Alternative 5
		1/3	1/3	1/5	4	5	1	1/5	Alternative 6
3 – SC3	Alternative 1	1	1	1	1	1	1	1	Alternative 1

Level	Reference	E10	E11	E12	E13	E14	E15	E16	Target
		1/3	1	1/5	2	1	1	3	Alternative 2
		1/3	3	1/5	1/4	1/4	1/3	5	Alternative 3
		1/6	3	1/7	1/2	1/2	1	1/3	Alternative 4
		1/3	3	1/5	1/2	1	1	3	Alternative 5
		1/6	1	1/7	5	6	1	1/5	Alternative 6
3 – SC4	Alternative 1	1	1	1	1	1	1	1	Alternative 1
		1	1/5	1/7	1	2	1	3	Alternative 2
		1/7	3	1/9	1/5	1/5	1/3	3	Alternative 3
		1/3	3	1/7	1/3	1/2	1	1/3	Alternative 4
		1	3	1/7	1/2	1	1	3	Alternative 5
		1/3	1	1/7	4	5	1	1/7	Alternative 6
3 – C2	Alternative 1	1	1	1	1	1	1	1	Alternative 1
		1	1/5	1	1/3	1/3	2	1	Alternative 2
		1/5	1	3	1/3	1/2	5	1	Alternative 3
		1/3	1	5	1/4	1/3	5	1/3	Alternative 4
		1	1/3	1	2	1	1	1	Alternative 5
		1/4	1/5	7	1/5	1/5	1/3	1/5	Alternative 6
3 – C3	Alternative 1	1	1	1	1	1	1	1	Alternative 1
		3	1	1	1/4	1	1	1/3	Alternative 2
		5	5	3	3	5	5	3	Alternative 3
		1/5	1/5	1/7	1/8	1/5	1/5	1/7	Alternative 4
		3	1	1	1/3	2	1	1/3	Alternative 5
		1/5	1/5	1/7	1/6	1/3	1	1/5	Alternative 6

4.2 Analysis

Table 6 presents the AHP results for seven experts (10 to 16), with weights and RC.

Table 6 – AHP results (sample)

Level	Variable	Description	Esp.10	Esp.11	Esp.12	Esp.13	Esp.14	Esp.15	Esp.16
1	C1	Technical features	0.333	0.429	0.072	0.429	0.540	0.258	0.731
	C2	Training demand	0.333	0.429	0.279	0.429	0.163	0.637	0.188
	C3	Maintenance costs	0.333	0.143	0.649	0.143	0.297	0.105	0.081
	RC		0.000	0.000	0.056	0.000	0.008	0.033	0.056
2 - C1	SC1	Flight simulation	0.516	0.391	0.654	0.300	0.562	0.520	0.562

Level	Variable	Description	Esp.10	Esp.11	Esp.12	Esp.13	Esp.14	Esp.15	Esp.16
	SC2	Effects simulation	0.076	0.151	0.191	0.300	0.110	0.078	0.110
	SC3	Environment simulation	0.333	0.391	0.077	0.300	0.069	0.201	0.069
	SC4	Instructor station	0.076	0.067	0.077	0.100	0.258	0.201	0.258
	RC		0.012	0.016	0.027	0.000	0.029	0.016	0.029
3 - SC1	ALT1	A-1 simulator	0.052	0.031	0.031	0.025	0.107	0.100	0.130
	ALT2	A-29 simulator	0.052	0.281	0.066	0.268	0.067	0.100	0.060
	ALT3	C-105 simulator	0.468	0.064	0.519	0.180	0.455	0.500	0.029
	ALT4	C-95M simulator	0.124	0.064	0.159	0.046	0.238	0.100	0.255
	ALT5	F-5M simulator	0.052	0.281	0.066	0.392	0.107	0.100	0.060
	ALT6	T-27 simulator	0.252	0.281	0.159	0.089	0.027	0.100	0.467
	RC		0.022	0.016	0.033	0.043	0.037	0.000	0.041
3 - SC2	ALT1	A-1 simulator	0.058	0.125	0.046	0.179	0.105	0.125	0.130
	ALT2	A-29 simulator	0.058	0.125	0.113	0.101	0.105	0.125	0.060
	ALT3	C-105 simulator	0.521	0.125	0.113	0.179	0.479	0.375	0.029
	ALT4	C-95M simulator	0.153	0.125	0.308	0.179	0.178	0.125	0.255
	ALT5	F-5M simulator	0.058	0.125	0.113	0.316	0.105	0.125	0.060
	ALT6	T-27 simulator	0.153	0.375	0.308	0.045	0.027	0.125	0.467
	RC		0.016	0.000	0.009	0.008	0.026	0.000	0.041
3 - SC3	ALT1	A-1 simulator	0.040	0.250	0.030	0.114	0.117	0.125	0.130
	ALT2	A-29 simulator	0.095	0.250	0.117	0.073	0.117	0.125	0.060
	ALT3	C-105 simulator	0.095	0.083	0.117	0.413	0.425	0.375	0.029
	ALT4	C-95M simulator	0.338	0.083	0.309	0.186	0.200	0.125	0.255
	ALT5	F-5M simulator	0.095	0.083	0.117	0.186	0.117	0.125	0.060
	ALT6	T-27 simulator	0.338	0.250	0.309	0.029	0.025	0.125	0.467
	RC		0.013	0.000	0.016	0.028	0.023	0.000	0.041
3 - SC4	ALT1	A-1 simulator	0.058	0.153	0.024	0.086	0.115	0.125	0.106
	ALT2	A-29 simulator	0.058	0.521	0.148	0.086	0.071	0.125	0.045
	ALT3	C-105 simulator	0.521	0.058	0.385	0.440	0.483	0.375	0.045
	ALT4	C-95M simulator	0.153	0.058	0.148	0.218	0.187	0.125	0.209
	ALT5	F-5M simulator	0.058	0.058	0.148	0.140	0.115	0.125	0.045

Level	Variable	Description	Esp.10	Esp.11	Esp.12	Esp.13	Esp.14	Esp.15	Esp.16
	ALT6	T-27 simulator	0.153	0.153	0.148	0.030	0.028	0.125	0.551
	RC		0.016	0.016	0.013	0.029	0.033	0.000	0.032
3 -C2	ALT1	A-1 simulator	0.065	0.061	0.268	0.061	0.063	0.192	0.082
	ALT2	A-29 simulator	0.065	0.334	0.268	0.145	0.179	0.120	0.082
	ALT3	C-105 simulator	0.386	0.061	0.112	0.145	0.105	0.040	0.082
	ALT4	C-95M simulator	0.164	0.061	0.055	0.239	0.179	0.040	0.222
	ALT5	F-5M simulator	0.065	0.150	0.268	0.041	0.063	0.192	0.082
	ALT6	T-27 simulator	0.256	0.334	0.030	0.369	0.412	0.417	0.451
	RC		0.010	0.009	0.022	0.018	0.011	0.022	0.006
3 -C3	ALT1	A-1 simulator	0.115	0.085	0.064	0.044	0.107	0.118	0.051
	ALT2	A-29 simulator	0.054	0.085	0.064	0.128	0.107	0.118	0.111
	ALT3	C-105 simulator	0.027	0.024	0.028	0.024	0.027	0.028	0.027
	ALT4	C-95M simulator	0.375	0.360	0.390	0.464	0.455	0.499	0.457
	ALT5	F-5M simulator	0.054	0.085	0.064	0.087	0.067	0.118	0.111
	ALT6	T-27 simulator	0.375	0.360	0.390	0.253	0.238	0.118	0.242
	RC		0.036	0.029	0.020	0.054	0.037	0.020	0.042
Final weights	ALT1	A-1 simulator	0.076	0.0978	0.1187	0.077	0.1009	0.1633	0.1097
	ALT2	A-29 simulator	0.062	0.2675	0.1225	0.1409	0.1017	0.1177	0.0652
	ALT3	C-105 simulator	0.2547	0.0638	0.0784	0.1837	0.2748	0.1422	0.0416
	ALT4	C-95M simulator	0.2464	0.1118	0.2826	0.2308	0.2808	0.1068	0.2565
	ALT5	F-5M simulator	0.062	0.147	0.1225	0.151	0.0892	0.1633	0.0652
	ALT6	T-27 simulator	0.2988	0.3122	0.2755	0.2165	0.1526	0.3067	0.4618

At the different hierarchical levels, it is possible to assess the specialists" marginal preferences based on average weights. Among the various averages, the harmonic average indicates a point value that is more representative of a data set than the arithmetic and geometric averages. For example, in a set of ten values, where nine of them are unity and the last is ten, the arithmetic mean is 1.9, the geometric mean is 1.26, and the harmonic mean is 1.1, indicating that the latter is closer to most values in the sample. Table 7 presents the harmonic average of the 32 experts" weights, by level.

Table 7 – Harmonic mean of AHP weights

Level	Variable	Description	Harmonic mean
1	C1	Technical features	0.2336
	C2	Training demand	0.2385
	C3	Maintenance costs	0.1334

Level	Variable	Description	Harmonic mean
2 - C1	SC1	Flight simulation	0.4127
	SC2	Effects simulation	0.1266
	SC3	Environment simulation	0.1162
	SC4	Instructor station	0.0989
3 - SC1	ALT1	A-1 simulator	0.0480
	ALT2	A-29 simulator	0.1030
	ALT3	C-105 simulator	0.1271
	ALT4	C-95M simulator	0.0882
	ALT5	F-5M simulator	0.0905
	ALT6	T-27 simulator	0.1121
3 - SC2	ALT1	A-1 simulator	0.0559
	ALT2	A-29 simulator	0.0768
	ALT3	C-105 simulator	0.1702
	ALT4	C-95M simulator	0.1187
	ALT5	F-5M simulator	0.0764
	ALT6	T-27 simulator	0.1296
3 - SC3	ALT1	A-1 simulator	0.0480
	ALT2	A-29 simulator	0.0851
	ALT3	C-105 simulator	0.1661
	ALT4	C-95M simulator	0.1493
	ALT5	F-5M simulator	0.0765
	ALT6	T-27 simulator	0.1162
3 - SC4	ALT1	A-1 simulator	0.0492
	ALT2	A-29 simulator	0.0932
	ALT3	C-105 simulator	0.1536
	ALT4	C-95M simulator	0.1224
	ALT5	F-5M simulator	0.0793
	ALT6	T-27 simulator	0.1046
3 -C2	ALT1	A-1 simulator	0.0435
	ALT2	A-29 simulator	0.1433
	ALT3	C-105 simulator	0.0768
	ALT4	C-95M simulator	0.1141
	ALT5	F-5M simulator	0.0707
	ALT6	T-27 simulator	0.2668
3 -C3	ALT1	A-1 simulator	0.0812
	ALT2	A-29 simulator	0.0705
	ALT3	C-105 simulator	0.0308
	ALT4	C-95M simulator	0.2684
	ALT5	F-5M simulator	0.0725
	ALT6	T-27 simulator	0.1825
Final weights	ALT1	A-1 simulator	0.0738
	ALT2	A-29 simulator	0.1155
	ALT3	C-105 simulator	0.1253
	ALT4	C-95M simulator	0.1735
	ALT5	F-5M simulator	0.0868
	ALT6	T-27 simulator	0.2605

Initially, the harmonic mean was applied to the 32 weights of Level 1, of the criteria. The means were C1 = 0.234, C2 = 0.238 and C3 = 0.133, showing a balance between the technical characteristics and the training demand of the FAB and, ultimately, the maintenance costs.

The similarity between the results of C1 and C2 motivated the checking of results by hypothesis testing, to verify, statistically, whether this difference is significant or not. In other words, the hypothesis test makes it possible to identify whether it makes sense to consider that C2 is preferable to C1 or if this difference of 0.004 between them is statistically insignificant. The use of hypothesis tests in support of AHP was applied in Lin et al. (2013), Ateş and Önder (2021), Lee et al. (2000) and Mufazzal et al. (2021).

Means describe specific values of a sample, so they should be considered as a preliminary preference, to be statistically tested. As they are not normally distributed samples, the Wilcoxon-Mann-Whitney non-parametric hypothesis test was applied to verify whether the differences between the results are statistically significant for a defined confidence interval. Thus, the 32 final results, at each level, were applied to hypothesis tests to verify if the differences between them were significant, clearly indicating the preference relationship, or if the differences were not significant.

In a hypothesis test, the p-value, a probability that measures the evidence against the null hypothesis, is calculated for a given confidence level. Generally, a significance level (denoted alpha) of 0.05 is conventional in statistics. This level of significance indicates the threshold 5% risk of concluding that there is a difference between the data sets, when in fact the difference is negligible. Thus, for a p-value $\leq \alpha$, the difference between the data medians is statistically significant, so we reject the hypothesis that nullifies the possibility of data similarity in the assumed risk level, which is why it is called the "null hypothesis". Otherwise, if the p-value $\geq \alpha$, we do not reject this null hypothesis and assume a similarity between the data. In this context, it is possible to conclude that the difference between the population medians is statistically significant.

The Wilcoxon-Mann-Whitney test to criteria 1 and 2 indicated a p-value = 0.7112, well above the 0.05 significance level, assuming that there is no significant preference for C2 over C1. However, the lower preference of C3 over C1 and C2 is more evident and was confirmed by the hypothesis test. The p-value for the comparison between C1 and C3 was 0.005145 and between C2 and C3 was 0.003358, both below alpha = 0.05, indicating significant differences. Equation (7) shows the final preference ($\succ$) or equivalence ($\approx$) relationship between these criteria.

$$C2 \approx C1 \succ C3 \tag{7}$$

The harmonic averages of the 32 weights to the Subcriteria indicated the marginal preferences of this level (SC1 = 0.4127, SC2 = 0.1266, SC3 = 0.1162 and SC4 = 0.0989). The results show a strong preference for "Flight Simulation" and an equivalence between the other Subcriteria. The difference between SC1 and the others was statistically significant, with p-values close to zero. However, the p-values for the comparisons between SC2, SC3 and SC4 were well above 0.05, so it is possible to assume that their differences are not considerable. Equation (8) indicates the final preference relation of these Subcriteria.

$$SC1 \succ SC2 \approx SC3 \approx SC4 \tag{8}$$

The harmonic mean values of the simulators in relation to SC1 were: A-1 (Alt.1) = 0.0480, A-29 (Alt.2) = 0.1030, C-105 (Alt.3) = 0.1271, C-95M (Alt.4) = 0.0882, F-5M (Alt.5) = 0.0905 and T-27 (Alt.6) = 0.1121. The results showed the C-105 ahead, followed by the T-27, A-29, F-5M, C-95M relatively close and the A-1 isolated in the last position. Possibly, the C-105 had the greatest preference because it was the most reliable, as its aerodynamic model and engine were identical to that of the real aircraft. Another relevant point is the position of the C-95M, close to the T-27, since both were built using the same technology and by the same Center to which the specialists belong.

The Wilcoxon-Mann-Whitney test showed that the difference between the C-105 and T-27 simulators is not statistically significant, as the p-value = 0.1193. However, between the C-105 simulator and the four remaining simulators, the differences were considerable, according to Equation (9). Between the simulator of the T-27 and the A-29 the p-value was 0.0820, but between the T-27 and the three remaining simulators the difference was significant, according to Equation (10). The other preference relations are indicated in Equation (11), in which the simulators of the A-29, F-5M and C-95M are equivalent, but preferable in relation to the simulator of the A-1.

$$Alt.3 \approx Alt.6 \wedge Alt.3 \succ \{Alt.2,\ Alt.5,\ Alt.4,\ Alt.1\} \tag{9}$$

$$Alt.6 \approx Alt.2 \wedge Alt.6 \succ \{Alt.5,\ Alt.4,\ Alt.1\} \quad (10)$$

$$Alt.2 \approx Alt.5 \approx Alt.4 \succ Alt.1 \quad (11)$$

The harmonic averages of the simulators to the SC2 were A-1 (Alt.1) = 0.0559, A-29 (Alt.2) = 0.0768, C-105 (Alt.3) = 0.1702, C-95M (Alt.4) = 0.1187, F-5M (Alt.5) = 0.0764 and T-27 (Alt.6) = 0.1296. The results showed the C-105 alone ahead, followed by the T-27 and C-95M with close values, followed by the A-29 and F-5M set, with the A-1 highlighted in the last position. Possibly, the C-105 had the greatest preference because it is the most reliable simulator for the aircraft, with sound effects closer to reality and the only one with a collimated visual system. The Wilcoxon-Mann-Whitney test confirmed that the C-105 simulator stands out in relation to the following (T-27) and the others, with p-value = 0.0077, according to Equation (12).

$$Alt.3 \succ Alt.6 \approx Alt.4 \succ Alt.2 \approx Alt.5 \approx Alt.1 \quad (12)$$

The harmonic averages for the weights to the SC3 were A-1 = 0.0480, A-29 = 0.0851, C-105 = 0.1661, C-95M = 0.1493, F-5M = 0.0765 and T-27 = 0.1162. The results showed the C-105 in first position, followed by the simulators of the C-95M, T-27, A-29 and F-5M with similar values and the A-1 in the last position. Once again, the C-105 had the greatest preference, for having a more reliable simulation system, in addition to having several visual scenarios with well-defined airports. The Wilcoxon-Mann-Whitney test confirmed the general preference for the C-105 simulator in relation to the second place (C-95M), with p-value = 0.0142 and the other relations, according to Equation (13).

$$Alt.3 \succ Alt.4 \approx Alt.6 \succ Alt.2 \approx Alt.5 \succ Alt.1 \quad (13)$$

The harmonic averages for the weights to the SC4 were A-1 = 0.0493, A-29 = 0.0932, C-105 = 0.1536, C-95M = 0.1224, F-5M = 0.0793 and T-27 = 0.1046. The results showed four well-defined groups, the C-105 simulator isolated in first position, followed by the C-95M and T-27 close by, the A-29 and the F-5M and again the A-1 isolated in the last position. Once again, the C-105 was preferred because it has a more reliable simulation system, in addition to possibly being easier to use the functions provided by the Instructor Station. The Wilcoxon-Mann-Whitney test confirmed the general preference for the C-105 simulator in relation to the C-95M, with p-value = 0.0052 and the other relationships, according to Equations (14) and (15).

$$Alt.3 \succ Alt.4 \approx Alt.6 \succ Alt.2 \approx Alt.5 \wedge Alt.2 \succ Alt.1 \quad (14)$$

$$Alt.5 \approx Alt.1 \quad (15)$$

The harmonic averages for the weights to the C2 were A-1 = 0,0435, A-29 = 0,1433, C-105 = 0,0764, C-95M = 0,1141, F-5M = 0,0707 e T-27 = 0,2668. The results showed the T-27, A-29 and C-95M in the top three positions. The T-27 simulators are used for the ground school of cadets at the Air Force Academy and for the instructors" training. The A-29 is used in three squadrons and the simulators are essential in the training of new pilots and for their flight instructors. C-95 is a transport aircraft with high demands on the Brazilian Air Force and also requires training simulators from its crews. The Wilcoxon-Mann-Whitney test confirmed the general preference for the T-27 simulator in relation to the A-29 simulator, with p-value close to zero and the other relationships, according to Equation (16).

$$Alt.6 \succ Alt.2 \approx Alt.4 \succ Alt.3 \approx Alt.5 \succ Alt.1 \quad (16)$$

The harmonic averages for the weights to the C3 were A-1 = 0.0812, A-29 = 0.0705, C-105 = 0.0308, C-95M = 0.2684, F-5M = 0.0725 and T-27 = 0.1825. The results showed the C-95M and T-27 in the first two positions for being the simulators with the lowest maintenance costs and built in 2018 and 2019, respectively. Then the A-1, F-5M and A-29 simulators had similar values, followed by the C-105, which has a very high maintenance cost. The last three placed still share the use of several components of the real aircraft (avionics), which can increase maintenance costs. The Wilcoxon-Mann-Whitney test confirmed the general preference for the C-95M simulator in relation to the T-27, with p-value = 0.050 and the other relationships, according to Equation (17).

$$Alt.4 \succ Alt.6 \succ Alt.1 \approx Alt.5 \approx Alt.2 \succ Alt.3 \quad (17)$$

Finally, the harmonic averages of the simulator"s weights were calculated, as shown in Fig. 3.

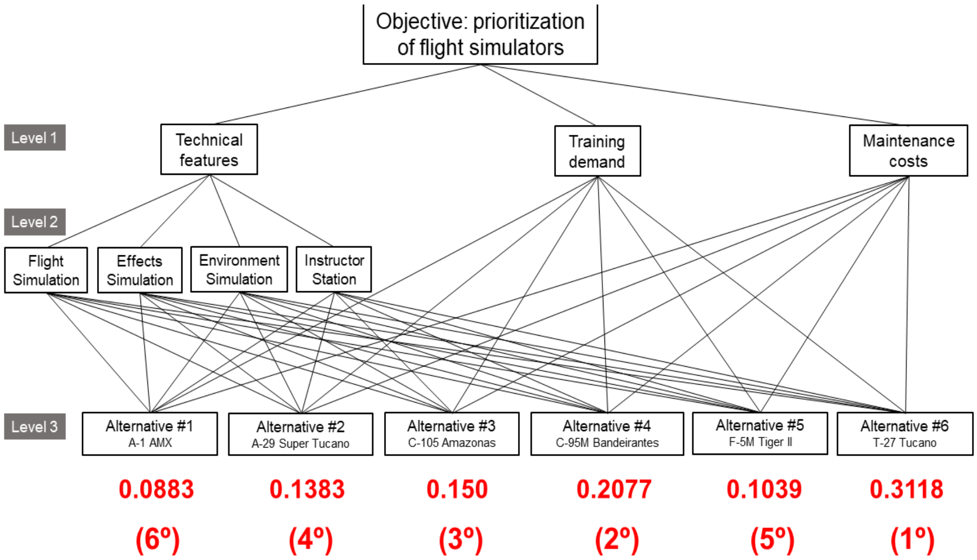

Figure 3 – Final weights

The T-27 Tucano simulator was the most marginally preferred, with a preference of 0.3118, followed by the C-95M Bandeirante simulator with 0.2077. In third was the C-105 Amazonas with 0.150 and in fourth was the A-29 Super Tucano with 0.1383. The simulators with lesser preferences were the F-5M Tiger II with 0.1039 and the A-1 AMX with 0.0883, achieving similar results.

The T-27 Tucano occupied the first position due to its regularity in the evaluations of the criteria and sub-criteria. Although the C-105 simulator had the highest preference in the four technical subcriteria, a low value in "Training Demand" and a very low performance in "Maintenance Costs" caused it to be repositioned to third place.

The Wilcoxon-Mann-Whitney test confirmed the general preference for the T-27 simulator in relation to the C-95M, with p-value close to zero and the other relations, according to Equations (18) and (19).

$$Alt.6 \succ Alt.4 \approx Alt.3 \wedge Alt.4 \succ \{Alt.2, Alt.5, Alt.1\} \quad (18)$$

$$Alt.3 \approx Alt.2 \succ Alt.5 \approx Alt.1 \quad (19)$$

This final list of preferences indicates that, in the event of scarcity of resources to serve all simulators, the demands of the T-27 simulator should be primarily met, followed by the C-95M or C-105 simulators. Next, the needs of the A-29 simulators and, finally, the F-5M or A-1 simulators must be observed.

5. CONCLUSION

This research aimed to apply a method of decision support that allows prioritizing the projects of flight simulators of the Air Force Command in view of the country"s budget constraints. Over the years, it has become evident that the biggest problem for Defense is the restriction of budgetary resources, as the amounts made available are insufficient to meet the financial needs of the Armed Forces, requiring the prioritization of the most relevant and urgent projects. In this context, a search was carried out in the research bases to survey studies that used decision support models, in which AHP was chosen, as it is a widely used method for solving similar problems. It is also worth noting that the use of hypothesis tests to assess the statistical differences between the AHP marginal preferences made the description of the preference or equivalence relationships between the simulators stricter.

The COMAER flight simulators selected for this work were the A-1 AMX, A-29 Super Tucano, C-105 Amazonas, C-95M Bandeirantes, F-5M Tiger II and T-27 Tucano. For modeling the hierarchical structure of the problem, the following criteria were defined: technical features of the simulators, training demand in the Air Force and maintenance costs. The first criterion was subdivided into four subcriteria: flight simulation, effects simulation, environment simulation and instructor station.

Data were collected through questionnaires, sent to 32 experts with experience in the criteria raised, to enable the application of the AHP method. The analysis and treatment of the collected data made it possible to indicate a prioritization of projects for the COMAER flight simulators.

The results indicated a prioritization among the projects analyzed, with the simulator of the T-27 Tucano as the most preferred, followed by the simulator of the C-95M Bandeirantes and the C-105 Amazonas, which obtained statistical similarity to each other. In fourth place was the A-29 Super Tucano simulator. The two simulators that had the least preference were the F-5M Tiger II and the A-1 AMX, which achieved results that were statistically close to each other.

This research can be improved. Initially, it is possible to expand data collection to another group of specialists, coming from other sectors of the defense industrial base, from the Ministry of Defense, among others. Finally, the use of other multicriteria decision support methods can bring new perspectives to decision makers, although it requires the development of new questionnaires to adapt data collection according to the chosen methodology.

REFERENCES

Abastante, F. et al. (2019), "A new parsimonious AHP methodology: assigning priorities to many objects by comparing pairwise few reference objects", *Expert Systems with Applications*, Vol.127, pp. 109–120.

Agápito, A. O. et al. (2015), "Utilização do método de análise hierárquica (ahp) como ferramenta de auxílio multicritério no processo de decisão de priorização de projetos de ciência, tecnologia e inovação na Amazônia azul", in *XVIII Simpósio de Pesquisa Operacional e Logística da Marinha*. Rio de Janeiro-RJ: Marinha do Brasil, pp. 1–10, http://pdf.blucher.com.br.s3-sa-east-1.amazonaws.com/marineengineeringproceedings/spolm2015/140542.pdf

Agápito, A. de O. et al. (2019) "Using multicriteria analysis and fuzzy logic for project portfolio management", *Brazilian Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 347–357.

Alonso, S. et al. (2008), "A consistency-based procedure to estimate missing pairwise preference values", International journal of intelligent systems, 23(2), pp. 155–175.

Alonso, S. et al. (2009), "Group decision making with incomplete fuzzy linguistic preference relations", *International Journal of Intelligent Systems*, Vol. 24, No. 2, pp. 201–222.

Arnaut, B. M. et al. (2012), "Multimetodologias na identificação, seleção e priorização de projetos de P&D no setor de defesa", in *XIV Simpósio de Aplicações Operacionais em Áreas de Defesa*. São José dos Campos - SP: Instituto Tecnológico da Aeronáutica, pp. 1–8, https://www.sigeold.ita.br/anais/XIVSIGE/pdf/III_3.pdf

Ateş, M. and Önder, D. E. (2021), "A local smart city approach in the context of smart environment and urban resilience", *International Journal of Disaster Resilience in the Built Environment*, https://doi.org/10.1108/IJDRBE-07-2021-0064

Balusa, B. C. and Gorai, A. K. (2019), "Sensitivity analysis of fuzzy-analytic hierarchical process (FAHP) decision-making model in selection of underground metal mining method", *Journal of Sustainable Mining*, Vol. 18, No. 1, pp. 8–17.

Bass, L., Clements, P. and Kazman, R. (2003), *Software architecture in practice*. Addison-Wesley Professional.

Bent, J. and Chan, K. (2010), "Flight training and simulation as safety generators", in *Human factors in aviation*. Elsevier, pp. 293–334.

Bezerra, T. A. R. et al. (2020), "Data Acquisition System for Revitalization of Aircraft EMB 312 T-27 and AT-29 Force Simulator", *International Journal of Astronautics and Aeronautical Engineering*, Vol. 5, pp. 1–9. https://doi.org/10.35840/2631-5009/7539

Bimo, E. A. et al. (2022), "The Application of AHP and PESTEL-SWOT analysis on the study of military amphibious aircraft acquisition decision making in Indonesia*", Technium Social Sciences Journal*, Vol. 27, pp. 837–853.

Brazil (2018a) "Comando da Aeronáutica. Portaria no 1.597/GC3, de 10 de outubro de 2018. Aprova a reedição da DCA 11-45 "Concepção Estratégica - Força Aérea 100".", Boletim do Comando da Aeronáutica, 180(11265).

Brazil (2018b), "Comando da Aeronáutica. Portaria no 2.102/GC3, de 18 de dezembro de 2018. Aprova a reedição da PCA 11-47 "Plano Estratégico Militar da Aeronáutica 2018 - 2027"", *Boletim do Comando da Aeronáutica*, 222(14766).

Camilo, J. A. P.; Gavião, L. O. and Kostin, S. (2020), "Priorização de projetos do segmento espacial por processo de análise hierárquica", Revista Brasileira de Estudos de Defesa, 7(1).

Chakrabarty, D. (2021), "Measuremental Data: Seven Measures of Central Tendency", *International Journal of Electronics*, Vol. 8, No. 1.

Ellman, J. et al. (2016), "Defense Acquisition Trends, 2015: Acquisition in the Era of Budgetary Constraints", 1st edn. Edited by *C. for S. & I. Studies*. Washington, DC: Rowman & Littlefield.

Emre, A. M. (2016), "Analysis of the Benefits of Motion Simulators in 5th Generation Fighter Pilots Training", *International Journal of Educational and Pedagogical Sciences*, Vol. 10, No. 2, pp. 411–415.

Gavião, L. O., Lima, G. B. A. and Garcia, P. A. de A. (2021), "Procedimento de redução das avaliações do AHP por transitividade da escala verbal de Saaty", in Senhoras, E. M. (ed.) *Engenharia de Produção: além dos produtos e sistemas produtivos*. 1st edn. Ponta Grossa - PR: Editora Atena, pp. 88–102, https://doi.org/10.22533/at.ed.9082115039

Goswami, S. S., Behera, D. K. and Mitra, S. (2020), "A Comprehensive Study of Weighted Product model for selecting the best product in our daily life", *Brazilian Journal of Operations & Production Management*, Vol. 17, No. 2, pp. 1–18.

Hamurcu, M. and Eren, T. (2020), "Selection of Unmanned Aerial Vehicles by Using Multicriteria Decision-Making for Defence", *Journal of Mathematics*, 2020.

Janzwood, S. (2021), "R&D priority-setting for global catastrophic risks: The case of the NASA planetary defense mission", *Research Policy*, Vol. 50, N. 6, p. 104225.

Junior, J. C. P. and Garcia, C. M. (2021), "Voo de instrução: importância do uso de simulador de voo para a formação de piloto", *Revista Brasileira de Aviação Civil & Ciências Aeronáuticas*, Vol. 1, No. 2, pp. 164–191.

Lee, D., McCool, J. and Napieralski, L. (2000), "Assessing adult learning preferences using the analytic hierarchy process", *International Journal of Lifelong Education*, Vol. 19, No. 6, pp. 548–560.

Li, C.-C. et al. (2019), "An overview on managing additive consistency of reciprocal preference relations for consistency-driven decision making and fusion: Taxonomy and future directions", *Information Fusion*, Vol. 52, pp. 143–156.

Lin, C., Kou, G. and Ergu, D. (2013), "An improved statistical approach for consistency test in AHP", Annals of Operations Research, Vol. 211, No. 1, pp. 289–299.

Liu, C. H. and Lin, C.-W. R. (2016), "The Comparative of the AHP Topsis Analysis Was Applied for the Commercialization Military Aircraft Logistic Maintenance Establishment", *International Business Management*, Vol. 10, No. 4, pp. 6428–6432.

Matos, P. V. et al. (2018), "The use of multi-criteria analysis in the recovery of abandoned mines: a study of intervention in Portugal", *RAUSP Management Journal*, Vol. 53, pp. 214–224.

Mavin, T. J., Kikkawa, Y. and Billett, S. (2018), "Key contributing factors to learning through debriefings: commercial aviation pilots" perspectives", *International Journal of Training Research*, Vol. 16, N. 2, pp. 122–144.

Mendes, J. B., Brandao-Ramos, A. C. and Mora-Camino, F. (2014), "Low Cost Helicopter Training Simulator: A Software Case Study from the Brazilian Military Police", *International Journal of Computer Science and Artificial Intelligence*, Vol. 4, No. 2, pp. 45–53.

Mufazzal, S. et al. (2021), "Towards minimization of overall inconsistency involved in criteria weights for improved decision making", Applied Soft Computing, 100, p. 106936.

Rodrigues, A. (2021), "Orçamento atende a metade das necessidades da Defesa, diz ministro", Agência Brasil, 5 May, p. 1, https://agenciabrasil.ebc.com.br/economia/noticia/2021-05/defesa-orcamento-atende-metade-das-necessidades-diz-ministro

Sá, F. R. de, Vieira, R. G. and Cunha, A. M. da (2022), "Learning Lessons From the Scrum Adoption in the Brazilian Air Force", *IT Professional*, Vol. 24, No. 1, pp. 49–55.

Saaty, T. L. (1980) The Analytic Hierarchy Process. New York: McGraw-Hill.

Salgado, F. A. S. (2021), *Proposta de modelo para seleção de navios de pesquisa Antártica por método AHP-TOPSIS e Planejamento Baseado por Capacidades*. Brazilian War College.

Santos, M. dos, Costa, I. P. de A. and Gomes, C. F. S. (2021), "Multicriteria decision-making in the selection of warships: a new approach to the AHP method", *International Journal of the Analytic Hierarchy Process*, Vol. 13, No. 1, pp. 147–169.

Silva, A. C., Belderrain, M. C. N. and Pantoja, F. C. M. (2010), "Prioritization of R&D projects in the aerospace sector: AHP method with ratings", *Journal of Aerospace Technology and Management*, Vol. 2, pp. 339–348.

Silva, M. H. de O. C. et al. (2021), "Mental Workload Assessment in Military Pilots Using Flight Simulators and Physiological Sensors", in *International Symposium on Human Mental Workload: Models and Applications*. Springer, pp. 99–115.

Silva, R. Q. (2019), "Orçamento da defesa nacional de 2010 a 2018: análises e perspectivas", Expediente, 9(1), pp. 74–96.

Simplício, R., Gomes, J. and Romão, M. (2017), "Projects selection and prioritization: a Portuguese Navy pilot model", *Procedia Computer Science*, Vol. 121, pp. 72–79.

Souza, G. M. et al. (2022), "Integrating fuzzy-MCDM methods to select project portfolios under uncertainty: the case of a pharmaceutical company", *Brazilian Journal of Operations & Production Management*, Vol. 19, No.

3, pp. 1–19.

Stein, W. E. and Mizzi, P. J. (2007), "The harmonic consistency index for the analytic hierarchy process", *European Journal of Operational Research*, Vol. 177, No. 1, pp. 488–497.

Stromgren, C. et al. (2018), "Investment portfolio prioritization for emerging homeland security threats", in *2018 Winter Simulation Conference (WSC)*. IEEE, pp. 2769–2780.

Vidakovic, J. et al. (2021), "Flight Simulation Training Devices: Application, Classification, and Research", *International Journal of Aeronautical and Space Sciences*, pp. 1–12.

Vogel, R. M. (2022), "The geometric mean?", *Communications in Statistics-Theory and Methods*, Vol. 51, No. 1, pp. 82–94.

Wind, Y. and Saaty, T. L. (1980), "Marketing Applications of the Analytic Hierarchy Process.", Management Science, Vol. 26, No. 7, pp. 641–658, https://doi.org/10.1287/mnsc.26.7.641

Zheng, N. and Ma, G. (2018) "Analytic Hierarchy Process Improvement", *International Journal of Engineering and Applied Sciences*, Vol. 5, No. 4, p. 257229.

Zheng, S. et al. (2009) "Flight simulator architecture development and implementation", in *2009 International Conference on Measuring Technology and Mechatronics Automation*. IEEE, pp. 230–233.

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