Science, Technology, and Innovation (ST&I) in the Armed Forces: Self-Sufficiency or Outsourcing?

Date of submission: July 6, 2025 **Date of approval:** November 27, 2025

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Executive Summary

The organization of and investment in Science, Technology, and Innovation (ST&I) within the Armed Forces are structural conditions for Brazil's strategic autonomy. Drawing on historical evidence and international comparison, this policy paper shows that neither full self-sufficiency nor broad outsourcing of defense ST&I is suited to the Brazilian reality. This reality is marked by low defense effort – around 1.08% of GDP, compared with higher levels in powers such as the United States, France, and Russia, as well as the 5% of GDP commitment undertaken by NATO allies by 2035 – and by a strong concentration of the budget on personnel and operating costs, to the detriment of investment and R&D (SIPRI, 2024; Macrotrends, 2024; OTAN, 2025; Brasil, 2023; 2025). An analysis of Brazil's national trajectory – including IME, ITA, IPqM, Embraer, and the Navy Nuclear Program – and of strategic projects such as PROSUB, Gripen, KC-390, and SISFRON, compared with the French model, which emphasizes state self-sufficiency in sensitive sectors, and the U.S. model, based on structured outsourcing through the Defense Industrial Base and universities, coordinated by institutions such as DARPA, indicates that Brazil already operates, in practice, a hybrid model. This model combines the pursuit of sovereignty in critical areas – nuclear technology, radars, cyber capabilities, and missiles – with partnerships and technology transfer in complementary domains, within the framework of the government–Defense Industrial Base–university Triple Helix (Melo, 2015; Etzkowitz; Zhou, 2017; Andrade, 2019; Brasil, 2020; DARPA, 2024; CRS, 2021; Moura, 2022; Souza, 2022). The main finding is that the conscious consolidation of this hybrid model – supported by a gradual increase in defense spending to a minimum level of 2% of GDP with greater predictability, by internal budgetary reallocation in favor of investment and ST&I, and by the strengthening of dual-use capabilities – represents the most realistic and effective strategy to reduce external vulnerabilities, strengthen the Defense Industrial Base, and position Brazil competitively in the technological and geopolitical landscape of the twenty-first century.

Keywords: defense; science and technology; innovation; sovereignty; Defense Industrial Base.

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1 ANALYSIS OF THE PROBLEM AND ITS IMPLICATIONS FOR DEFENSE

1.1 CONTEXT AND RELEVANCE OF THE TOPIC

The organization of and investment in ST&I within the Armed Forces are essential to ensuring strategic autonomy, sovereignty, and power projection (Brasil, 2020). Global technological competition, driven by advances in critical technologies such as Artificial Intelligence (AI), hypersonic systems, and cyber warfare, requires Brazil to adopt a clear position on the prioritization of defense investment, despite budgetary constraints and unpredictability (SIPRI, 2024).

1.2 HISTORY OF ST&I IN THE BRAZILIAN ARMED FORCES

The development of Science, Technology, and Innovation (ST&I) in the Brazilian Armed Forces is closely tied to state formation and to the pursuit of autonomous defense capabilities in a vast territory exposed to external pressures. During the colonial period, defense-related ST&I was virtually nonexistent, limited to coastal fortifications built with local labor and imported knowledge (Melo, 2015).

The arrival of the Portuguese Court in 1808 led to the establishment of the Royal Military Academy in 1810, the precursor of the Military Institute of Engineering (IME), and helped consolidate the training of military engineers (Brasil, 2020). Under the Empire, war arsenals were created, including the Rio de Janeiro Navy Arsenal (AMRJ), but external dependence on armaments persisted (Amarante, 2012). During the Old Republic and the interwar period, modernization relied on imports and foreign missions, such as the French Military Mission of 1919, without creating an autonomous ST&I structure (Andrade, 2019).

World War II and the postwar period made the need for technological autonomy increasingly clear, prompting the creation of the Aeronautics Institute of Technology (ITA) in 1950, the Military Institute of Engineering (IME), and the Navy Research Institute (IPqM), both in 1959. These institutions became milestones in technical training and in the development of Brazil’s defense industry (Matos; Ferreira, 2020). From the 1960s to the 1980s, Brazil invested in strategic sectors, including Embraer, founded in 1969, and the Navy Nuclear Program (PNM), launched in 1979, as part of a broader effort to reduce external dependence (Amarante, 2012; Brasil, 2020).

The creation of the Ministry of Defense in 1999 consolidated the governance of strategic programs and strengthened coordination among the Defense Industrial Base (DIB), universities, and research institutes, in line with the National Defense Strategy (Brasil, 2020). In the twenty-first century, projects such as PROSUB, Gripen, KC-390, and SISFRON stand out for seeking to combine technological sovereignty with the strengthening of the DIB and the reduction of external dependence (Moura, 2022; Souza, 2022).

Brazil's current approach to defense ST&I follows the Triple Helix model, integrating government, the DIB, and universities, with a focus on critical areas such as radars, cyber warfare, nuclear propulsion, and command-and-control systems, despite budgetary constraints (Etzkowitz; Zhou, 2017; Andrade, 2019). Table 1 summarizes the historical evolution of defense ST&I in Brazil.

Table 1 – Historical Evolution of Defense ST&I in Brazil

Períod	Historical milestone	Relevant characteristics and advances
Colonial Brazil (1500–1822)	Coastal fortifications	Coastal defense based on imported technologies and artisanal construction; absence of autonomous ST&I.
Empire (1822-1889)	Establishment of the Royal Military Academy (1810) and institutionalization of the AMRJ (1808).	Initial training of military engineers; structured naval maintenance and construction; early institutional advances in defense ST&I.
Old Republic and interwar period (1889–1939)	French Military Mission (1919)	Doctrinal and technical modernization; importation of armaments; consolidation of war arsenals.
World War II and postwar period (1939–1964)	Brazilian Expeditionary Force (FEB), establishment of ITA (1950), IME and IPqM (1959)	Consolidation of technical training and research centers; beginning of strategic industrial planning, especially in the aeronautical sector.
Military Regime (1964–1985)	Founding of Embraer (1969), beginning of PROSUB (1979)	Pursuit of autonomy in strategic sectors, including nuclear, aeronautical, and land domains; strengthening of the Defense Industrial Base.
Redemocratization and the 1990s	Establishment of the Ministry of Defense (1999)	Integration of the Armed Forces; strategic alignment and beginning of defense programs integrated with the DIB.
Twenty-first century	PROSUB, Gripen, KC-390, SISFRON.	Advances in sensitive technologies; adoption of the Triple Helix model; strengthening of partnerships among the DIB, universities, and government.

Source: prepared by the author based on Amarante (2012), Brasil (2020), Matos and Ferreira (2020), Melo (2015), Moura (2022), Souza (2022), and Etzkowitz and Zhou (2017).

1.3 CURRENT DEFENSE BUDGETS IN BRAZIL AND WORLDWIDE

Defense budgets reflect each nation's strategic priorities, directly shaping its ability to maintain operational readiness, project power, and invest in Science, Technology, and Innovation (ST&I) in the defense sector (Brasil, 2023). The level of defense investment is a key factor in the development of autonomous capabilities in sensitive technologies, while also enabling modernization programs and technology-transfer initiatives (Melo, 2015; Andrade, 2019).

In 2023, the countries that invested the largest shares of their GDP in defense were Russia (5.9%), the United States (3.5%), India (2.4%), and France (1.9%). China allocated 1.6% of its GDP to the sector, while Venezuela (1.3%) and Brazil (1.08%) maintained lower levels, reflecting economic constraints and differing priorities in their strategic agendas (SIPRI, 2024; Macrotrends, 2024). Table 2 consolidates data on defense budgets and their respective shares of GDP for Brazil and other actors in 2023.

Table 2 – Comparative Defense Budget (2023)

Country/Region	Total spending (US$ billions)	% of GDP
Russia	109.0	5.9%
United States	877.0	3.5%
India	81.0	2.4%
France	58.0	1.9%
China	296.0	1.6%
Venezuela	2.5	1.3%
Brazil	22.9	1.08%
Latin America	65.4	-
World	2,387	-

Source: prepared by the author based on SIPRI (2024), Macrotrends (2024), and Brasil (2023; 2025).

Comparative analysis shows that countries allocating higher shares of GDP to defense are better positioned to sustain robust ST&I programs, ensure technological sovereignty in sensitive areas, and incorporate innovations more rapidly (DARPA, 2024; CRS, 2021). The United States, for example, channels substantial investment into ST&I through institutions such as DARPA, fostering disruptive innovation in close coordination with the DIB and universities while preserving its global technological leadership (DARPA, 2024). Russia, in turn, maintains autonomous capabilities in strategic systems such as nuclear propulsion, hypersonic missiles, and cyber defense, in line with its geopolitical context (SIPRI, 2024).

China, despite allocating a moderate share of GDP to defense, invests large amounts in absolute terms, enabling advanced programs in areas such as artificial intelligence, intercontinental ballistic missiles, and cyber warfare (Macrotrends, 2024). India, with defense spending at 2.4% of GDP, has prioritized reducing external dependence and strengthening its DIB through indigenous projects and strategic international partnerships (SIPRI, 2024).

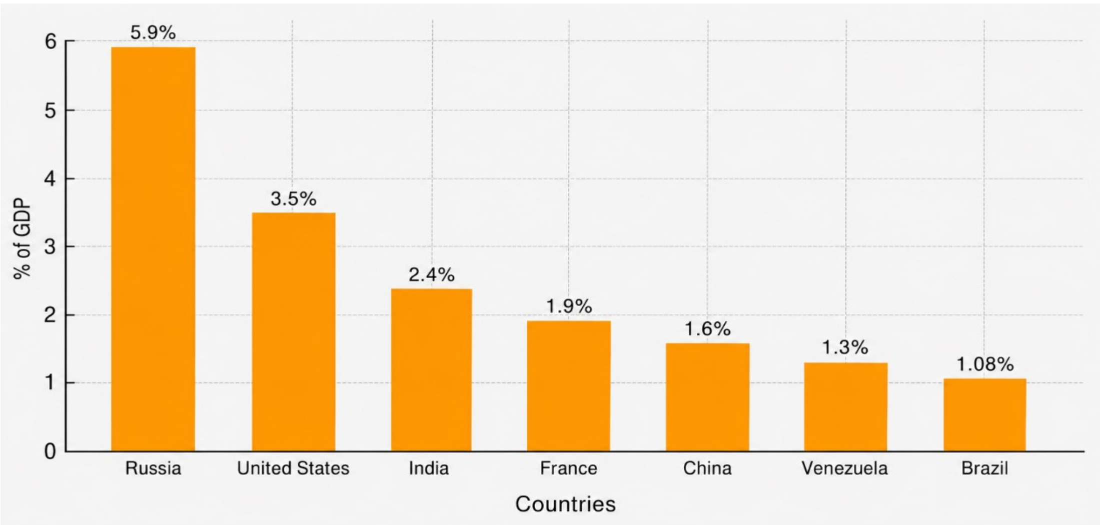
In Brazil's case, allocating 1.08% of GDP to defense – less than Venezuela – limits the scope and pace of ST&I programs. This makes it necessary to focus selectively on sensitive technologies while pursuing structured partnerships with the DIB and universities to absorb complementary technologies, maximize available resources, and preserve strategic capabilities (Etzkowitz; Zhou, 2017; Andrade, 2019).

Brazil's low level of defense spending becomes even clearer when compared with recent commitments made by NATO allies. At their 2025 meeting, member countries committed to investing 5% of GDP annually in core defense requirements and defense- and security-related expenditures by 2035 (OTAN, 2025).

A proposed constitutional amendment currently under discussion in the Brazilian National Congress (PEC No. 55/2023) seeks to guarantee the Ministry of Defense a minimum annual budget equivalent to 2% of GDP. The measure aims to increase investment in the sector, provide greater predictability for defense spending, and prevent cuts during periods of fiscal crisis (Brasil, 2023).

The following figure clearly illustrates the disparity among the countries analyzed in defense investment as a share of GDP, providing a reference for understanding Brazil's challenges in financing defense ST&I.

Figure 1 – Defense spending as a share of GDP in 2023



Source: prepared by the author based on Brasil (2025), SIPRI (2024), and Macrotrends (2024).

The gap between NATO allies' commitment – reaffirmed in 2025 — to invest 5% of GDP in defense and security expenditures by 2035 (OTAN, 2025), and Brazil's defense spending, which remains around 1.08% of GDP (SIPRI, 2024; Macrotrends, 2024), points to structural and conceptual differences in how nations understand the role of defense in their strategic and budgetary agendas.

In NATO countries, defense spending is broadly distributed across operating costs, personnel, and investment, with emphasis on research, development, and the acquisition of new systems. The 5% of GDP commitment seeks to ensure operational and technological sustainability, covering not only the cost of maintaining forces at readiness but also the continuous renewal of capabilities, equipment modernization, and direct funding for R&D in critical technologies such as artificial intelligence, autonomous systems, cyber warfare, advanced propulsion, and hypersonic missiles (DARPA, 2024; CRS, 2021). A significant share of this spending is therefore channeled into capital investment and innovation, with the DIB and universities playing a central role (Etzkowitz; Zhou, 2017).

By contrast, in Brazil, most of the defense budget is absorbed by mandatory personnel and operating expenses, leaving limited room for effective investment in ST&I (Brasil, 2023; 2025). According to data from the Ministry of Defense, more than 80% of the budget is allocated to salaries, pensions, and infrastructure maintenance, while only a residual share is directed toward structural investment or technological innovation (Brasil, 2023; 2025; Andrade, 2019). This budgetary profile reflects a model focused on operational sustainment rather than technological transformation, limiting the progress of strategic projects and reducing the country's ability to keep pace with innovation trends observed among military powers (Melo, 2015; Brasil, 2020).

Geopolitical context also helps explain differences in investment intensity. NATO countries face direct and immediate threats in their strategic environment, which supports higher levels of spending and a political commitment to maintaining modern, interoperable forces. Brazil, by contrast, is located in a relatively stable region and tends to adopt a more reactive and budget-constrained posture, prioritizing fiscal stability over long-term investment in defense and innovation (Melo, 2015; Andrade, 2019).

As Etzkowitz and Zhou (2017) emphasize, however, sustained investment in defense ST&I translates not only into military power but also into industrial and technological competitiveness, with direct effects on the Defense Industrial Base (DIB) and the national economy. Maintaining spending below 1.1% of GDP, without mechanisms that ensure predictability, therefore undermines Brazil's technological autonomy and sovereign innovation capacity, deepening external dependence in sensitive areas and restricting the development of dual-use technologies.

In this regard, Proposed Constitutional Amendment No. 55/2023, which seeks to raise the minimum level of defense investment to 2% of GDP, represents a fundamental step toward repositioning the country at a level consistent with its geopolitical scale and strategic ambitions (Brasil, 2023). Even if approved, however, this increase must be accompanied by a reformulation of the internal structure of resource allocation, redirecting a significant share of operating costs and mandatory expenditures toward productive and technological investment; otherwise, the higher percentage may fail to translate into real gains in defense capabilities.

In summary, while NATO allies use their defense budgets as instruments of innovation and technological power, Brazil still concentrates its spending on structural maintenance and personnel, revealing a mismatch between the amount invested and the strategic quality of resource allocation. Overcoming this gap requires not only increasing the share of GDP allocated to defense, but also undertaking a structural budgetary reconfiguration capable of ensuring stable and continuous resources for the scientific, technological, and industrial development that underpins sovereignty and deterrence in the twenty-first century.

1.4 THE BRAZILIAN MODEL OF DEFENSE S&T&I AND ITS STRATEGIC PROJECTS

Brazil’s budgetary constraints, combined with its continental scale and extensive defense requirements, have led the country to adopt a hybrid model for defense science, technology, and innovation (S&T&I). This model combines self-sufficiency in critical areas with structured partnerships in complementary technologies (Etzkowitz; Zhou, 2017; Andrade, 2019). Brazil’s National Defense Strategy (END) identifies sensitive sectors—including nuclear propulsion, radar technology, command-and-control systems, and cyber warfare—as priorities for investment and the development of sovereign capabilities (Brazil, 2020).

Cooperation among the government, the Defense Industrial Base (DIB), and universities lies at the heart of this model, reflecting the Triple Helix framework (Etzkowitz; Zhou, 2017). This structure enables Brazil to pursue technological advancement despite budgetary constraints through strategic projects that combine technology absorption, technology transfer, and the development of indigenous industrial capabilities.

This form of cooperation is evident in programs such as PROSUB, KC-390, Gripen, and SISFRON, through which Brazil promotes technology absorption and establishes strategic partnerships involving the DIB and universities, in line with the Triple Helix model.

These initiatives support technological progress even under financial constraints, gradually strengthening the DIB and reducing dependence on foreign suppliers (Brazil, 2020; Moura, 2022; Souza, 2022). Thus, even within a limited budgetary environment, consistent long-term policies and the prioritization of critical areas are essential for strengthening Brazil's defense S&T&I, securing sovereign technological capabilities, and safeguarding national security in an increasingly competitive and uncertain global environment.

Table 3 classifies these projects according to their technological profile and identifies their principal partners. It thus provides an integrated, evidence-based overview of Brazil's defense S&T&I strategy and demonstrates how institutional cooperation helps reduce foreign dependence and strengthen the country's defense technological capabilities.

Table 3 – Main Strategic Projects within the Brazilian Armed Forces

Project	Technology Category	Main Partners
PROSUB	Sensitive Technology	Brazilian Navy; Naval Group (France); Itaguaí Construções Navais (ICN)
KC-390	Complementary Technology	Brazilian Air Force (FAB); Embraer; Aeronautics Institute of Technology (ITA)
Gripen	Complementary Technology	Brazilian Air Force (FAB); Saab (Sweden); Aeronautics Institute of Technology (ITA)
SISFRON	Sensitive Technology	Brazilian Army; Bradar; Embraer Defense; Center for Research and Development in Telecommunications (CPqD); Federal University of Mato Grosso do Sul (UFMS); University of Brasília (UnB)

Source: Prepared by the author based on Brasil (2020), Moura (2022), Souza (2022), and Etzkowitz and Zhou (2017).

Despite these constraints, Brazil has sought to strengthen its defense ST&I capabilities, in line with a hybrid model of self-sufficiency and selective outsourcing. Projects such as PROSUB and SISFRON exemplify the focus on sensitive technologies under national control, while the KC-390 and Gripen illustrate the use of international partnerships for the absorption and development of complementary technologies. Integration among government, the DIB, and universities, combined with the prioritization of critical areas, is essential to promoting technological sovereignty, innovation, and industrial strengthening, thereby ensuring Brazil's defense capabilities and the protection of its strategic interests in a dynamic geopolitical environment (Etzkowitz; Zhou, 2017; Andrade, 2019).

Limited financial resources, however, affect both the pace and the scope of technological innovation, requiring strategic choices about where to invest in order to achieve technological self-sufficiency without compromising budgetary efficiency (SIPRI, 2024; Macrotrends, 2024; Brasil, 2023).

1.5 INTERNATIONAL MODELS OF DEFENSE ST&I MANAGEMENT: FRANCE AND THE UNITED STATES

Among international examples, the defense ST&I management models adopted by France and the United States stand out, as their strategies offer relevant lessons for Brazil.

In France, defense ST&I management is characterized by strong state leadership in the funding of research and development, with the aim of maintaining self-sufficiency in critical areas such as the nuclear and aerospace sectors. This strategy relies on technology-transfer policies and the continuous strengthening of the DIB, enabling the country to preserve sensitive capabilities with a high degree of independence (Melo, 2015).

In the United States, the model is distinguished by the role of the Defense Advanced Research Projects Agency (DARPA), which coordinates an accelerated innovation ecosystem integrating government, the DIB, and universities. This structure allows the country to outsource much of the development of disruptive technologies in a structured and flexible manner, while maintaining strategic control over critical areas and ensuring agility in the absorption of innovations (DARPA, 2024; CRS, 2021).

To support a comparative analysis of defense ST&I management models in France, the United States, and Brazil, Table 4 presents the qualitative parameters and quantitative values used to estimate the relative participation of government, the Defense Industrial Base (DIB), and universities in each country.

Table 4 – Qualitative and quantitative parameters used to estimate participation shares in defense ST&I

Evaluated Parameter	Criterion Description	France	United States	Brazil	Sources
1. Government centrality in defense R&D	Degree of direct funding, definition of strategic priorities, and control over sensitive sectors, such as nuclear, aerospace, and cyber.	Very high (50%)	High (30%)	High (40%)	Melo (2015); Brasil (2020); DARPA (2024); and CRS (2021)
2. Role of the DIB in R&D and Production	Industrial and technological capacity, volume of contracts, role in innovation, and execution of strategic projects.	Moderate (30%)	Very high (40%)	Moderate (35%)	Melo (2015); DARPA (2024); Andrade (2019); and Moura (2022)
3. Role of universities in defense R&D	Engagement in applied research, absorption of defense resources, human-resource development, and innovation partnerships.	Moderate (20%)	High (30%)	Moderate (25%)	Etzkowitz and Zhou (2017); Brasil (2020); and Souza (2022)
4. Structure of the Triple Helix Model	Integration among government, the DIB, and universities in defense ST&I ecosystems.	Integrated, government-led	Integrated, DIB-led	Integrated, government -led	Etzkowitz and Zhou (2017); Melo (2015); and DARPA (2024)

Fonte: Elaboração própria a partir de Melo (2015); Brasil (2020); DARPA (2024); CRS (2021); Etzkowitz e Zhou (2017); Andrade (2019); Moura (2022); e Souza (2022)

The percentages presented in Table 4 and illustrated in Figure 2 were defined by cross-referencing secondary qualitative and quantitative data from the cited sources, complemented by comparative interpretation based on Melo's (2015) methodology and the Triple Helix analytical framework (Etzkowitz; Zhou, 2017). They should not, therefore, be understood as exact accounting figures, which do not exist in standardized form across the countries analyzed, but rather as weighted estimates derived from the following indicators:

a) Government centrality: based on the proportion of defense R&D funded directly by the state, including public defense and research budgets, as reported in official documents from Ministries of Defense and related agencies (Brasil, 2020; DARPA, 2024; CRS, 2021).

Cases in which the state defines strategic priorities and directly controls implementation in sensitive areas were classified as “very high” (e.g., France), while those in which the state acts as coordinator and funder, but partially delegates execution to industry, were classified as “high” (e.g., Brazil and the United States);

b) Role of the Defense Industrial Base (DIB): estimated on the basis of domestic industry’s participation in the execution of strategic programs, contract volume, and technological autonomy (Andrade, 2019; Moura, 2022; Souza, 2022). Higher percentages (40%) therefore reflect strong industrial involvement and innovation capacity, as in the United States, while moderate percentages (30–35%) correspond to relevant participation that remains dependent on state direction, as in France and Brazil;

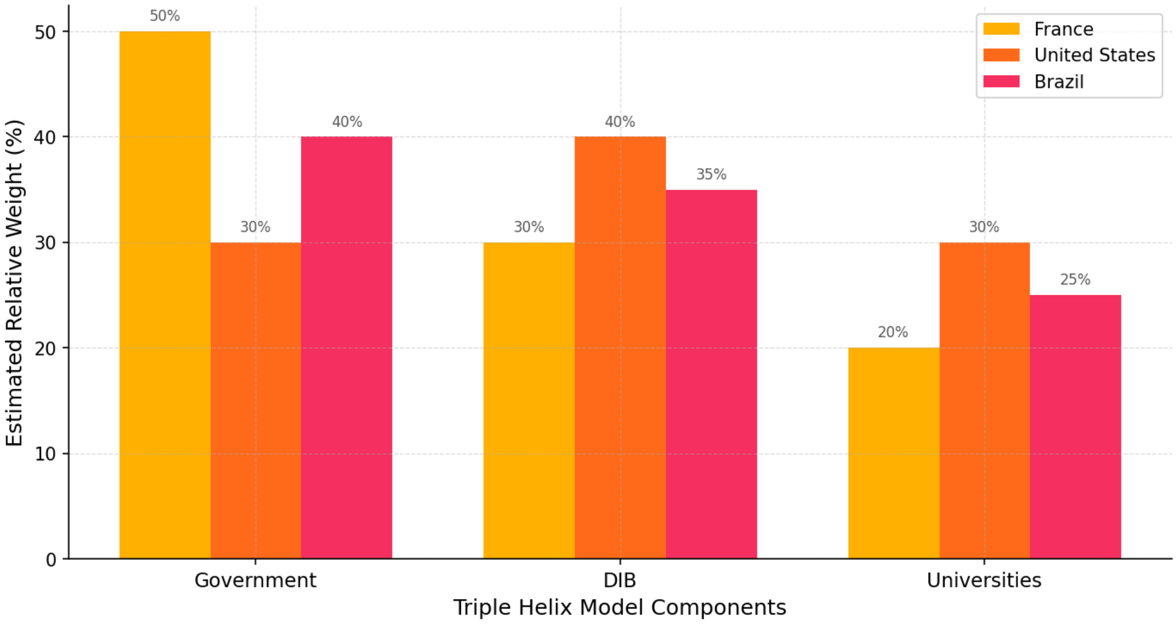
c) Role of universities: inferred from the density and relevance of applied research agreements, graduate programs, and defense-related human-resource development initiatives (Etzkowitz; Zhou, 2017; Souza, 2022). The assigned percentages (20–30%) represent the estimated share of academic contribution to knowledge generation and technological innovation in defense, based on each country’s model of university–industry–government integration; and

d) Systemic integration (Triple Helix): assessed qualitatively according to the degree of institutional coordination and interdependence among the three vertices of the innovation system. Classifications such as “integrated, state-led” or “integrated, industry-led” derive from the analysis of institutional structures and R&D flows described in the comparative sources (Melo, 2015; DARPA, 2024; Etzkowitz; Zhou, 2017).

The final weighting resulted from an interpretive average across these axes, converting the observed intensity into percentages of relative participation, in accordance with the categories adopted in the specialized literature. This methodology ensures theoretical consistency and analytical transparency, allowing comparison among defense ST&I ecosystems with different levels of institutional maturity without creating an artificial sense of statistical precision. Thus, the percentages in Table 2 should be understood as synthetic trend indicators rather than strict financial data – a heuristic device intended to clarify the governance structure and the balance of forces among the state, industry, and academia in each country.

These indicators strengthen the understanding of how each country organizes its innovation and defense ecosystems. Based on these parameters, Figure 2 was prepared to present defense ST&I management models, highlighting the estimated relative weight of government, the DIB, and universities in Brazil, France, and the United States.

Figure 2: ST&I Management Models in France and in the USA



Source: prepared by the author based on Melo (2015), Brasil (2020), DARPA (2024), CRS (2021), Andrade (2019), Etzkowitz and Zhou (2017), Moura (2022), and Souza (2022).

Overall, Brazil's defense ST&I management model, although still constrained by limited funding, resembles the French model in keeping government at the center of coordination and financing for sensitive technologies, while also mobilizing the DIB and universities to strengthen strategic capabilities and reduce external dependencies.

Brazil's approach differs from France's, however, in that the French state exercises tighter control over the DIB, whereas Brazil has gradually adopted partnership mechanisms to foster innovation in complementary areas, closer to the U.S. experience of harnessing the technological potential of the DIB and universities. The U.S. model is marked by the leading role of the DIB and by the speed with which disruptive technologies are developed, coordinated through institutions such as DARPA, with government acting as strategic enabler and funder.

The data presented in Table 2 show that, while France prioritizes self-sufficiency in critical sectors and the United States emphasizes speed and flexibility in innovation, Brazil selectively balances both approaches. Despite resource constraints, this hybrid model has enabled concrete advances in defense ST&I through strategic projects and growing coordination among government, the DIB, and universities, in line with the Triple Helix model.

1.6 COMPARISON BETWEEN SELF-SUFFICIENCY AND OUTSOURCING MODELS IN RESEARCH AND DEVELOPMENT

Analysis of international and Brazilian defense ST&I management models shows that both self-sufficiency and outsourcing have advantages and limitations. The choice between them depends on each country's budgetary capacity, strategic priorities, and institutional architecture (Melo, 2015; DARPA, 2024; Brasil, 2020).

France follows a strong self-sufficiency model, marked by robust state leadership in the funding and control of sensitive areas such as the nuclear and aerospace sectors. This model helps ensure technological sovereignty, reduce external vulnerabilities, and preserve independence in critical technologies, although it requires substantial public investment and long-term policies to sustain critical mass in R&D (Melo, 2015; Brasil, 2020).

The United States relies primarily on a structured and flexible outsourcing model, coordinated through institutions such as DARPA. Under this model, the Defense Industrial Base (DIB) and universities take the lead in developing disruptive technologies, while government acts as strategic coordinator and funder. This arrangement accelerates the incorporation of innovation and helps reduce costs (DARPA, 2024; CRS, 2021). It also requires strong governance and oversight mechanisms to prevent external dependencies in sensitive areas.

Brazil, facing budgetary constraints as well as territorial and strategic challenges, adopts a hybrid model that seeks to balance self-sufficiency in sensitive technologies with outsourcing in complementary areas through structured partnerships with the DIB and universities (Etzkowitz; Zhou, 2017; Andrade, 2019).

This model has enabled progress in critical areas such as nuclear propulsion and cyber warfare under state control, while allowing the country to absorb technologies in fields such as aviation and monitoring systems through international partnerships and technology-transfer agreements, as seen in the Gripen, KC-390, and SISFRON projects (Brasil, 2020; Moura, 2022; Souza, 2022).

To make this argument clearer, Table 5 compares the strengths, limitations, practical examples, and strategic effects of self-sufficiency, outsourcing, and hybrid models in defense ST&I, helping to synthesize the main elements of the analysis.

Table 5 – Consolidated comparison of defense ST&I models: Self-Sufficiency, Outsourcing, and the Hybrid Model

Aspect	Self-Sufficiency (e.g., France)	Outsourcing Model (e.g., United States)	Hybrid Model (Brazil)
Strengths	Full control over sensitive technologies; lower external vulnerability; technological sovereignty	Faster incorporation of innovation; lower costs; broader access to emerging technologies	Combines sovereignty in critical areas with efficiency in complementary domains; greater flexibility
Limitations	High development costs; requires long-term policies; depends on critical mass in R&D	Potential external dependence; possible loss of control over sensitive technologies	Requires clear prioritization; depends on stable governance and budget predictability
Practical example	French nuclear and aerospace sectors (Melo, 2015)	DARPA ecosystem, with the DIB and universities leading innovation under government oversight (DARPA, 2024; CRS, 2021)	PROSUB, Gripen, KC-390, and SISFRON, combining self-sufficiency and partnerships (Brasil, 2020; Moura, 2022; Souza, 2022)
Economic and strategic effects	Strengthening of the national DIB; dual-use technologies; sovereignty	Generation of disruptive technologies; stronger technology clusters; technology exports	Gradual strengthening of the DIB; creation of skilled jobs; reduced external dependence
Sources considered	Melo (2015); Brasil (2020)	DARPA (2024); CRS (2021)	Andrade (2019); Brasil (2020); Moura (2022); Souza (2022)

Source: prepared by the author based on Melo (2015); Brasil (2020); DARPA (2024); CRS (2021); Andrade (2019); Moura (2022); e Souza (2022).

A análise consolidada neste tópico demonstra que o modelo híbrido adotado pelo Brasil constitui a estratégia mais compatível com suas condições orçamentárias e necessidades estratégicas, permitindo avanços em tecnologias sensíveis sob controle nacional enquanto promove a absorção de tecnologias complementares por meio de parcerias. Isso garante o fortalecimento da Base Industrial de Defesa, reduz a dependência tecnológica externa e contribui para o desenvolvimento econômico, criando empregos qualificados e fortalecendo a cadeia produtiva tecnológica nacional (Etzkowitz; Zhou, 2017; Andrade, 2019; Brasil, 2020).

Assim, ao equilibrar soberania tecnológica, eficiência orçamentária e agilidade em inovação, o Brasil poderá proteger seus interesses estratégicos em um cenário internacional de rápidas transformações tecnológicas e tensões geopolíticas crescentes, consolidando sua capacidade de defesa de forma sustentável e soberana.

1.7 DISCUSSION

This policy paper has shown that the organization, structuring, and funding of Science, Technology, and Innovation (ST&I) within the Armed Forces are essential to strengthening Brazil's strategic autonomy, defense capabilities, and power projection in the international arena. The comparison of self-sufficiency, outsourcing, and Brazil's hybrid model shows that there is no single path. Rather, combined strategies are needed, tailored to the country's budgetary constraints and strategic requirements.

The self-sufficiency model, as seen in France, ensures technological sovereignty and control over sensitive technologies, reducing external vulnerabilities, but requires substantial public investment, long-term policies, and sustained critical mass in R&D. The structured outsourcing model adopted by the United States and coordinated through institutions such as DARPA allows for greater speed and efficiency in incorporating disruptive innovations, mobilizing the Defense Industrial Base (DIB) and universities under state oversight. It also requires robust governance mechanisms to avoid dependence in critical sectors.

Brazil's hybrid model, in turn, balances sovereignty in sensitive technologies with the efficiency offered by structured partnerships in complementary areas, using the DIB and universities to absorb and develop technological capabilities essential to the country.

Based on the analysis, Brazil should prioritize sensitive areas such as cyber warfare, nuclear propulsion, radars, and missile systems, ensuring self-sufficiency in critical technologies – including artificial intelligence (AI), quantum computing, autonomous vehicles, and sensors – while strengthening structured partnerships with the DIB and universities through technological procurement and technology-transfer clauses. Budget predictability is essential to ensure the continuity of strategic programs such as PROSUB, KC-390, Gripen, and SISFRON. The Triple Helix model should serve as a coordination framework, aligning government, the DIB, and academia in the development of Brazil's defense ecosystem.

Dual-use technologies should also be encouraged, allowing military innovation to spill over into the civilian sector, strengthen production chains, and generate skilled employment. Human-resource development in defense-critical areas must be treated as a priority, expanding the pool of engineers, technicians, and researchers needed to sustain strategic programs and reduce external dependencies.

Governance of defense ST&I programs should be strengthened through performance indicators, timelines, and targets, ensuring efficient use of public resources and delivery within planned schedules and budgets. Brazil should also expand its participation in international forums and establish strategic partnerships in defense ST&I to consolidate technological expertise, strengthen its international position, and improve the global competitiveness of the DIB.

By balancing technological sovereignty, budgetary efficiency, and speed in innovation, Brazil can strengthen its defense capabilities, reduce strategic vulnerabilities, and position itself competitively in an international environment shaped by geopolitical tensions and rapid technological change. Defense ST&I not only supports national security and sovereignty but also drives industrial, technological, and economic development by generating skilled jobs, strengthening production chains, and supporting broader economic growth. Consistent adoption of the hybrid model, supported by long-term policies and coordination among government, the DIB, and universities, would enable Brazil to protect its strategic interests, keep pace with essential technological advances, and promote prosperity and security in the twenty-first century.

2 RECOMMENDATIONS

Based on the historical, comparative, and budgetary analysis presented above, the following recommendations are proposed to strengthen ST&I within the Brazilian Armed Forces, together with a brief assessment of their political, fiscal, and institutional feasibility, as well as the main risks and barriers to implementation:

• **Increase defense investment to at least 2% of GDP**, in line with Proposed Constitutional Amendment No. 55/2023, cited in Brasil (2023), ensuring budget predictability and the sustainability of strategic ST&I programs. In terms of feasibility and risk, this recommendation is politically viable in the medium term, given the growing recognition of defense as a pillar of national sovereignty. It nevertheless faces structural fiscal barriers and budget rigidity linked to spending-cap rules and the high share of mandatory expenditures

(Andrade, 2019). Implementation would require interministerial coordination and a gradual approach, supported by a multi-year expansion schedule;

• **Reorient the internal composition of the defense budget**, reducing the share allocated to operating costs and personnel while increasing the portion directed to investment and defense R&D (Brasil, 2023; SIPRI, 2024). This recommendation is difficult to implement in the short term, as it would require revising legal and pension-related commitments and overcoming corporate resistance. It is, however, essential to ensure that any budget increase produces real effects on ST&I. The experience of countries such as France and the United States shows that the quality of spending matters more than overall budget volume (Melo, 2015; DARPA, 2024; CRS, 2021);

• **Prioritize sensitive areas under national control**, such as artificial intelligence, cyber warfare, nuclear propulsion, radars, and missile systems, ensuring technological sovereignty and continuity in critical programs (Brasil, 2020; Moura, 2022). Although strategically highly relevant, this recommendation depends on political continuity and budget stability. The main risk is discontinuity across administrations and the effect of budget cuts on long-cycle technology programs such as PROSUB and SISFRON;

• **Strengthen coordination among government, the DIB, and universities**, expanding the Triple Helix model (Etzkowitz; Zhou, 2017) to absorb complementary technologies, foster dual-use innovation, and reduce external dependencies (Souza, 2022). This recommendation is institutionally feasible, as it builds on existing structures and successful experiences. It nevertheless requires governance mechanisms and R&D tax incentives that encourage private-sector engagement and prevent asymmetries among the parties involved (Andrade, 2019);

• **Implement governance and monitoring mechanisms**, with transparent indicators and targets for defense ST&I (Brasil, 2020). This recommendation is highly feasible and has low fiscal cost, as it involves streamlining processes and adopting tools already consolidated in public administration. The main challenge lies in interservice integration and in establishing common metrics across different programs; and

• **Promote the development of specialized human resources in strategic defense areas**, building the critical mass needed to sustain and advance sensitive programs, while expanding scholarships and military–academic research agreements (Melo, 2015; Souza, 2022). This recommendation is feasible through partnerships with universities and existing graduate programs, but depends on stable funding for scholarships and on the continuity of policies that encourage scientific careers in the public sector.

Taken together, these recommendations are technically grounded and politically plausible, but their full implementation requires fiscal alignment and institutional continuity. The main challenge is not only to increase spending, but to ensure that resources are allocated strategically and sustainably, with priority given to innovation, the development of critical capabilities, and the integration of Brazil's defense ST&I ecosystem. This approach is consistent with the international lessons examined above (Melo, 2015; DARPA, 2024; CRS, 2021) and with the gradual maturation of Brazil's Defense Industrial Base (Andrade, 2019; Moura, 2022), reinforcing defense as a driver of sovereign and competitive development.

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