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Definition of requirements for anti-ship cruise missile projects aimed at anti-access and area denial (A2/AD) defense in Brazil

Definición de requisitos para proyectos de misiles de crucero antibuque en defensa antiacceso y denegación de área (A2/AD) en Brasil

Abstract: This study investigates and establishes foundational requirements for the development of anti-ship cruise missiles tailored to support Brazil's anti-access and area-denial (A2/AD) defense strategy. Addressing critical operational gaps in the Brazilian Armed Forces, the analysis identifies immutable operational demands, termed "zero requirements," defined during the early stages of the development process. Through a comprehensive geopolitical and strategic assessment, the paper contextualizes Brazil's defense challenges, accounting for territorial characteristics, regional threats, and the need for enhanced military interoperability. Operational capabilities are detailed, including the necessity for mobile launch platforms, maximum range, and the ability to engage strategic naval targets. The findings underline the importance of incorporating technological advancements and aligning product development with Brazil's National Defense Strategy. The application of zero requirements proves instrumental in guiding strategic decisions and bolstering national deterrence capabilities, with prospects for exportability and future technological evolution.

Keywords: Cruise Missile, Project Requirements, A2/AD, Anti-Ship Missile.

Resumen: Este estudio analiza y define los requisitos fundamentales para el desarrollo de misiles de crucero antibuque, operados desde tierra, destinados a la estrategia de defensa antiacceso y denegación de área (A2/AD) en Brasil. Se abordan las carencias operativas en las Fuerzas Armadas Brasileñas y se identifican exigencias prioritarias, denominadas requisitos cero, que engloban demandas operativas inalterables establecidas desde las fases iniciales de desarrollo. Mediante un análisis geopolítico y estratégico, el trabajo contextualiza los desafíos defensivos nacionales, considerando las características territoriales, amenazas regionales y necesidades de interoperabilidad de las Fuerzas Armadas. Se especifican las capacidades operativas necesarias, con enfoque en sistemas de lanzadores móviles terrestres, alcance máximo y ataque a blancos navales estratégicos. Los resultados enfatizan la relevancia de integrar innovaciones tecnológicas y alinear el desarrollo del producto con los principios de la Estrategia Nacional de Defensa. La aplicación del concepto de requisitos cero demuestra ser eficaz para orientar decisiones estratégicas y fortalecer la capacidad disuasoria nacional.

Palabras clave: Misil de crucero, Requisitos de proyecto, A2/AD, Misil antibuque.

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1 INTRODUCTION

Throughout its recent history, Brazil has remained far from the main centers of international tension in a favorable geopolitical position that has granted it relative tranquility regarding the defense of its territory. However, the current geopolitical competition between the United States, China, and Russia has changed the Brazilian strategic environment by converting Latin America and the Caribbean into a new focus of attention for the major military powers (Teixeira Júnior, 2020). Thus, it becomes essential for Brazil to be able to fully exercise its sovereignty and deterrence capacity on the international stage (Brasil, 2020).

Harvey (1997) presents the concept of deterrence as the use of force to cause inaction in adversaries, making them reluctant to act by fearing failure, costs, and consequences. However, as Mazarr (2018) points out, deterrence should be understood as a complex approach that goes beyond mere threats. This strategy includes guarantees or benefits that foster the elimination of aggressive actions and broad and systematic methods that can demotivate potential aggressors. Brazil conceptualizes deterrence as a strategy of several means (including military ones) that aim to discourage or remove real or potential adversaries with possible or presumed warlike intentions (Brasil, 2015). Thus, deterrence constitutes an essential element of the Brazilian National Security, evaluating it according to its ability to mobilize and apply its protection resources and the necessary prompt response in the face of possible hostile actions against the sovereignty and legitimate interests of Brazil (Brasil, 2020).

In this scenario, anti-access/area denial (A2/AD) strategies play an important role in hindering enemy operations. The anti-access (A2) strategy aims to prevent the entry of opposing forces into a theater of operations, usually at long distances. In turn, the area denial (AD) strategy seeks to limit the short-distance freedom of action of these forces in more restricted spaces under direct control of the enemy (United States, 2023). Ground AD operations can include short- and medium-range artillery, ballistic and guided rockets, and cruise missiles aimed at tactical and strategic positions on the ground. On the other hand, A2 actions can use anti-ship cruise and ballistic missiles (Krepinevich; Watts; Work, 2003). Thus, A2 and AD operations include cruise missiles.

The possibility of launching cruise missiles from mobile or fixed land-based platforms represents a relevant strategic asset for A2/AD strategies (Teixeira, 2021) as such systems contributes to strengthening the deterrent capacity of a country (Monteiro, 2021; Brazil, 2022a) in conjunction with other weapons systems and strategies.

Currently, the Brazilian Army stands in the final stages of development of a tactical cruise missile (TCM) within its ASTROS Strategic Program. This munition has a 300-km range and a high degree of accuracy, aiming at fixed ground targets (Silveira, 2022). However, the Brazilian Army has an operational gap regarding terminally guided cruise missiles to neutralize or destroy moving targets. Its absence in the Portfolio of Strategic Defense Projects is to be filled by a new development project called TCM – Block II, which is yet to start (Brasil, 2022a).

An adequate definition of the operational demands that will guide the development of this new defense product would integrate such a system into a comprehensive national A2/AD strategy, strengthening deterrence and territorial defense capabilities by combining long-range armaments, advanced sensors, and command and control networks. This would limit the freedom of action of adversary forces in strategic theaters of operations and ensure the protection of critical areas, such as the Brazilian coast and the Amazon, promoting greater interoperability between the Armed Forces (Brasil, 2020, 2022b).

Thus, there is a valuable opportunity to strengthen inter-institutional interactions between the agents of military innovation in the early stages of the development of new defense systems—as in the case of cruise missiles intended for the Ground Force[1] to defend the coast and fight against moving targets on land and at sea—and in the analysis of possibilities to adapt specifications of existing projects, such as MANSUP-ER (MANSUP-ER [...], 2024) to meet the operational requirements of the Brazilian Armed Forces. Strengthening the relationships between innovation agents directly benefits the defense industrial base, improving national capabilities and strengthening the deterrent power of Brazil (Azevedo, 2018).

Guerra and Barreto (2023) argue that, during innovation cycles to generate new military capabilities, an essential step in the interaction between sponsoring agencies and developers refers to the study and joint and consensual definition of operational requirements that must be maintained even in the face of technical, commercial, or industrial challenges. The military innovation cycle must establish and prioritize these immutable demands (called zero requirements) since its early stages, ensuring their preponderance over other considerations and operational/technical requirements.

Thus, the hypothesis for this study regards the feasibility of applying the concept of zero requirements in Guerra and Barreto (2023) as an effective tool to find and characterize unalterable operational requirements. These demands significantly impact the costs and timelines of developing new cruise missiles, directly influencing the physical aspects and functionalities of adopted solutions.

Thus, this study analyzes the current geopolitical environment and strategic factors to answer the following questions: considering the characteristics of the Brazilian territory, what are the main defensive challenges currently underway? What constitute the main strategic areas for defense forces in Brazil? This research analyzed the answers to these questions from a technological perspective, serving as a basis for finding characteristics and functionalities that could greatly impact the design of a defense product.

This study aims to turn the zero requirements herein identified into capabilities, characteristics, and quality levels that can serve the subsystems and components of a

1 The Ground Force is the action instrument of the Army, which is structured and prepared to carry out operational land missions (Brasil, 2015).

cruise missile that has been designed to integrate an A2/AD strategy under the national Ground Force. These operational demands can assess the adequacy of previously proposed operational and technical requirements in other missile developments and subsidize strategic decisions by the sponsoring authority. Such deliberations may produce new dedicated munitions for a specific purpose, adapt existing solutions, or develop a family of multipurpose missiles.

The initial analysis in this study can also incorporate knowledge regarding the technologies and manufacturing capacity in the Brazilian industrial base to outline the stages of possible new engineering projects and plan the necessary financial, human, and material resources. Thus, the relevance of this study lies in its possibility of incorporating an analysis of the scientific-technological branch to other tactical, strategic, and doctrinal debates regarding the A2/AD theme in Brazil (Teixeira, 2021; Rodrigues, 2022; Alves, 2023) and of offering a first set of technological data regarding the interaction between military innovation agents dedicated to national cruise missiles.

Regarding its structure, this text, in addition to this introduction and its final considerations, analyzes the current geopolitical environment and strategic factors, describes A2/AD strategies, and establishes immutable operational demands (zero requirements) associated with a terminally guided cruise missile to neutralize or destroy moving targets.

2 THEORETICAL FRAMEWORK

2.1 Characteristics of the Brazilian territory and its current defensive challenges

The Brazilian National Defense Policy (Brasil, 2020) deems that Brazil must maintain its deterrence capacity and ability to fully exercise its sovereignty since the current international environment includes the growth of strategic military conflicts and the resurgence of competition for supremacy between the largest powers in the world.

Such task requires constant efforts due to the continental dimensions of Brazil. Its territory spans about 8.51 million km^2 (Instituto Brasileiro de Geografia e Estatística, 2023) and its wide coastline, about 8,500 km. The oceanic area the Brazilian Navy calls "Blue Amazon"[2] spans 4.5 million km^2. Its position in the South Atlantic confers its economic maritimity, encompassing 90% of world trade (according to transported volume) (Centro de Excelência para o Mar Brasileiro, 2019). Except for Argentina, Chile, Paraguay, and Uruguay, all South American countries share the Amazon biome with Brazil.

The border in the Amazon and its difficult access to land transportation, low population density, and the dependence of its logistics network on air and river routes

2 "The Blue Amazon is the region that comprises the surface of the sea, overlying waters of the seabed, marine soil, and subsoil contained in the Atlantic extension that projects from the coast to the outer limit of the Brazilian continental shelf" (Centro de Excelência para o Mar Brasileiro, 2019).

challenge the implementation of public defense and security policies (Medeiros Filho, 2020). Its abundant natural resources and a growing international movement to provide foreign intervention to avoid alleged environmental catastrophes worsens this complexity (Nobre, 2014). Other local threats include border problems related to transnational crime. The peculiarity of the Amazon and the inadequacy of the State can cause emergencies and consolidate parallel powers (Rosero; Cediel, 2014). This reality requires vigilance, international cooperation, and deterrence as a priority strategy to maintain the national sovereignty (Brasil, 2020).

However, the abundant national wealth and its defensive challenges go beyond the dry land. The privileged South Atlantic Brazilian vast coastline marks the relevance of its maritime space, from its intense maritime trade to the possession and use of marine biodiversity and mineral resources, especially large oil and gas reserves. As in the Amazon, scientific research, job creation, and the implementation of communication lines and energy exploration that contribute to the economic and social development of Brazil evince the significance of the potential of the Blue Amazon (Andrade *et al*, 2020).

The geographical facts of the area are evident. Since 58% of the Brazilian population lives within 200 km from the coast, the coastal region houses most of the national industrial park (Instituto Brasileiro de Geografia e Estatística, 2018). The Brazilian Northeast (14.2%), Southeast (51.9%), and South (17.2%) total 83.3% of the national GDP (Instituto Brasileiro de Geografia e Estatística, 2020), which still has room for growth via marine resources and maritime activities (the economy of the sea). These sources of funds alone produced results that would position the Brazilian maritime economy as the second largest in South America in 2018 (Andrade *et al*, 2022). This suggests that the Brazilian economy may depend on the ocean due to the significant contribution of the riches from the sea or its proximity, a fact Kildow and Mcilgorm (2010) have also corroborated.

Such extensive coastline also facilitates the establishment of several outflow lines for foreign trade. Brazil has 36 public ports and 203 private terminals (Diretor-Geral [...], 2022), which act as communication gateways between points in its territory and other nations. However, the vastness that provides wealth also attracts greed and imposes difficulties and challenges to the defense of the national maritime border.

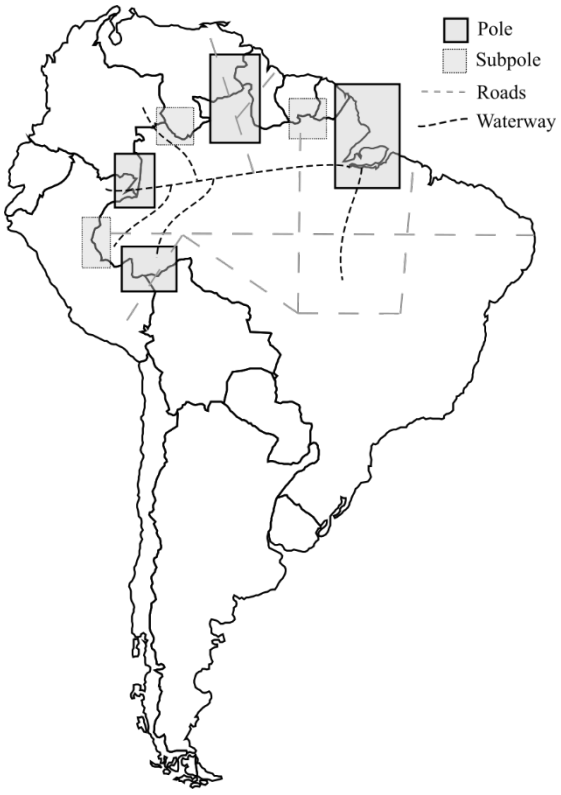
This suggests that the geographic characteristics and the political, economic, environmental, and social peculiarities of Brazil prioritize defense efforts in its border, the Amazon, and the South Atlantic. This thinking also falls in line with the Brazilian National Defense Policy (Brasil, 2020).

2.2 Strategic areas for the defense forces in Brazil

As per the previous section, the border areas, and especially the Amazon and the South Atlantic, constitute points to be defended from external threats that aim to diminish Brazilian sovereignty and/or take possession of the national heritage.

Paiva (2015) sees no conflict zone that encompasses the entire Pan-Amazon (involving the countries the territory of which feature the Amazon rainforest) since its extensive territory protects this area against invaders. However, the author warns of the strategic priority areas to defend the Amazon region: Pan-Amazon integration poles and subpoles (Figure 1).

Figure 1. Pan-Amazon integration poles and subpoles



Source: Adapted from Paiva (2015).

The threats to the Amazon can fall into two major fronts: one from the Pacific Ocean, passing by the Andes and Latin Iberian countries, and another from the Atlantic Ocean and the Guianas. The inland border with the Pacific front shows lesser vulnerability and tends to impose difficulties for larger-scale military operations. However, the region shows problems related to transnational crimes, and specific defense actions may be required in scenarios of the establishment of power parallel to the State.

In turn, the border facing the Atlantic proves challenging. Paiva (2015) highlights the connection of the Guianas with Great Britain, the Netherlands, and France (and thus with the North Atlantic Treaty Organization) in addition to its proximity to the Southern Command and the United States Fourth Fleet in Florida, reactivated in 2008 with a focus on the Caribbean and with a projection to the South Atlantic (Perez, 2020). The author also points out the importance of the country being able, by strategic and governmental decisions, to attack its enemy before the invasion

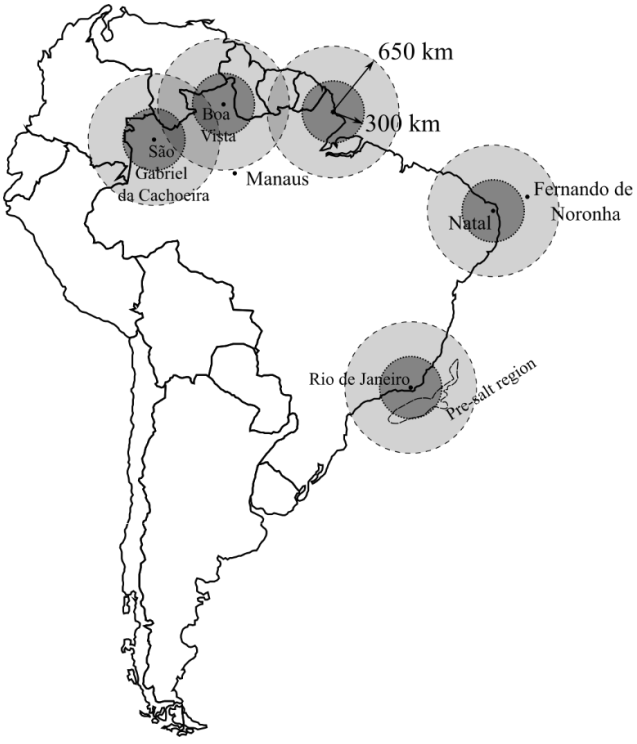
of its national territory; situations in which neighboring countries, unable to remain neutral, offer their territories for the landing of adversarial troops and equipment (Paiva, 2015).

The author states that the mouth of the Amazon River and the state of Roraima configure the most sensitive points for the defense of the Brazilian North. Their geographical conditions and poor transport structure favor the isolation of the Roraima capital Boa Vista in case of a border violation via Venezuela and/or Guyana. At the mouth of the Amazon River, Amapá, the Marajó Island, and Belém constitute navigation control points for the river, which provide access to inner Brazil and supply the municipality of Manaus. This again entails the operational need to neutralize an enemy squadron before the landing of troops and equipment.

Other points of vulnerability include attacks to damage strategic targets in the Brazilian Midwest and South (Paiva, 2015), such as blockades or temporary occupations of oil basins (or of pre-salt oil fields off the coast of Espírito Santo to that of Santa Catarina), oceanic islands (Fernando de Noronha, Trindade, Martim Vaz, and the archipelagos of São Pedro and São Paulo), oil platforms, submarine cables, and maritime communication lines (foreign trade flows) (Vasconcelos; Nunes, 2021).

A recent fact that adds complexity to the defense of areas in the Brazilian North refers to the discovery of large oil reserves in the region. This Equatorial Margin (nicknamed the "new pre-salt") between the coasts of the states of Amapá and Rio Grande do Norte is considered the new Brazilian exploratory frontier in deep and ultra-deep waters, which Petrobras deems a strategic region. The first site to be explored by this Brazilian company lies 160 km from the coast and more than 500 km from the mouth of the Amazon River (Descubra [...], 2024).

Figure 2. Illustration of distances in strategic areas of defense of Brazil



Source: Figure prepared by the author (2023).

The analysis of the current geopolitical environment and strategic factors establishes the technological bases to define operational demands that must persist under any circumstances, ensuring that defense products meet their main purpose.

In the case under analysis, three fundamental requirements strongly impact the definition of the final solution for a cruise missile operated by the Brazilian Ground Force: munition range, launch means, and target types. Figure 2 shows the need for mobile launch platforms that can defend strategic areas in the Brazilian territory, especially against maritime targets. A munition range of 300 to 650 kilometers would make it possible to neutralize threats in the pre-salt region and in the Equatorial Margin. These considerations configure essential elements to characterize unalterable operational requirements based on the zero requirement concept.

2.3 Anti-Access/Area Denial (A2/AD) Strategies

The formulation of the concept involving the term "A2/AD" emerges from historical defensive strategies, such as fortifications and coastal barriers, being consolidated after the Cold War. According to Krepinevich, Watts, and Words (2003), it is directly linked to the dissolution of the Soviet Union, when asymmetric adversaries began to use technologies such as ballistic missiles, air defenses, and integrated operations to limit the projection of U.S. power. On the other hand, Frühling and Lasconjarias (2016) stress that the concept gained greater relevance after the 1991 Gulf War, in which U.S. technological advances, such as precision strikes and real-time intelligence, motivated adversaries to develop advanced capabilities to counter U.S. military superiority.

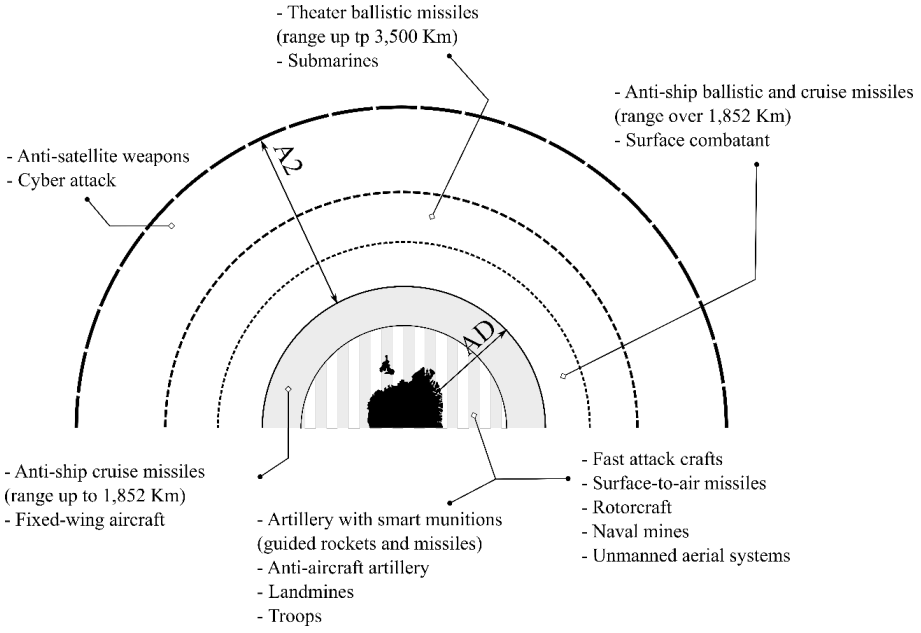
Of the countries that rival the military power of the United States, China prominently exemplifies military modernization to meet the fundamental idea that basis A2/AD strategies (Frühling; Lasconjarias, 2016), i.e., prevailing over an adversary at a distance (especially if it has superior military power), preventing the access of its forces to the theater of operations (Tangredi, 2013). In the last three decades, China has substantially invested in combat systems, including ballistic (range of 3000-5000 km) and cruise missiles with supersonic and hypersonic speeds and the ability to destroy warships (Tangredi, 2019).

The term A2/AD is not exclusively relevant and current in China. From 2000 onward, debates in the defense area began to address the theme more often. Since then, A2/AD has had semantics with subtle differences. For some, it represents a code to indicate an area where the violation of which poses serious risks to the attacker. Others use it to refer to a family of technologies or weapons systems that can prevent invasions of a region. Others still use it to express a military strategy. However, the best reading considers A2/AD as a strategy that involves a multi-domain military campaign by trying to obtain all necessary means of power (including weapons systems and diplomatic approaches) to deny access to a given

area (Tangredi, 2019). In these general terms, it constitutes an extra-regional conventional deterrent power.

The Joint Operational Access Concept (United States, 2012) of the United States Department of Defense lists the capabilities adopted for anti-access strategies. Saint-Pierre and Vitelli (2018) list the same examples (Figure 3). The application of these capabilities occurs in layers in nations with more abundant defense resources (United States, 2012), relevant examples of which include China, Russia, and Iran (Krepinevich; Watts; Word, 2003). Naval, land, air, space, and cyber forces follow a unified command and control system and act together in such a way that if the opponent exceeds a certain capability, they become immediately exposed to others (United States, 2012).

Figure 3. Anti-access (A2) and area denial (AD) capabilities layers



Source: Figure prepared by the author (2023), adapted from United States (2012); Saint-Pierre and Vitelli (2018).

This evinces that the current military power of a nation follows a multi-domain perspective since it can affect the combat capacity of the adversary at more than one level (political, strategic, or tactical), one geographic dimension (sea, land, air, space) and other domain (such as cybernetics) (Sloan, 2008). This change in the geopolitical environment largely stems from technological advances, which have provided, among other things, the development of precise long-range strike capabilities, expanding conventional deterrent power (Teixeira Júnior, 2020). This context has given rise to ballistic and cruise missiles, which are relatively easy to obtain and operate but difficult to destroy, as the backbone of munitions to defend against asymmetric forces (Stillion; Orletski, 1999).

The ASTROS System, a manufactured material in Brazil with its design based on rapid mobility, saturation firepower, and the possibility of launching different calibers and munition from a single launch vehicle—AV-LMU (ASTROS, 2021)—can configure the framework of capabilities of a Brazilian A2/AD strategy (Alves, 2023). The current TCM development project for launch from the AV-LMU will add a 300-km range to the system, aiming only at fixed ground targets. This version adds combat and deterrence power to defend strategic priority areas in the Amazon (Alves, 2023).

The Congressional Research Service (United States, 2023) points out that important defense products adopted in A2/AD strategies show long-range precision and anti-ship capability from land launches, with rapid mobility and rapid dispersion from their launch position. The Manual of Fundamentals of the Operational Concept of the Brazilian Army Operations of Convergence 2040 subsidizes the evolution of the concept of transformation of the Brazilian Army and states that A2/AD strategies will require updating its military missile capabilities (Brasil, 2023).

Thus, the maritime space configures a likely scenario for future conflicts between States. The Brazilian Armed Forces currently have an operational gap regarding their ability to use cruise missiles equipped with sensors that can guide munitions toward moving targets at sea (Brasil, 2022a). This defense product is to be allocated to the second layer of AD capabilities (Figure 3).

A strategic defense company is currently developing anti-ship missiles (with a 200-km estimated maximum range) for the Brazilian and United Arab Emirates navies to be launched from vessels (Grupo [...], 2023). This system would occupy the first anti-access layer (A2) in surface combat ships (Figure 3). However, from a technological point of view, adaptations in project specifications may occur to meet operational requirements of the Brazilian Armed Forces.

In December 2024, this strategic defense company advanced toward this goal by launching a MANSUP missile, a short-range (70 km) anti-ship missile supported by an ASTROS AV-LMU vehicle belonging to the Brazilian Marine Corps (Wiltgen, 2024). Despite being only a proof of concept to evaluate the launch of MANSUP from land platforms, this initiative represents a significant innovation, with relevant contributions to the strengthening of the Brazilian defense industrial base and potential use in A2/AD defense in Brazil.

However, note that combining maximum range, launch pads, and targets to be neutralized or destroyed imposes operational constraints that increase the probability of impositions and the risk of affecting all other decisions and engineering solutions during the development of the defense product. Thus, the main challenge lies in the early identification of the zero requirements that will guide the engineering project design.

2.4 Zero requirements

Zero requirements constitute a class of demands related to defense systems development projects that represent unalterable operational needs that decisively affect aspects and functionalities of final products and strongly impact project costs and deadlines. Such requirements determine all phases of the engineering project and are related to the mission; operational environment; types of operation; functionalities to be performed; expected performances; necessary logistical support; and technological, material, or human constraints that may limit the procurement of the defense product.

The zero requirements for application to cruise missiles fall into eight categories, which include launch means, range, target types, accuracy, performance constraints, countermeasures, logistical aspects, and critical technologies (Guerra; Barreto, 2023).

3 METHODS

3.1 Type of research

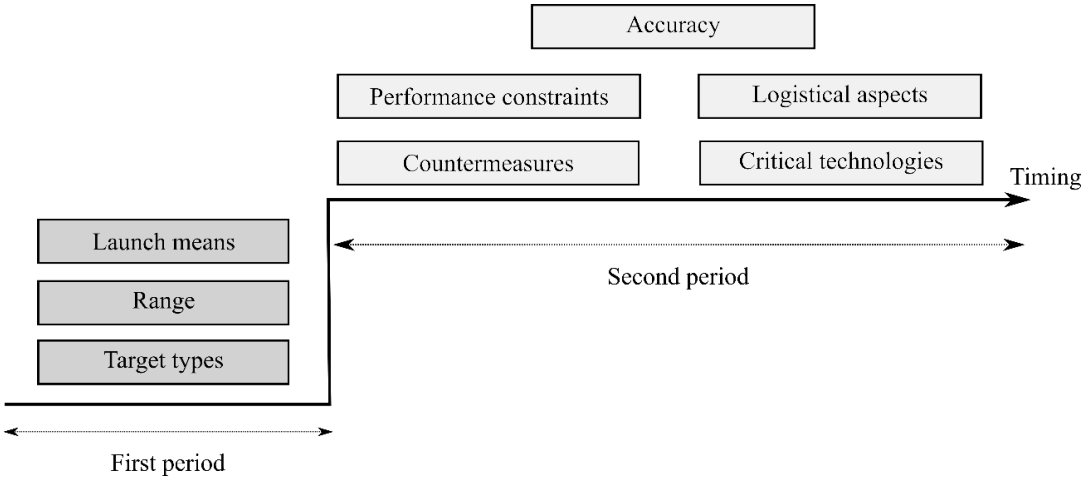
This theoretical and qualitative research encompasses data from the year 2000 to the present, from academic sources, government documents, and observation of events and specialists to find the needs and requirements for defense products within the geopolitical context in which they will be used. This descriptive and applied study sought solutions to practical issues and aimed to provide subsidies for decision-making regarding national defense. It used a bibliographic search of primary and secondary sources, survey procedures, and interactions with specialists in military operations and sponsors of defense projects whose main purpose is to increase the deterrent power of Brazil.

3.2 Procedure to define zero requirements

Practice has shown that a good approach involves segmenting the categories of zero requirements and treating them at two temporally distinct points in time (Figure 4). First, data related to the group formed by the categories launch means, range, and target types were defined. Then, accuracy, performance constraints, countermeasures, logistical aspects, and critical technologies were discussed. Only the first time period is discussed in this study.

The procedure in the first period treated the problem under the perspective of determining the fundamental mission, operational environment, context of action, and capabilities to be obtained. This approach achieved a broad view of the operational situation. This first stage obtained enough elements to detail issues such as the expected operational performance, necessary logistical support, relations with other defense systems, and technological constraints. Due to the specificity of these themes, it is appropriate to address the second period in studies dedicated to the subject.

Figure 4. Time division during the definition of zero requirements for cruise missiles



Source: Figure prepared by the author (2023).

4 RESULTS AND DISCUSSIONS

The theoretical framework above showed a potential gap in the operational capacity of the Brazilian Ground Force: the absence of ground-launched cruise missiles equipped with sensors that can guide munition toward moving targets at sea. Below, we present the results obtained at the first moment of this research to define zero requirements for cruise missiles (Figure 4).

4.1 Launch Means

Currently, the ASTROS System offers the Brazilian defense industrial base an airborne product with high ground mobility, great fire saturation capacity, many calibers, and possible employment in field artillery and coastal defense (ASTROS, 2021), with strong potential for use in A2/AD strategies. Developed by AVIBRAS, it will soon include a ground-to-ground TCM (AV-MTC, 2021), which, although limited to fixed targets, will contribute to increasing the deterrent capabilities of the Brazilian Army (Programa [...], 2022).

The development of TCM constitutes one of the objectives of the ASTROS Strategic Program, which includes implementing Fort Santa Bárbara (Formosa/GO) as a physical base for the missile and rocket artillery of the Brazilian Army (Silveira, 2022). The centralization at Fort Santa Bárbara facilitates logistics, maintenance, instruction, and training of operators and enables the Brazilian Army to use the system anywhere in the Brazilian territory in a timely manner to fulfill its defensive task and impose extra-regional deterrence (Lima Júnior, 2022).

Many military science researchers (Teixeira Júnior, 2020; Lima Júnior, 2022; Alves, 2023) consider the ASTROS System the most suitable choice to incorporate A2/AD

capabilities via land-launched anti-ship cruise missiles. This research obtained the same position from its initial interaction with the sponsoring agent: the Army Project Office, manager of the Army ASTROS Strategic Program. The importance of this preliminary contact stems from the addition of the following operational requirement: the AV-LMU launch vehicle should undergo no changes in its mechanical, hydraulic, and hardware systems, only software updates could be implemented.

The operational demand for the launch of anti-ship cruise missiles from the AV-LMU vehicle of the ASTROS System exemplifies a typical zero requirement. This requirement automatically restricts the limit of the total length of the munition, which must be compatible with the dimensions of the AV-LMU launcher container. The limitation decisively impacted the external aspect and the performance of the final product, especially regarding its maximum range.

4.2 Target types

The study of the Brazilian strategic environment in the theoretical framework found that the maritime space may configure a propitious scenario for future conflicts between States. Thus, adding anti-ship cruise missiles contributes to upgrading the Brazilian military capabilities, especially under the A2/AD concept.

The current composition of the ASTROS System (Alves, 2023) expands the Brazilian defensive capacity of its coast (Campos, 2021). However, even after including TCM, the system will have insufficient resources to intercept moving or stealthy targets and will endure significant limitations in restricting ships of various categories in naval warfare operations (Caldas, 2020).

A conflict at sea may involve several naval assets (such as surface ships, amphibious vehicles, and submarines) in operations to control maritime areas, deny the use of the sea, and project power over land. Amphibious operations stand out for their high demands regarding effective defense devices (which must include a ground force) and especially their artillery (Brasil, 2014).

Paiva (2015) believes that there is potential for hostile intentions from first-order powers with the military capacity to interfere in the independence and integrity of Brazil and harm its international projection regarding national interests. The author states that Brazil must have a conventional military power that can match the deterrence of military powers of the size of France and Great Britain. Figure 5 illustrates the current naval assets of countries with modern military arsenals.

According to the Use of Artillery in the Defense of the Coast manual (Brasil, 2014), artillery takes a central position in coastal defense. Specifically, long-range missiles must target enemy naval vectors at the greatest possible distance. Anti-ship cruise missiles must engage the following targets, according to the Brazilian Navy nomenclature (Santos, 2017): aerodrome ships; frigates; destroyers; corvettes; tank landing ships; multi-purpose dock ships; and troopships.

Figure 5. Examples of naval assets in amphibious operations

Mistral class (amphibious assault) - France

Cavour (aircraft carrier) - Italy

Charles de Gaulle (aircraft carrier) - France

Freedom class (light combat ship) - USA

Queen Elizabeth class (aircraft carrier)
Great Britain

Trieste class (amphibious assault) - Italy

Source: Figure prepared by the author (2023), adapted from Williams *et al*. (1999).

4.3 Range

The range of cruise missiles is related to their dimensions, total weight, engine, flight height, among many other factors (Fleeman, 2012). Of these, engine type (and thus its flight regime[3]) strongly influence the maximum range of the munition. Supersonic and hypersonic

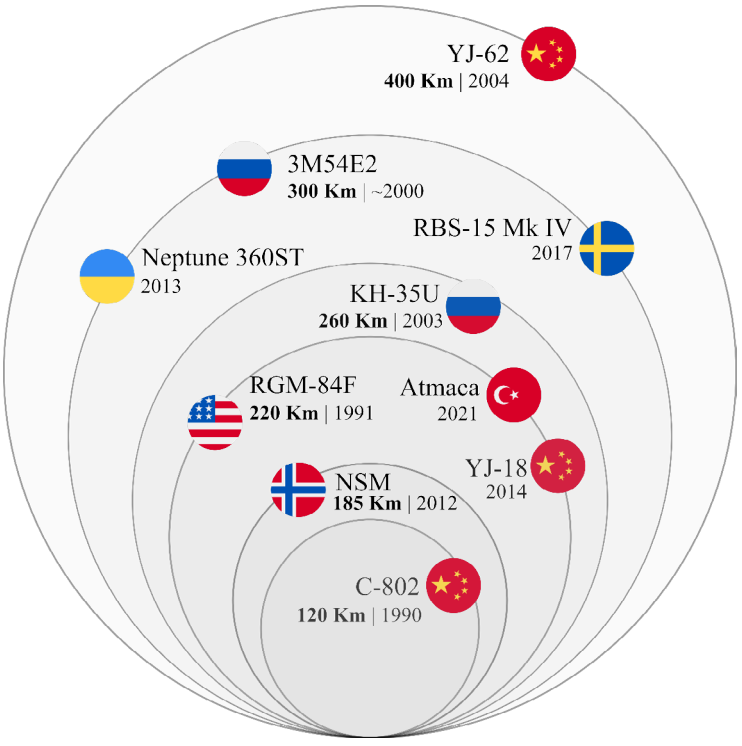
3 Subsonic regimes occur when velocities remain below the speed of sound (Mach 1). In supersonic regimes, velocities range from Mach 1 to Mach 5. In hypersonic regimes, velocities exceed five times the speed of sound (March 5) (Anderson Jr, 2011).

flights consume significantly more fuel than subsonic flights (Anderson Jr, 2011). Thus, munitions that fly at speeds above that of sound tend to require a larger fuselage than subsonic missiles to hold a greater amount of fuel.

The definition of the launch of a munition from the ASTROS System AV-LMU limits its maximum length and height (a zero requirement for launch means). Thus, one option to extend the range refers to performing most of the cruise flight at subsonic speeds (which offer better energy efficiency). China adopts this strategy on its YJ-18 (220-km range), covering the initial 180 km at Mach 0.8, increasing this speed to its terminal value of Mach 2 to 3 only in its final 40 km to hinder the defenses of enemy ships (United States, 2015).

Figure 6 illustrates the range of the main anti-ship cruise missiles currently in operation, which are launched from the ground by vehicles and which operate at subsonic speeds for most of their cruise flight. Ranges are considerably lower than those of cruise missiles targeting ground targets (greater than 1,000 km in Chinese, Russian, and American examples) (United States, 2020). This fact stems from, for example, the need for systems with radar technology to enable terminal navigation toward moving targets at sea, which tend to have a high weight and large voluminous fuselage, which reduces fuel capacity (Guerra, Barreto; 2023).

Figure 6. Range of subsonic anti-ship cruise missiles launched from the ground. The year represents the date of entry into operation



Source: Figure prepared by the author (2023), adapted from Missiles... (2023); Missiles database... (2023).

Figure 7. Examples of ground-launched anti-ship missiles

YJ-62 - China

Naval Ship Missile (NSM) - Norway

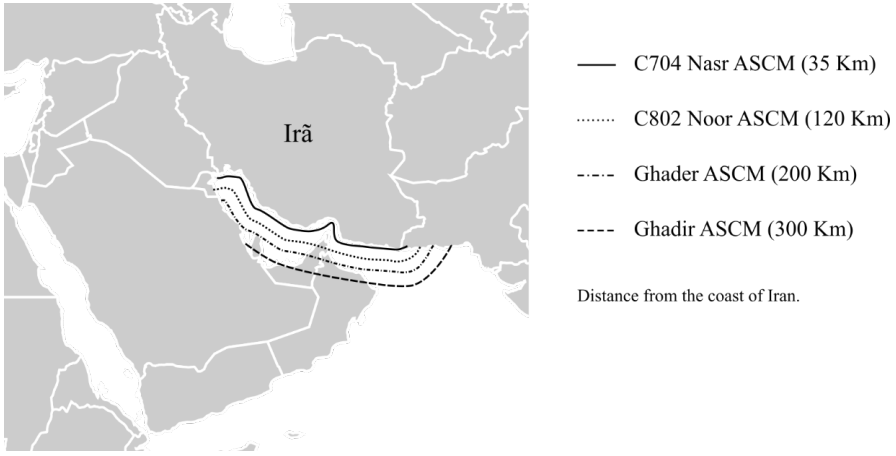
Neptune 360ST - Ukraine

KH-35U - Russia

Source: Figure prepared by the author (2023), adapted from Missiles... (2023).

The arsenal of Iranian anti-ship cruise missiles shows the same range. The country has heavily invested in this type of munition, which can reach ranges of up to 300 km with the Ghadir (Figure 8), launched from the ground and ships (United States, 2019).

Figure 8. Iranian anti-ship cruise missile ranges



Source: figure adapted from United States (2019).

Currently, the US subsonic Tomahawk missile is no longer launched from the ground, but it offers an important reference for cruise missile developments. Its latest anti-ship version (Block Va), introduced in 2021, featured significant innovations such as new terminal sensor technology and a new warhead, extending its range from 460 (BGM-109B version, operational from 1983 to 1994) to 1852 km (Larter, 2021; Tomahawk, 2023). This prominence in relation to analogues from other nations also results from constant improvements in its turbofan-type reaction engine and a fuel specially developed for aeronautical engines (JP-10) (UGM [...], 2018). However, such technological advances took place after decades of investments in science, technology, and military innovation, configuring the state of the art of military missile engineering in the West (Tomahawk, 2023).

From the above, the range of a first anti-ship cruise missile for the Brazilian Armed Forces capable of operating in the second layer of A2/AD capabilities (Figure 3) should range from at least 200 to 300 km based on the current anti-ship arsenal of China, Russia, and Iran, highlighting the application of the A2/AD operational concept. However, considering range as an unalterable operational requirement that strongly impacts the search for maximum extra-regional deterrence, 300 km constitutes the most appropriate value. This value equals the one achieved by TCM and would still enable national exports since it complies with the Missile Technology Control Regime (Missile Technology Control Regime, 2023).

At this point, defining zero requirements at a very early stage of munition development offers advantages that enable preliminary engineering studies to find the feasibility of a Brazilian version with a range from 400 to 500 km, matching the Chinese YJ-62 or the first anti-ship Tomahawk (BGM-109B).

4.4 Description and organization of the zero requirements

This study ordered the chosen three zero requirements by classifying them into an ascending order of the immutability of their categories. The means of launching configure the main operational requirement according to the sponsoring agent, and must remain unchanged under any circumstances. Target types should include surface warships, defining the fundamental mission of the munition as part of the Brazilian A2/AD operational concept. As its third requirement, this study set the maximum range of the missile to at least 300 km under any flight conditions, including at altitudes close to the sea (the immutability of the operational demand falls on this value).

The description for each zero requirement included the following information fields: numbering (relative ordering of the three categories), drafting of the requirement, and justification (Table 1).

Table 1. Categories: Means of launching, target types, and range of the zero requirements for a cruise missile for anti-access defense and area denial in Brazil

Category	Numbering	Requirement	Justification
Launching means	0.1	The cruise missile is to be launched by the ASTROS AV-LMU without modifications to its mechanical, hydraulic, and hardware systems. Only software updates will be allowed.	The missile is to be launched from the same platform on which conventional rockets of the ASTROS system are launched, greatly facilitating logistics, especially regarding the components of the launch vehicles.
Target types	0.2	To neutralize or destroy surface ships, such as carriers (or aircraft carriers), frigates, destroyers, corvettes, tank landing ships, multi-purpose dock ships, and troopships. Targets should include naval assets of the first-order powers and their respective defense systems.	Brazil must have a conventional anti-ship military power that can counter the naval force of military powers of, for example, France, and Great Britain.
Range	0.3	The maximum range shall exceed 300 km under any flight conditions, including at altitudes close to the sea (sea skimming).	The maximum range of at least 300 km would match the national anti-ship capability with that of the current TCM for fixed ground targets. This would position the new anti-ship cruise missile at the same level of maximum range as those from the main military powers, enabling exports by the Brazilian defense industry. However, the possibilities of extending this range from 400 to 500 km should be considered toward a Brazilian version that can match the current Chinese YJ-62 missile.

Source: Table prepared by the author (2023).

5 FINAL CONSIDERATIONS

The new geopolitical panorama of Latin America and the characteristics of the Brazilian territory and its current defensive challenges demand that Brazil increase its strategy of conventional deterrence. It must adapt to the current multi-domain geostrategic operational environment. Thus, the concept of A2/AD can anchor a solid Brazilian extra-regional deterrence.

Of the layers of A2/AD capabilities, anti-ship cruise missiles stand out as defensive weapons against asymmetric forces, featuring in the arsenals of the major global powers. The current level of Brazilian technological missile domain can enable the country to invest in improving and updating systems that contribute to the ongoing transformation of the Brazilian Army in line with the guidelines of its National Defense Strategy. This investment may develop a national ground-launched anti-ship cruise missile as an evolution of its

current TCM or as an adaptation of the MANSUP-ER project to enable on-board and ASTROS launches.

Applying the concept of zero requirements proved relevant to find immutable operational demands that decisively impact the appearance and functionalities of the final solution. This study defined the means of launch as the primary operational requirement after initial interactions with the sponsoring agent. A Ground Force-operated anti-ship cruise missile is expected to be launched from the ASTROS System AV-LMU without any changes to its physical systems. The mobile ASTROS System can rapidly distance itself from the launch position, offering it A2/AD capabilities with high long-range accuracy. After launching, the munition is expected to engage carriers, frigates, destroyers, corvettes, tank landing ships, multipurpose dock ships, and troopships, i.e., means that act in amphibious operations by naval forces from first-order powers. This research set the maximum range of the missile as at least 300 km, similar to that of the arsenal of major military powers such as Russia, China, and Iran. Such reach also enables the national defense industry to export it as it lies within the Missile Technology Control Regime limits.

Another significant result from applying the zero requirements refers to the early finding of the possibility of initiating technical and feasibility studies to extend the range from 400 to 500 km in Brazilian missiles launched from the ASTROS System AV-LMU. Preliminary studies can find the needed technologies or innovations and their associated costs and timescales to obtain the achievements of world leaders in anti-ship defense.

This study offers a more detailed understanding of the material to be developed, gathering technological data that can complement other subsidies to support the sponsoring authority for strategic decision-making.

Finally, future studies should continue research by defining the logistical aspects, the countermeasures to neutralize threats from cruise missiles, and the critical technologies to render such enterprises viable.

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