FLIGHT SIMULATORS IN PILOT TRAINING AT THE AIR FORCE ACADEMY: CONTRIBUTIONS TO BRAZILIAN AEROSPACE POWER

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The Brazilian Air Force (FAB) is the main constitutive element of Aeronautics. It is the military expression of aerospace power. In this context, the relevance in providing greater efficiency in the pilots training is noted. Therefore, the objective of this work is to analyze the relationship between the modernization of teaching at the Air Force Academy (AFA), specifically through the increase of new flight simulators, and aerospace power. Using theoretical references on Air Power, Teaching and Simulators, a bibliography and documentary research was conducted to describe these concepts in the scope of the FAB. Data on the performance of cadets during primary instruction on the T-25 Universal aircraft in 2020 and 2021, before and after the adoption of flight simulators, were analyzed. A reduction in course failures was observed, indicating the first signs in the efficiency of modernizing the air instruction. The initial results demonstrate the relevance of simulated flight and new technologies in the training of military pilots, in consonance with what is done in the operation of combat aircrafts such as the A-29 Super Tucano, F5M Tiger and the F-39 Gripen. Hence, by understanding that the use of simulators has positively influenced the efficiency of the primary instruction and that these are the aviators who will fly modern combat aircraft, it can be indicated that the adoption of simulated flight training at the AFA has increased the military capacity of the FAB, thus supporting the application of aerospace power.

Keywords: simulators; air instruction; aerospace power; modernization; education.

SIMULADORES DE VOO NA FORMAÇÃO DE PILOTOS DA ACADEMIA DA FORÇA AÉREA: CONTRIBUIÇÕES PARA O PODER AEROESPACIAL BRASILEIRO

A Força Aérea Brasileira (FAB) é o principal elemento constitutivo da Aeronáutica. É a expressão militar do poder aeroespacial. Neste contexto, nota-se a relevância de prover maior eficiência na formação dos pilotos. O objetivo deste trabalho é analisar a relação entre a modernização do ensino na Academia da Força Aérea (AFA), especificamente a partir do incremento de novos simuladores de voo, e o poder aeroespacial. Com referencial teórico sobre poder aeroespacial, ensino e simuladores, foi realizada uma análise bibliográfica e documental a fim de descrever tais conceitos no âmbito da FAB. Foram analisados dados relativos ao desempenho de cadetes durante a instrução primária, na aeronave T-25 Universal, nos anos de 2020 e 2021, antes e após a adoção dos simuladores de voo. Observou-se uma redução na proporção de reprovações no curso, constatando-se os primeiros indícios de eficiência da modernização da instrução aérea. Os resultados iniciais demonstram a relevância do voo simulado e de novas tecnologias na formação dos pilotos militares, em consonância com o que é realizado na operação das aeronaves de caça, como o A-29 Super Tucano, o F-5M Tiger e o F-39 Gripen. Portanto, ao constatar-se que o uso de simuladores tem influenciado positivamente a eficiência da instrução primária dos aviadores que

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irão conduzir as modernas aeronaves de combate, pode-se, então, indicar que a adoção do voo simulado na AFA tem incrementado a capacidade militar da FAB, corroborando, assim, o emprego do poder aeroespacial brasileiro.

Palavras-chave: simuladores; instrução aérea; poder aeroespacial; modernização; ensino.

SIMULADORES DE VUELO EN LA FORMACIÓN DE PILOTOS DE LA ACADEMIA DE LA FUERZA AÉREA: CONTRIBUCIONES AL PODER AEROESPACIAL BRASILEÑO

La Fuerza Aérea Brasileña (FAB) es el principal elemento constitutivo de la Aeronáutica. Es la expresión militar del poder aeroespacial. En este contexto, se nota la relevancia de proporcionar una mayor eficiencia en la formación de los pilotos. El objetivo de este trabajo es analizar la relación entre la modernización de la enseñanza en la Academia de la Fuerza Aérea (AFA), específicamente a partir del incremento de nuevos simuladores de vuelo, y el poder aeroespacial. Con un marco teórico sobre Poder Aéreo, Enseñanza y Simuladores, se realizó un análisis bibliográfico y documental con el fin de describir dichos conceptos en el ámbito de la FAB. Se analizaron datos relativos al desempeño de los Cadetes durante la instrucción primaria, en la aeronave T-25 Universal, en los años 2020 y 2021, antes y después de la adopción de los simuladores de vuelo. Se observó una reducción en la proporción de reprobaciones en el curso, constatándose los primeros indicios de eficiencia en la modernización de la instrucción aérea. Los resultados iniciales demuestran la relevancia del vuelo simulado y de las nuevas tecnologías en la formación de los pilotos militares, en consonancia con lo que se realiza en la operación de aeronaves de combate, como el A-29 Super Tucano, el F-5M Tiger y el F-39 Gripen. Por lo tanto, al constatar que el uso de simuladores ha influido positivamente en la eficiencia de la instrucción primaria y que serán estos aviadores quienes pilotarán las modernas aeronaves de combate, se puede indicar que la adopción del vuelo simulado en la AFA ha incrementado la capacidad militar de la FAB, corroborando así con el empleo del poder aeroespacial Brasileño.

Palabras clave: simuladores; instrucción aérea; potencia aeroespacial; modernización; enseñanza.

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1 INTRODUCTION

Since the creation of the modern State in Europe, the concept of military power has been intrinsically linked to national development. Weber (2011) establishes that the State essentially holds the monopoly on the legitimate use of physical force. This capacity legitimizes both State actions and the conduct of national policy. The maintenance of such a policy, however, requires the establishment of State institutions capable of imposing their objectives – within the dialectic of will between actors – through the legitimate use of force.

In this context, Meira Mattos (2001, p. 50, our translation) states that the fundamental objective of Brazilian Policy is “to vitalize the country’s human and geographic potential in order to build one of the most prosperous and respected nations in the world." Based on these principles – and aiming to guarantee national sovereignty – the 1988 Brazilian Federal Constitution establishes that the Armed Forces are intended "for the defense of the Homeland, the guarantee of the constitutional powers, and, on the initiative of any of these, the guarantee of law and order" (Brasil, 1988, Article 142, our translation).

Within this framework, the Brazilian Air Force (FAB) stands as the main component for the military expression of aerospace power. In fulfillment of the Air Force's constitutional mandate, the Air Force Command established, through DCA 11-45, the service's mission statement: "to maintain the sovereignty of the national airspace and to integrate the national territory, with a view to the defense of the homeland" (Brasil, 2018a, p. 20, our translation).

To accomplish its mission, the FAB relies on a strategic education framework aimed at developing and enhancing the knowledge, skills, and attitudes of its personnel, shaping the essential competencies of the military professional (Brasil, 2021a). In this context, the Air Force Academy (AFA)[3] plays a fundamental role in developing the competencies sought by the FAB in future aviator, quartermaster, and infantry officers.

Among the competencies expected of future aviator officers are the skills required to perform maneuvers, operate the aircraft and its systems within established limits, and apply air traffic rules, among others. Also included, among other attributes, are the attitudes necessary to carry out a flight safely and with emotional balance, both under instrument and visual conditions, while respecting the aircraft's operational limits (Brasil, 2021a).

Recognizing these capabilities as essential and indispensable for pilot training, Comaer has established the use of flight simulators as a preparation tool for Aviator Cadets in the operational field, aimed at supporting the employment of the Force (Brasil, 2018a).

The Aviator Officer Training Course (CFOAV), which lasts four years, is essentially based on subjects from the Administration program and Aeronautical Sciences program, in addition to military, sports, and military doctrine training. Air Instruction – when cadets learn to pilot aircraft – is provided in the second and fourth years of the course. In the second year, primary instruction is conducted on the T-25 Universal aircraft (figure 1), and in the fourth year, basic instruction is carried out on the T-27M Tucano aircraft (figure 2).

3. The AFA is a Military Organization (OM) of the Brazilian Air Force Command (Comaer) whose purpose is to train Officer Cadets for the Aviator Officer Corps (QOAv), the Quartermaster Officer Corps (QOInt), and the Air Force Infantry Officer Corps (QOInf) (Brasil, 2022a).

The flight instructor corps is composed of pilots from various operational squadrons of the FAB who, after several years serving at different air bases throughout the national territory, return to the AFA to contribute to the training of future pilots.

FIGURE 1
T-25 Universal Aircraft

Source: Air Force Agency. Retrieved from: https://www.flickr.com/photos/portalfab/10381224554/in/photostream/.

FIGURE 2
T-27M Tucano Aircraft

Source: Air Force Agency. Retrieved from: https://www.fab.mil.br/noticias/mostra/38353/MODERNIZADOS%20-%20Cerim%C3%B4nia%20de%20entrega%20das%20aeronaves%20T-27M%20acontece%20na%20Academia%20da%20For%C3%A7a%20A%C3%A9rea.

Starting in 2021, new flight simulators were implemented at the AFA with the aim of enhancing cadet aviator training, improving preparedness, and reducing operational costs. The systems were developed with the support of the Air Force's Directorate of Information Technology, the Aeronautics Computing Center of São José dos Campos, and the AFA, serving both primary and basic instruction needs.

Moreover, the analysis of the modernization of air instruction at the AFA is not limited to internal gains in operational efficiency; it must also be understood in light of Brazil's strategic needs in the contemporary geopolitical landscape. As part of the Global South, the country faces challenges such as the protection of the Amazon, the security of South Atlantic maritime routes, and the defense of its natural resources – demands that require modern and effective aerospace capabilities. Thus, advancements in the initial training of pilots provided by simulators have a direct impact on the operational readiness of the FAB and, consequently, on the strengthening of national aerospace power in the face of defense and international projection requirements.

Considering the constitutional mandate of the FAB and the influence of education in fulfilling that mission, this article poses the following research question: How can the implementation of flight simulators in the AFA's training program be considered an enhancement of the FAB's military capability, contributing to the employment of Brazilian aerospace power?

The objective of this study is to analyze the incorporation of new flight simulators into the air instruction of the AFA and their implications for the training of military pilots and the strengthening of Brazilian aerospace power.

To achieve the general objective, the following specific objectives are defined: i) Contextualize the adoption of new technologies in air instruction; and ii) statistically analyze the performance of cadet aviators before and after the introduction of the simulators, in the years 2020 and 2021.

To this end, the article is organized into an introduction, methodology, and theoretical framework, addressing the concepts of "aerospace power," "education," and "flight simulators." The results are then presented, followed by the final considerations.

2 METHODOLY

The study employed a quantitative method through statistical analysis of data related to air instruction at the AFA, as well as a bibliographic and documentary review of references relevant to the topic. According to Lakatos and Marconi (2003), the statistical method consists of reducing phenomena to quantitative terms and performing statistical manipulation, thus allowing the measurement and comparison of variables in order to verify relationships between phenomena and obtain generalizations about their nature, occurrence, or meaning.

The data were obtained from the AFA's Education Division (DE), the sector responsible for recording all grades, averages, and rankings of cadets, as well as data on the various subjects of the training courses. The dataset comprises the final average scores achieved by cadets upon completing primary flight instruction in 2020 and 2021, as well as the number of cadets who failed or were discharged in both years. Two distinct periods were considered: before 2020 and after 2021 the implementation of flight simulators in cadet training.

It is important to note that the courses offered in 2020 and 2021 followed the same evaluation parameters, in accordance with the AFA's Instruction and Operational Maintenance Program (Brasil, 2020, 2021c). It should also be emphasized that the number of instructional missions and flight hours per cadet remained unchanged, with the only difference between the periods being the use of simulators to complement actual flights.

Inclusion criteria for the data analysis were the availability of records for the period and the completeness of the necessary data for the variables of interest. Furthermore, the data were anonymized to ensure participant privacy and avoid any possibility of personal identification.

Additionally, a bibliographic review was conducted, which, according to Gil (2002), consists of gathering information from already prepared materials, mainly books and scientific articles. Consulting bibliographic materials made it possible to deepen the theoretical understanding of the topic, establish relationships, and substantiate the research objectives. Thus, the bibliographic research method played a key role in conducting this study.

According to Gil (2002), documentary research aims to analyze documents that have not yet been analytically processed. This research technique was applied to collect relevant information from procedure manuals, legislation, technical regulations, and other documentary materials important for understanding the practical and normative aspects of the topic under study.

3 THEORETICAL FRAMEWORK

3.1 Aerospace power

The attainment of air superiority precedes and surpasses other domains of warfare and should be pursued whenever the necessary means are available (Warden III, 1998). From this premise, it can be inferred that nations must maintain the modernization of their aerial platforms, since, according to Warden III (1998), ever since the German attack on Poland in 1939, no country has won a war in the face of the enemy's air superiority, and no defense has held against an opponent controlling the skies.

German General Erwin Rommel, popularly known as "The Desert Fox," observed that "anyone who has to fight, even with the most modern weapons, against an enemy with total control of the air, fights like a savage against a modern European army" (Rommel, 1953, p. 285). In light of this, it is evident that technological advancements in military aviation are paramount for maintaining control of the air.

Regarding military technology more broadly, the *Manual of Fundamentals of the Brazilian Army Land Military Doctrine* emphasizes: "the need for a force with new operational capabilities, equipped with highly advanced technology, supported by a constantly evolving doctrine, and staffed by highly trained and motivated personnel" (Brasil, 2022d, p. 1-2, our translation).

Concerned with the constant evolution of military technologies across nations, states seek to develop their defense capabilities. This evolution is highlighted by theorists such as John Ashley Warden III, Daniel Byman, Matthew Waxman, and Eric V. Larson, who emphasize the importance of technological advantages – particularly in air forces, which are critical for coercion and deterrence.

In modern times, aerial platforms are increasingly advanced and possess greater lethality, making them essential for the strengthening and maintenance of national sovereignty. Fifth-generation fighter aircraft stand out for their stealth technology, also known as low-observable technology, which makes the aircraft difficult to detect by radar, thereby enhancing air superiority capabilities. The technological leap that makes a fifth-generation aircraft superior to others is illustrated by Lockheed Martin, a U.S.-based multinational in the aerospace and defense industry: "The 5th Generation F-22's unique combination of stealth, speed, agility, and situational awareness, combined with lethal long-range air-to-air and air-to-ground weaponry, makes it the best air dominance fighter in the world" (Lockheed Martin, 2023).

To date, only three countries possess the technology to effectively produce this generation of aircraft: the United States of America (with the Lockheed Martin F-22 Raptor and F-35 Lightning II); the People's Republic of China (with the Chengdu J-20 and Shenyang J-31); and the Russian Federation (with the Sukhoi Su-57).

Tactical Datalink technology is used to establish secure communications between platforms and can be considered a key factor in 21st-century military advancements. As highlighted by the British company BAE Systems: "Tactical Datalinks are secure military communication standards that exchange tactical data between platforms and commands" (Bae Systems, 2023). Clearly, nations that master these capabilities gain significant advantages in operational theaters, which is one of the reasons for the acquisition of the F-39 Gripen under the FAB's FX-2 Project.

Analyzing the Brazilian context, the acquisition of the F-39 Gripen by Comaer is justified when considering the operational and geopolitical factors of modern warfare. The F-39 employs Network-Centric Warfare (NCW) capabilities through its advanced modular electronic warfare system and low-observable operability, which provide enhanced pilot protection and situational awareness (Borges, 2018).

It is also important to note its capacity to operate cutting-edge weaponry, such as the European radar-guided beyond-visual-range Meteor missile and the German Iris-T system, as well as its adaptability to deploy domestically produced armaments. This feature facilitates the technology transfer program to the Brazilian aerospace industry, aiming for future domestic production of the aircraft.

The combination of these factors provides Brazil with a significant leap in the employment capacity of its aerospace power and strengthens the development of the national industry – a fundamental pillar for the long-term sustainability of the Armed Forces.

According to the United Kingdom (2009), the combination of the F-39 Gripen aircraft and the Meteor missile system used by the FAB closely approximates the F-22 and AIM-3 combination employed by the United States Air Force. The acquisition of the Gripen represents a milestone for the national defense system, as Brazil not only acquires a highly capable and technologically advanced deterrent platform but also positions itself as a key player in the development of fighter aircraft, aligning with the standards of modern warfare.

The FX-2 Project presents unique characteristics; therefore, preparation for the arrival of this aircraft must address its specific requirements. Since the beginning of the aircraft's acquisition, Anápolis Air Base has been preparing to meet the operational needs of the new aircraft, not only through the physical, intellectual, and operational training of pilots but also via the updating and renovation of the base's infrastructure.

Among the new structural implementations are the construction of a photovoltaic plant, renovations of hangar facilities, aircraft apron and alert dispersal areas, a maintenance hangar for fighter aircraft, and buildings to host the F-39 units (1st GDA and 1st/6th GAV), in addition to improvements in the simulator building. Operational and safety aspects are evaluated in all these implementations to ensure the full deployment of the Gripen system (Galante, 2021).

3.2 Education

The technological transformations in the aerospace industry are not limited to aerial vectors; they also affect, among other areas, the sector responsible for training and educating military pilots. Modernization in the aeronautical sector, for example, has increasingly driven the renewal of teaching methods, incorporating advanced technologies to promote more effective and efficient learning processes.

Gagné (1983, p. 2 apud Sousa, 2016) emphasizes that learning involves a change in a person's disposition, which manifests itself as an alteration in behavior, generally resulting in an increased capacity for performance. In the case of military pilots, this change is essential to ensure they are prepared not only to face the challenges and risks inherent to military activity but also to guarantee the safety of missions.

Kolb (1984), human development is continuous, and the process of building knowledge occurs through experience. In other words, behavioral change would occur through constant interaction between theoretical and empirical processes.

In flight instruction, theoretical processes occur through preparatory studies, classes, and assessments, aiming to develop the pilot's knowledge. Experience, in turn, develops through instructional flights and the use of flight simulators (Sousa, 2016). Wise, Hopkin and Garland (2010, p. 442) explain, at this point, that

> as a tool within a broader training program, it provides an excellent training environment that is well accepted by the aviation community. It provides an opportunity for initial qualification or requalification in type and is a means for experiencing critical conditions that may never be encountered in flight.

In the context of pilot training and that of future pilots, flight instruction simulations are carried out through an association of software and hardware known as a "flight simulator".

3.3 Flight simulator

Flight simulators, or Flight Training Devices (FTD), can be defined as electronic devices that simulate an aircraft's flight conditions in a virtual environment. They are used to train pilots and help them develop skills in different scenarios. Allerton (2009) states that simulators are used to reduce costs and provide an effective form of training for pilots without the need for exposure to unnecessary risks.

Simulators use a combination of hardware and software to replicate the instrument controls of a real aircraft. These devices can simulate a wide range of situations, from routine flights to adverse conditions such as engine failure, turbulence, and extreme weather. More modern simulators can be connected to computer networks, thus enabling collaborative pilot training in real time.

In this context, the FAB has sought to establish teaching doctrines and infrastructure capable of adapting to the pilot's preparation needs. The Aeronautics Military Strategic Plan (Pemaer) for the period between 2018 and 2027 already foresaw the use of simulation equipment as one of the guidelines for ensuring personnel readiness (Brasil, 2018b).

Thus, greater attention was given to the teaching capacity through immersion in a virtual environment. The Aeronautics General Staff (EMAER) began designating a series of projects to be developed by the FAB's Major Commands, contributing to the enhancement of teaching capabilities (Brasil, 2021b).

3.3.1 Flight simulators in the Air Force Squadrons

In a more specific scenario, several military organizations have sought to enhance their pilots' immersion in a controlled virtual environment. The training of A-29 Super Tucano aircraft pilots, for example, includes the use of simulation software for specialization and operational advancement in the aircraft.

The Operational Specialization Course Program for Fighter Aviation (Brasil, 2021d), which guides the initial training of fighter aircraft pilots, establishes approximately 29 hours of simulator use for trainees, who must also complete around six missions per quarter for operational maintenance. The Operational Advancement Course Program for the A-29 Aircraft (Brasil, 2021e), responsible for the operational progression of already qualified pilots, stipulates about 50 hours of simulator use to achieve the highest levels of proficiency in the aircraft.

For the training of F-5M Tiger II aircraft pilots – currently Brazil's main aerial vector – the Operational Advancement Program (PEVOP F-5M) (Brasil, 2022b) sets approximately 60 hours of virtual environment missions to better prepare service members. Furthermore, even at a doctrinal and operational development stage, based on initial information collected from the 1st Air Defense Group (1º GDA),[4] the use of simulators has a significant impact on the training and operational maintenance of F-39 Gripen pilots.

4. The 1st Air Defense Group (1º GDA) is an organization of the Comaer, headquartered at the Anápolis Air Base, whose purpose is to conduct the preparation and employment of its assets with a view to carrying out Air Force Actions. It is currently the unit that houses the F-39 Gripen aircraft and its support infrastructure (Brasil, 2022c).

Thus, with the aim of providing appropriate instructional methods and ensuring the continuous development of pilots throughout the training phases, as well as separating training and operational maintenance according to specific operational applications, the Operational Advancement Program for the F-39 Gripen aircraft was divided into three subprograms: the Operational Training Subprogram, the Operational Maintenance Subprogram, and the Specific Qualification Subprogram (Brasil, 2023a). The Operational Training and Operational Maintenance Subprograms include 26 and 14 simulator missions, respectively.

In this way, it can be seen that the use of simulation software for flight instruction will be of great relevance to the operational readiness of the 1st GDA's air defense pilots.

3.3.2 Flight simulators at the AFA

Although the AFA has had simulators since 1991, these initially served only basic instruction in T-27 Tucano aircraft and did not cover primary training conducted in the T-25 Universal aircraft. Paradoxically, the primary training phase represented the highest attrition rate (number of dropouts) during the training period, with an average of 30% of cadets leaving the course in 2018 due to failure (Gonçalves, 2018). Additionally, according to Costa (2010), the average failure rate in primary instruction at the 2nd Air Instruction Squadron was 23%, based on the years 2000 to 2007. Considering a historical average class size of approximately 140 cadet pilots, around 35 were removed from the course annually. At the same time, the simulators used for basic instruction in T-27 Tucano aircraft were inefficient and, in some ways, negatively impacted cadet performance during certain phases of flight training. This was because the systems at the time lacked image projection and were in poor condition, with malfunctions in the movable hydraulic platform (Gonçalves, 2018).

Herculian (2017) states that, when comparing flight records of cadets in the T-27 course during the use of older simulators versus real flight, there was an 18.55% decrease in flight grades, contrary to the system's objective of simulating actual aircraft flight. The Aeronautics Computing Center (CCA-SJ), in a Technical Advisory Visit to the Simulators (Vatsim), concluded that the AFA simulators at the time did not have the technical conditions to provide positive training transfer; in fact, they produced negative transfer and undesirable results (Herculian, 2017).

The Air Operations Division of the AFA, based on these analyses, identified two main issues: the lack of a flight simulator capable of supporting primary training in the T-25 Universal aircraft and a deficient flight simulation infrastructure for T-27 Tucano instruction.

In response to these findings, the AFA, in collaboration with the CCA-SJ, sought to develop new simulation training tools. This cooperation led to the creation of two main systems: the T-4000, designed specifically for T-27 instruction, and the T-2000, capable of supporting flight instruction in both the T-25 and T-27 aircraft.

The T-2000 simulator (figure 3), the focus of this research, features customizable hardware using Force Feedback technology. This system allows a single platform to support both primary training in T-25 Universal aircraft and basic training in T-27 Tucano aircraft. The software also incorporates visual reality glasses and allows simulator network connectivity, enabling the operation of multiple simulated aircraft in the same space and the presence of a flight controller, providing the pilot with conditions closer to real flight (Inforzatto, 2020).

FIGURE 3
T-2000 Simulator

Source: Air Force Agency. Retrieved from: https://www.fab.mil.br/noticias/mostra/35997/ENSINO%20-%20FAB%20inaugura%20novo%20sistema%20de%20simulador%20de%20voo%20para%20instru%C3%A7%C3%A3o%20dos%20Cadetes%20Aviadores.

The T-4000 simulator (figure 4), designed exclusively for basic training in the T-27 Tucano, is a virtual immersion platform that simulates an aircraft cockpit, featuring a set of screens providing a 180° view of the training environment. This platform offers an experience closer to that of an actual aircraft, including a dedicated system for simulating emergencies integrated with the cockpit systems (Pandini, 2022).

FIGURE 4
T-4000 Simulator

Source: Air Force Agency. Retrieved from: https://www.fab.mil.br/noticias/mostra/39635/TECNOLOGIA%20-%20AFA%20inaugura%20novo%20Simulador%20de%20Voo%20para%20instru%C3%A7%C3%A3o%20de%20Cadetes%20Aviadores.

Currently, the missions are formative rather than summative, meaning that the grades assigned during training missions are not counted for classification or failure purposes. In addition to mandatory missions, the simulators are available for cadets to use freely for training at pre-scheduled times or after the daily routine (Brasil, 2023b).

In practice, simulator training is conducted in a manner similar to real flights, with one-hour instructional missions and the presence of a flight instructor who evaluates performance and provides guidance to the cadet.

Considering the focus of this research on primary training in the T-25 Universal, it is noteworthy that in 2020 and 2021, during the initial flight phase (pre-solo), each cadet completed 14 real instructional flights. In 2021, in addition to real flights, each cadet completed at least 15 simulated flights. Thus, with the use of the T-2000 simulators, cadets gained more practice and, consequently, more opportunities for learning.

4 RESULTS AND DISCUSSION

The statistical analyses of this study were conducted using data obtained from the AFA's DE, relating to the number of cadets who failed, cadets who were dismissed, and the final average grades of all course graduates in 2020 and 2021.

Initially, information regarding failures and dismissals was analyzed. According to the AFA Instruction and Operational Maintenance Program for the years 2020 and 2021 (Brasil, 2020, 2021c), a cadet is considered to have failed the course if they receive a grade of one on a single flight evaluation or a grade of two on three flight evaluations during the learning phase.

A cadet deemed to have failed may be dismissed (permanently removed) or may have the opportunity to re-enter the course and attempt to pass, depending on a specific review by the AFA Commander. In 2020, of a class of 152 cadets, 121 completed the course, with 31 failing and 19 dismissed. In 2021, the class had 134 cadets, with 119 graduates, 15 failing, and 13 permanently removed.

It is important to note that in 2020 and 2021, the primary course took place during the first year of AFA training and covered only the pre-solo phase, i.e., 14 instructional missions. The courses in both years followed the same standards, with identical flight hours and aircraft. Moreover, the instructors in both years underwent the same training and standardization for flight instruction.

For data analysis, two software tools were used: Jasp and RStudio. Jasp is an open-source data analysis software offering standard and advanced statistical techniques, developed by a research group at the University of Amsterdam (Damásio, 2022). RStudio is an Integrated Development Environment (IDE) that uses the R programming language to organize data and generate graphs (Noleto, 2022).

To analyze the data on failures and dismissals, a z-test for proportions with continuity correction was conducted. Using RStudio, the point estimates for the proportion of cadets who failed were $p_1 = 0.2039$ and $p_2 = 0.1119$; for the proportion of dismissed cadets, the estimates were $p_1 = 0.1250$ and $p_2 = 0.0970$.

For failures, $X^2 = 3.8111$, df = 1, p-value = $0.9745 > \alpha = 0.05$ for a one-tailed alternative hypothesis H_1 that the proportion of failures in 2020 (p_1) is less than the proportion in 2021 (p_2), i.e., $p_1 < p_2$. For dismissals, $X^2 = 0.3149$, df = 1, p-value = $0.5746 > \alpha = 0.05$ for a two-tailed alternative hypothesis H_1 that the proportion of dismissals in 2020 (p_1) differs from that in 2021 (p_2), i.e., $p_1 \neq p_2$.

Based on the hypothesis tests at a significance level of $\alpha = 0.05$, there is no evidence to reject the null hypothesis in favor of the alternative hypothesis that the proportion of failures was higher in 2021. Similarly, there is no evidence at the $\alpha = 0.05$ level that the proportions of dismissals differ significantly.

Thus, considering the analysis of the proportions of failures and dismissals, it can be stated that there was a reduction in failures between 2020 and 2021, providing initial indications of the positive influence of simulators as a complementary tool in flight instruction at AFA.

On the other hand, regarding dismissals, it is argued that the simulator did not have a significant effect, as the decision to allow cadets to continue the course after failing is made by the AFA Commander and is based on various subjective factors related to students' academic performance.

To complement the analyses, descriptive statistics of the average flight grades for the courses conducted in 2020 and 2021, as well as empirical density graphs and box plots, are presented in table 1 and figure 5. Finally, a normality test was conducted on the grade data.

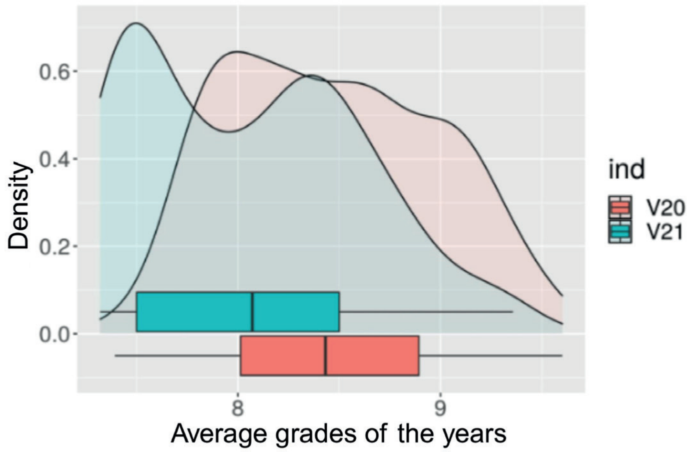
According to Fávero et al. (2009, p. 51, our translation), "descriptive statistics allow the researcher a better understanding of data behavior through tables, graphs, and summary measures, identifying trends, variability, and outliers".

TABLE 1
Descriptive statistics

	Flight20	Flight21
n	121	119
Median	8.432	8.071
Mean	8.464	8.060
Standard Error	0.047	0.050
Standard Deviation	0.513	0.550
Coefficient of Variation	0.061	0.068
Variance	0.263	0.302
Skewness	0.192	0.386
Standard Error of Skewness	0.220	0.222
Kurtosis	-0.997	-0.849
Standard Error of Kurtosis	0.437	0.440
Range	2.207	2.036
Minimum	7.393	7.321
Maximum	9.600	9.357

Source: Data provided by the AFA.
Authors' elaboration

FIGURE 5
Density and box plot graph



Source: Data provided by the AFA.
Authors' elaboration.

The combined analysis of the descriptive statistics in table 1 and figure 5 shows empirical curves that deviate from normality, differing primarily in terms of skewness, as the calculated value for 2021 is roughly twice that of 2020. Mean and median values are approximately equal within the same year but differ by about 0.4 between different years.

Qualitatively, the relative differences between medians (and consequently means) can be observed directly in the box plots. However, quantitative verification of these differences should be accompanied by a t-test if the data meet the required assumptions, or by a non-parametric test otherwise.

Considering differences between the means, the Shapiro-Wilk test was employed to test the null hypothesis H_0 that the data, individually, come from a normal distribution versus the alternative hypothesis H_1 that the data do not come from a normal distribution. The results – W = 0.9664, p-value = 0.004064 for the 2020 data, and W = 0.9322, p-value = 0.0000 for the 2021 data – provide evidence to reject the null hypothesis in favor of the alternative in both cases, indicating that the data are not normally distributed. Thus, the use of a t-test for comparing the two samples should be replaced by an alternative test that does not require normality assumptions. This topic will be addressed in future studies.

Analyzing the average grades between the years, the mean and median grades were higher in 2020, indicating that there was no overall increase in flight grades after the simulators were introduced in 2021. This observation may be associated with improved training and reduced failures. In 2020, without simulator training, cadets with lower performance were likely to fail. In 2021, with simulator use, many cadets who would have performed poorly were able to train in simulators, improving their performance and avoiding failure. Consequently, these cadets may have completed the course with lower grades, resulting in a lower overall class average.

Although further in-depth analysis is warranted – requiring additional years of instruction with simulators and the inclusion of more variables for observation – initial evidence indicates that the implementation of simulators has positively influenced cadet training, making the course more efficient (with fewer failures) and providing pilots with initial exposure to simulated flight training, preparing them for the operational reality of the FAB.

It can be concluded that the updates described in this research regarding the initial training of military pilots at the AFA prepare future officers for real flight conditions, with reduced costs and greater versatility. These updates also align with the modernization trends of the Brazilian Air Force in its main deterrent aircraft (A-29 Super Tucano, F-5M Tiger II, and F-39 Gripen), supporting the enhancement of Brazilian aerospace power.

5 FINAL CONSIDERATIONS

This study analyzed the impact of modernizing training at the AFA, focusing on the incorporation of new flight simulators into flight instruction. The research sought to understand how this modernization contributes to the training of military pilots and, consequently, to the strengthening of Brazilian aerospace power.

The results obtained from comparing 2020 (without simulators in primary instruction) and 2021 (with the implementation of the T-2000 simulators) indicate a reduction in the failure rate of cadet pilots. Although no increase in final flight grades was observed, it is reasonable to consider that the availability of simulator-based training allowed cadets with initially lower performance to meet the minimum passing requirements, increasing course efficiency and reducing attrition throughout the training process.

The adoption of flight simulators at the AFA immerses future officer pilots in a learning environment aligned with the operational practices of the FAB, which already extensively employs this resource in attack and fighter aircraft squadrons, such as the A-29 Super Tucano, F-5M Tiger II, and F-39 Gripen. This early integration helps accelerate the adaptation of new pilots to highly complex systems, enhancing operational readiness.

Although this study is limited to the analysis of flight instruction data at the AFA, the findings suggest that the modernization of initial training through simulators positively impacts the operational capacity of the Air Force. When projected across overall air operations, this gain reinforces the contribution of high-quality training to maintaining airspace sovereignty and advancing Brazilian aerospace power.

Beyond operational impact, the use of simulators represents a strategic investment for Brazil. By reducing training costs, increasing safety, and allowing greater flexibility in pilot preparation, this technology strengthens the defense industrial base, stimulates innovation, and reduces external dependencies – decisive factors for strategic autonomy in the Global South. Emerging countries have adopted similar strategies to maximize military capabilities under budgetary constraints, and Brazil positions itself competitively in this context.

By aligning the modernization of pilot training with the country's strategic demands, simulator use at the AFA extends beyond the educational realm, directly connecting to threat deterrence, regional integration, and Brazil's enhanced presence in international security and defense forums. This convergence reinforces Brazil's role as a relevant actor in the strategic balance of the twenty-first century and as a reference in adopting technological solutions to strengthen defense in the Global South.

Finally, it is recommended to continue monitoring results in the coming years, incorporating new cadet cohorts and variables to enable more robust statistical analyses. This will not only validate the trends observed here but also provide concrete support for strategic decisions regarding investments in instructional technology within the scope of National Defense.

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