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. INTRODUCTION

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; Vidakov 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
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 | Carbon fiber with dimensions similar to aircraft | Carbon fiber with dimensions similar to aircraft | Real aircraft cockpit | Real aircraft cockpit |
| Flight instrument layout               | Same aircraft layout     | Same aircraft layout       | Same aircraft layout       | Real aircraft cockpit                 | Real aircraft cockpit |
| Simulation systems                     | Electric, hydraulic and fuel, which can simulate normal, abnormal and emergency conditions | Electric, hydraulic and fuel, which can simulate normal, abnormal and emergency conditions | Electric, hydraulic and fuel, which can simulate normal, abnormal and emergency conditions | 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 |
| 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 simulating the forces applied to the joysticks and pedals | Electric control loader capable of simulating the forces applied to the joysticks and pedals | Electric control loader capable of simulating the forces applied to the joysticks and pedals | 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, 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 | 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 | Collimated 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 | Visual scenery has aerodromes of interest to the FAB | Visual scenery has aerodromes of interest to the FAB | Visual scenery has aerodromes of interest to the FAB | Visual scenery has aerodromes of interest to the FAB |
### Characteristics of Education 4.0: Its possibilities in times of Pandemic

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| 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 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 | 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 (Simplicio, Gomes and Romao, 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), Agapito 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 (Agapito 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.

![Hierarchical structure](https://doi.org/10.14488/BJOPM.1366.2022)
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|              | 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. | Which simulator has the best technical features? |
|                   |              | The layout of the flight cabin involves its physical structure, internal environment, instrument presentation, controls and crew seats. |                   |
| Flight simulation | 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. |                   |
|                   | 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. |                   |
| Effects simulation| 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 |
|------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| Environment      | Simulation            | 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                | 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                 | 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.

| Exp | Graduation | Post-Graduation | Occupation | Prof. Experience (years) | Experienc with flight simulator s (years) | Best knowledge about |
|-----|-------------|-----------------|------------|--------------------------|------------------------------------------|----------------------|
| 1   | Aeronautica l 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   | Aeronautica l Sciences | MBA in Public Management | Commanding Officer - Simulator Maintenance Squadron/Air Force Academy | 22 | 20 | Technical features |
| 5   | Aeronautica l Sciences | MBA in Public Management | Executive Officer - Simulator Maintenance Squadron/Air Force Academy | 10 | 5 | Technical features |
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| Exp | Graduation     | Post-Graduation          | Occupation                                                                 | Prof. Experience (years) | Experiene with flight simulators (years) | Best knowledge about                                      |
|-----|----------------|--------------------------|----------------------------------------------------------------------------|--------------------------|------------------------------------------|-----------------------------------------------------------|
| 6   | Computer       | Master in Computer       | Professor at the Research & Scientific Production Department/Air Force Academy | 7                        | 7                                        | Technical features, Maintenance costs                     |
|     | engineering    | Engineering              |                                                                            |                          |                                          |                                                           |
| 7   | Aeronautica I | Brazilian Air Force      | Operational IT Department - Chief                                           | 24                       | 20                                       | Maintenance costs                                         |
|     | Sciences       | Command and Staff College|                                                                            |                          |                                          |                                                           |
| 8   | Aeronautica I | Specialization in        | Infrastructure of IT Systems Division - Chief                              | 25                       | 7                                        | Maintenance costs                                         |
|     | Sciences       | Information Systems      |                                                                            |                          |                                          |                                                           |
|     | Management     | Management               |                                                                            |                          |                                          |                                                           |
| 9   | Aeronautica I | Public Management         | Simulator Division/São José dos Campos Aeronautics Computing Center         | 22                       | 3                                        | Custos de manutenção                                     |
|     | Sciences       | Brazilian Air Force      |                                                                            |                          |                                          |                                                           |
| 10  | Computer       | Master in Computer       | Research and Innovation Promotion Agency – Staff Officer                   | 14                       | 14                                       | Technical features                                       |
|     | Science        | Science                  |                                                                            |                          |                                          |                                                           |
| 11  | Information    | xxx                       | Research and Innovation Promotion Agency – Staff Officer                   | 7.5                      | 0.5                                      | Technical features                                       |
|     | Systems        |                          |                                                                            |                          |                                          |                                                           |
| 12  | Computer       | Master in Computer       | Research and Innovation Promotion Agency – Staff Officer                   | 14                       | 8                                        | Technical features                                       |
|     | Engineering    | Engineering              |                                                                            |                          |                                          |                                                           |
| 13  | Ciências       | Master in Computer       | Subdivision of Application Systems Development and Maintenance – Staff Officer | 35                       | 3                                        | Training demand                                           |
|     | Econômicas     | Science                  |                                                                            |                          |                                          |                                                           |
| 14  | Aeronautica I | Intermediate Officers    | Development and Maintenance Subdivision/São José dos Campos Aeronautics Computing Center | 22                       | 3                                        | Technical features                                       |
|     | Sciences       | Course – Brazilian Air   |                                                                            |                          |                                          |                                                           |
|     |                | Force                    |                                                                            |                          |                                          |                                                           |
| 15  | Computer       | Master in Oil & Gas      | Simulator Division/São                                                      | 10                       | 10                                       | Training demand                                           |
|     | engineering    |                          |                                                                            |                          |                                          |                                                           |
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| Exp | Graduation | Post-Graduation | Occupation | Prof. Experience (years) | Experienc e with flight simulator s (years) | Best knowledge about |
|-----|------------|-----------------|------------|--------------------------|---------------------------------------------|---------------------|
| 16  | Aeronautica l Sciences | Master in Computer Science | IT Governance Advisor/São José dos Campos Aeronautics Computing Center | 25 | 3 | Technical features |
| 17  | Aeronautica l 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  | Aeronautica l 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  | Aeronautica l Sciences | Swedish Defense University – Command and Staff College | COMPREP / Brazilian Air Force - Organization and Legislation | 26 | 17 | All criteria |
| 21  | Computer engineering | - | - | 2 | 2 | Technical features |
| 22  | Computer engineering | - | - | 5 | 1.5 | Technical features |
| 23  | Computer engineering | - | - | 8 | 5 | Technical features |
| 24  | Aeronautica l Sciences | Intermediate Officers Course – Brazilian Air Force | - | 19 | 9 | Technical features |
| 25  | Computer engineering | Information Safety/Security | - | 17 | 1.5 | Maintenance costs |
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) and 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.

| Exp | Graduation | Post-Graduation | Occupation | Prof. Experience (years) | Experienc e with flight simulator (years) | Best knowledge about |
|-----|-------------|-----------------|------------|--------------------------|------------------------------------------|----------------------|
| 26  | Computer engineering | Master in Computer Science – Modeling, Virtual Environments and Simulation (MOVES) – Naval Postgraduate School (NPS) – EUA | Master in Computer Science | 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 |
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 et al. (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.

\[
A = \begin{bmatrix}
1 & a_{12} & \cdots & a_{1n} \\
a_{21} & 1 & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & 1 
\end{bmatrix}
\] (1)

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

\[
A_s = \begin{bmatrix}
1 & a_{12} & \cdots & a_{1n} \\
a_{21} & 1 & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & 1 
\end{bmatrix} \times \begin{bmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{bmatrix} = \begin{bmatrix}
w_1' \\
w_2' \\
\vdots \\
w_n'
\end{bmatrix}
\] (3)

\[
\lambda_{\text{max}} = (1/n) \times (w_1' / w_1 + w_2' / w_2 + \cdots + w_n' / w_n)
\] (4)

\[
IC = \frac{\lambda_{\text{max}} - n}{n - 1}
\] (5)

\[
RC = \frac{IC}{IR}
\] (6)

Mathematical notations:
- \(A\): matrix of expert assessments
- \(a_{ij}\): value of the corresponding pairwise assessment on the Saaty scale
- \(w_i\): eigenvector of alternatives (weights of criteria, sub-criteria or alternatives)
- \(\lambda_{\text{max}}\): 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 | 0.0 | 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 | 1/3 | 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 |
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4.2 Analysis

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

| 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   | Alternative 1 |
|       |           | 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   | Alternative 1 |
|       |           | 1/5 | 1   | 1/3 | 1/3 | 2   | 1   | Alternative 2 |
|       |           | 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   | Alternative 1 |
|       |           | 3   | 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 |

| Level | Reference | 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 – SC1 | C1        | Flight simulation | 0.516  | 0.391  | 0.654  | 0.300  | 0.562  | 0.520  | 0.562  |

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| 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 |
| 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 | 0.032 | 0.090 | 0.027 | 0.100 | 0.467 |        |
| RC    |          | 0.022 | 0.016 | 0.033 | 0.043 | 0.037 | 0.000 | 0.041 |
| ALT1  | A-1 simulator | 0.058 | 0.125 | 0.046 | 0.179 | 0.105 | 0.125 | 0.130 |
| ALT2  | A-29 simulator | 0.058 | 0.032 | 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 |
| ALT1  | A-1 simulator | 0.040 | 0.250 | 0.030 | 0.114 | 0.117 | 0.125 | 0.130 |
| ALT2  | A-29 simulator | 0.095 | 0.032 | 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 |
| 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 |
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        |

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| 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 $C_1 = 0.234$, $C_2 = 0.238$ and $C_3 = 0.133$, 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 Onder (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 ≤ α, 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 > α, 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 (≽) or equivalence (≅) relationship between these criteria.

\[ C_2 ≽ C_1 \succ C_3 \]

(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.

\[ SC1 \succ SC2 \approx SC3 \approx SC4 \]

(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.

\[ Alt.3 \approx Alt.6 \land Alt.3 \succ \{Alt.2, Alt.5, Alt.4, Alt.1\} \]

(9)
Alt.6 ≈ Alt.2 ∧ Alt.6 ≻ \{Alt.5, Alt.4, Alt.1\} (10)
Alt.2 ≈ Alt.5 ≈ Alt.4 ≻ Alt.1 (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 ≻ Alt.6 ≈ Alt.4 ≻ Alt.2 ≈ Alt.5 ≈ Alt.1 (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 ≻ Alt.4 ≈ Alt.6 ≻ Alt.2 ≈ Alt.5 ≻ Alt.1 (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 ≻ Alt.4 ≈ Alt.6 ≻ Alt.2 ≈ Alt.5 ∧ Alt.2 ≻ Alt.1 (14)

Alt.5 ≈ Alt.1 (15)

The harmonic averages for the weights to the SC2 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 ≻ Alt.2 ≈ Alt.4 ≻ Alt.3 ≈ Alt.5 ≻ Alt.1 (16)

The harmonic averages for the weights to the SC3 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
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Finally, the harmonic averages of the simulator’s weights were calculated, as shown in Fig. 3.

\[
\text{Alt.} 4 \succ \text{Alt.} 6 \succ \text{Alt.} 1 \approx \text{Alt.} 5 \approx \text{Alt.} 2 \succ \text{Alt.} 3
\]  \hspace{1cm} (17)

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.

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