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Requirements for an Attack Remotely Piloted Aircraft System for the Brazilian Army

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Abstract

This paper presented a method for capturing system requirements and applied it to the design of an Attack Remotely Piloted Aircraft System intended to address operational needs of the Brazilian Army in the fulfilment of its constitutional missions. The study considered both wartime operations and interagency cooperation in non-war situations involving illegal activities. The method identified the mission need and defined the project objectives, goals, constraints, and assumptions. It subsequently developed the Concept of Operations and Use Case diagrams to support requirements elicitation. Its application captured the main system requirements and organized them according to the operational capabilities and functions required for the intended missions. The resulting requirements provided an initial structured basis for subsequent system definition and development activities. The study concluded that the proposed method supported the systematic elicitation of requirements for the considered military application and provided a basis for further refinement toward a complete system concept.

1. Introduction

Technological advances pose challenges to modern armed forces, which must adapt and conduct continuous studies to remain capable of responding to threats in a dynamic and multidimensional environment.

For a country with continental dimensions, such as Brazil, this undertaking becomes even more important because of the difficulty of integrating, controlling, and defending a territory of approximately 8.5 million km². Air power is therefore essential to provide the response speed and firepower required for this mission.

Given the different types of threats (foreign invasions, international drug trafficking, illegal exploitation of natural resources, etc.) that may arise sequentially or simultaneously against national sovereignty, public security, and border control, this air power cannot be provided with the required effectiveness by a single institution (the Brazilian Air Force) without support from the others [1]. Broad and continuous interagency surveillance is therefore required, including participation by the institution with the greatest nationwide presence: the Brazilian Army.

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For these reasons, Army Aviation (the Land Force's aviation branch) must possess the means to project such air power, with capabilities not only for troop transport, surveillance, and reconnaissance, which it already possesses, but also for lethality.

Recent combat experience in conflicts around the world has demonstrated the effectiveness, efficiency, and potential of Remotely Piloted Aircraft Systems (RPAS) to destroy enemy military equipment, obtain imagery of force positions, and eliminate high-value human targets [2]–[6]. Compared with manned aircraft, RPAS also offer lower acquisition, operating, and maintenance costs, as well as reduced exposure of operators during missions [7], especially in adverse weather conditions recognized to be challenging for manned aircraft [8], [9]. Their use is consistent with the trend of assigning combat missions to lighter, smaller, and less expensive aircraft [10].

This context indicates that an attack-capable RPAS can enable Army Aviation to project lethal air power, complementing its existing capabilities and supporting the Brazilian Army in the fulfilment of its constitutional missions, thereby contributing to national sovereignty. Moreover, such a project is important for maintaining Brazilian technological and military capabilities at a level compatible with those of leading countries that develop and operate UAS, such as the United States, Russia, Türkiye, France, and China, which field multiple RPAS in different

configurations and for a wide range of operational roles [1], [11].

Accordingly, this paper aims to present a Systems Engineering method and apply it to capture the requirements of a system capable of providing the Brazilian Army with an air asset with attack capability for the fulfilment of its constitutional missions.

2. Theoretical background

According to INCOSE's latest definition, Systems Engineering is a transdisciplinary activity that supports and enables collaboration among all disciplines involved in product conception. It may be applied in different ways according to situational factors or its suitability for the problem to be solved [12]. The term 'transdisciplinarity,' replacing the previously adopted term 'interdisciplinarity,' emphasizes the importance of an integrated view of the problem. Under this approach, different fields of knowledge interact collaboratively and transcend disciplinary boundaries, rather than each contributing separately from its own specific perspective.

Systems Engineering addresses performance and cost throughout the entire product life cycle. These principles are applied to defense acquisitions, as shown by [13], [14], which commonly involve complex systems with high acquisition costs and are generally operated for several decades.

Regarding costs, a matter of major importance in public procurement, Systems Engineering focuses on anticipating problems and reducing the costs committed early in the project, which affect the final feasibility of the developed product. Neglect of the early development phases increases life-cycle expenditure. As shown in Fig. 1, total expenditure on a product over thirty years may generally be five times its acquisition price [15]–[18]. This effect is aggravated when supportability and maintainability during product operation have not been properly structured from conception [19], [20].

The potential of Systems Engineering may therefore contribute to meeting the Land Force's operational needs concerning an attack capability for its aviation branch, while remaining compliant with budget constraints, increasing the operational outcome benefiting Brazilian sovereignty over investment.

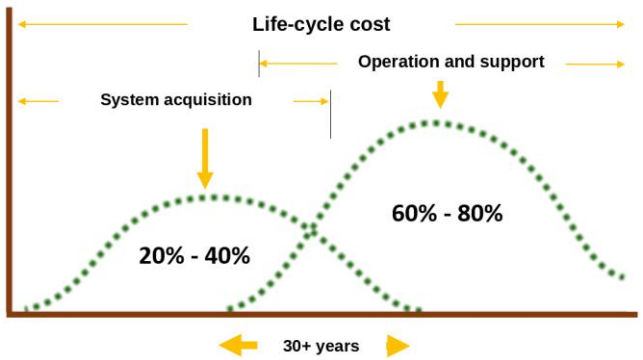


Fig. 1. Distribution of costs across the life cycle, comparing product acquisition costs with operation and support expenditure (adapted from [16]).

3. Method

To initiate the conceptual development of the system required by the Brazilian Army, a Systems Engineering method for requirements capture is proposed. The method combines documentation-based approaches (sometimes referred to as "Traditional" or "Legacy" Systems Engineering [17]) and model-based approaches, drawing on [21]–[26]. It consists of seven steps:

- **Step 1: Mission Need Identification**: in which the development team clarifies with project stakeholders the highest-level need to be addressed through development of the system. This need should be translated from customer language into engineering language, as recommended in the literature [25];
- **Step 2: Definition of Project Goals and Objectives**: in which the mission need is decomposed into more specific goals that clarify how it will be satisfied, and the quantitative values (objectives) considered appropriate and sufficient for achieving each goal are defined;
- **Step 3: Identification of Constraints and Assumptions**: in which the main external constraints on the project, its interfaces, or its in-service operation are identified, together with the assumptions adopted;
- **Step 4: Assignment of Responsibilities**: in which the principal roles of those involved in the project are assigned;
- **Step 5: Development of the Concept of Operations**: in which concepts are established for nominal situations (with the system operating under the conditions for which it was designed) and non-nominal situations;
- **Step 6: Development of Use Case Diagrams**: which present the system's functions from the perspective of its users in order to achieve the established objectives;
- **Step 7: System Requirements Elicitation**: in which models, in the form of requirements diagrams, are proposed to describe functional and non-functional requirements and their relationships

Regarding Step 6, Development of Use Case Diagrams, use cases have been regarded as a mechanism for capturing system functional requirements in terms of system uses, as described in [27]. In use cases, system users are represented by actors, which may be external systems, entities, or people interacting with the system.

The use of model-based systems engineering (MBSE) diagrams contributes to a better understanding of the system and a shared vision of its behavior by developers, users and other stakeholders, and the use of specialized software to model the system improves traceability and consistency [28].

Finally, the organization of the method into steps provides a formal structure but does not require them to be performed sequentially. The method is strongly iterative: each step produces results that may be used to refine or revise the others.

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4. Case study

The application of each step of the proposed method to capture the requirements of an Attack Remotely Piloted Aircraft System intended to meet the operational needs of the Brazilian Army in the fulfilment of its constitutional missions is presented below.

4.1. Step 1: Mission Need Identification

The relevant stakeholders were identified through meetings and interviews, and the project Mission Need was subsequently defined as follows:

"The Brazilian Army needs a low-cost air asset capable of conducting reconnaissance and attacks against high-value targets of different types in areas where air superiority is unavailable."

4.2. Step 2: Definition of Project Goals and Objectives

The project goals and objectives were also defined jointly with the stakeholders, and an extract of the results is presented in Table I. Some of the listed objectives, particularly those related to reconnaissance, surveillance, and monitoring, have dual-use applicability: they apply not only to wartime situations but may also support interagency efforts undertaken by the Brazilian State as a whole through its various oversight and enforcement bodies, such as the Armed Forces, police forces, and government agencies, to prevent cross-border crimes (including trafficking and smuggling) and environmental crimes (including illegal extraction of natural resources, wildfires, and deforestation). Requirements related to long-range or long-endurance flights over regions such as the Amazon rainforest, the Pantanal wetlands, or the Brazilian Exclusive Economic Zone may enable surveillance and monitoring of these areas.

Table I. Extract of project goals and objectives.

Goals	Objectives
Goal 1: Conduct target and area reconnaissance	Obj. 1.1: Conduct flights with 4 h endurance Obj. 1.2: Conduct flights with 120 km range Obj. 1.3: Acquire UV and visible-spectrum imagery of the overflown area Obj. 1.4: Transmit data at TBD kbps
Goal 2: Conduct air-to-ground attacks (personnel, materiel, and facilities)	Obj. 2.1: Be capable of penetrating more than 150 mm of steel protected by reactive armor Obj. 2.2: Be capable of antipersonnel action with a lethal radius greater than 30 m Obj. 2.3: Be capable of causing fires above 800 °C for at least 20 seconds
Goal 3: Conduct air-to-air attacks against other aircraft	Obj. 3.1: Be capable of maneuvering at an acceleration of 2 g Obj. 3.2: Be capable of hitting targets moving at speeds of up to 50 m/s Obj. 3.3: Be capable of penetrating more than 15 mm of steel Obj. 3.4: Be capable of autonomously tracking targets within a 30° field of view

4.3. Step 3: Identification of Constraints and Assumptions

The constraints and assumptions identified in view of the budgetary, regulatory, and operational context are presented below.

Constraints:

- Constr 1: The system shall comply with flight-safety regulations (Brazilian Civil Aviation Regulations and applicable military standards).
- Constr 2: The system shall be capable of communicating with ground stations and other aircraft in operation.
- Constr 3: The system shall be capable of being carried by dismounted troops.
- Constr 4: The system shall have a maximum cost of R$ 300,000 (three hundred thousand Brazilian reais) per aircraft.

Assumptions:

- Assum 1: Air superiority is not required to employ the RPAS.
- Assum 2: The RPAS constitutes a family of systems (FoS), with different types of aircraft specialized to perform different tasks on the battlefield.

4.4. Step 4: Assignment of Responsibilities

An extract of the assignment of responsibilities, established to support project management and human-resource allocation, is presented below:

a) Sponsor: Fund the project;

b) Marketing Department: support the capture of customer needs and market trends;

c) Finance Department: perform budget and feasibility analyses jointly with engineering;

d) Project Manager: coordinate the project team;

e) Aerodynamics Specialist: perform the system's aerodynamic design;

f) Propulsion Specialist: develop the system's propulsion design;

g) Structures Specialist: develop the system's structural design;

h) Airborne Weapons Specialist: develop the system's weapon-integration design;

i) Systems Engineer: balance the various system domains, conduct trade-off studies, and provide technical oversight of project development.

4.5. Step 5: Development of the Concept of Operations

To continue the conceptual development of the system, one ConOps (Concept of Operations) diagram was developed for a nominal scenario and another for a non-nominal scenario, illustrating the application of the method:

a) Nominal Scenario: as shown in Fig. 2, two RPAS (RPAS A and RPAS B) observe and attack enemy positions

while exchanging information. A third RPAS (RPAS C, a loitering munition with explosives integrated into its structure, which is destroyed together with the target during the attack), shown on the right, flies a search pattern. Upon finding a high-value target, RPAS C dives into it, striking the target and detonating.

b) Non-Nominal Scenario: shown in Fig. 3, in which RPAS B has been lost. This compromises the ability to attack some structures (in the example, industrial facilities that are now outside the range of RPAS A and RPAS C) and degrades the reconnaissance capability of the RPAS network (the infantry troops that are no longer under observation). Even so, the remaining RPAS are still capable of identifying and attacking targets.

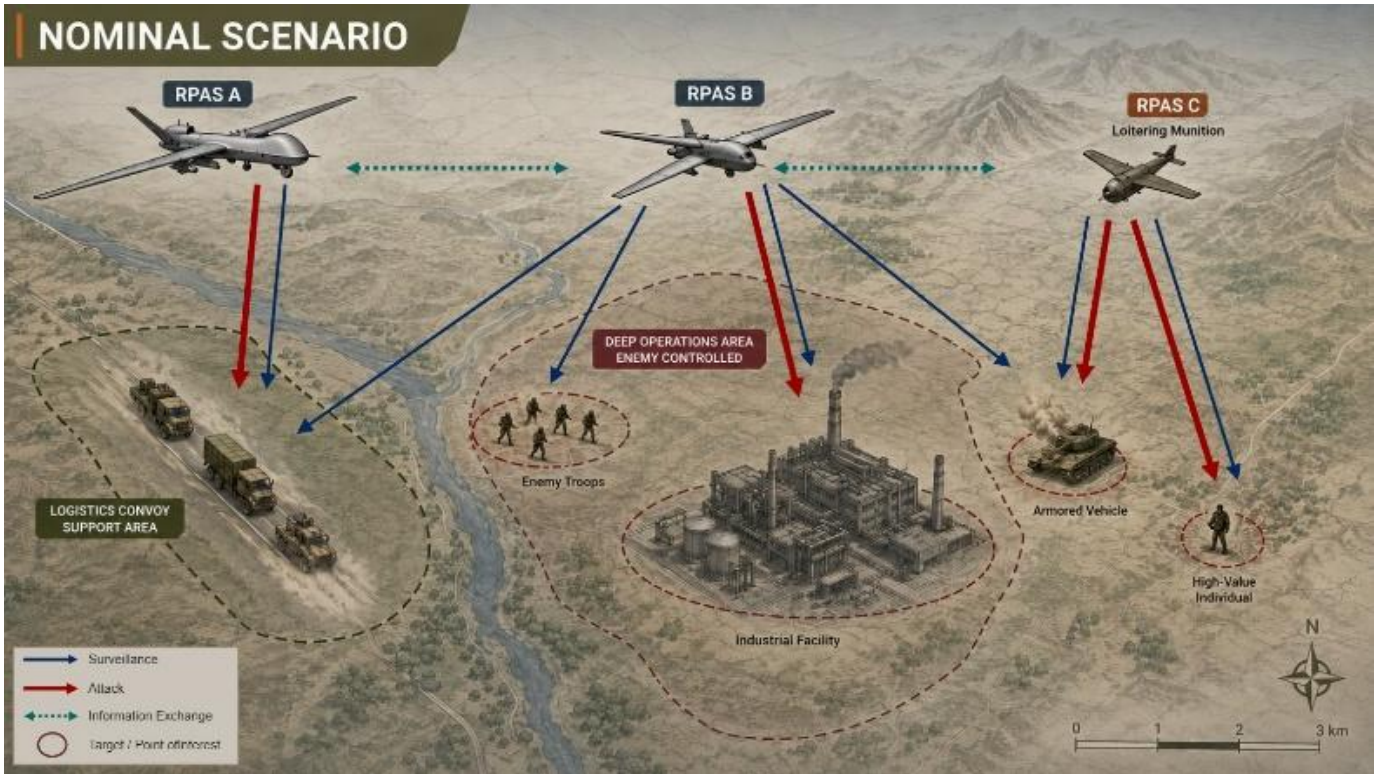


Fig. 2. Nominal Scenario (with RPAS dedicated to identifying targets for the other systems located elsewhere in the combat zone).

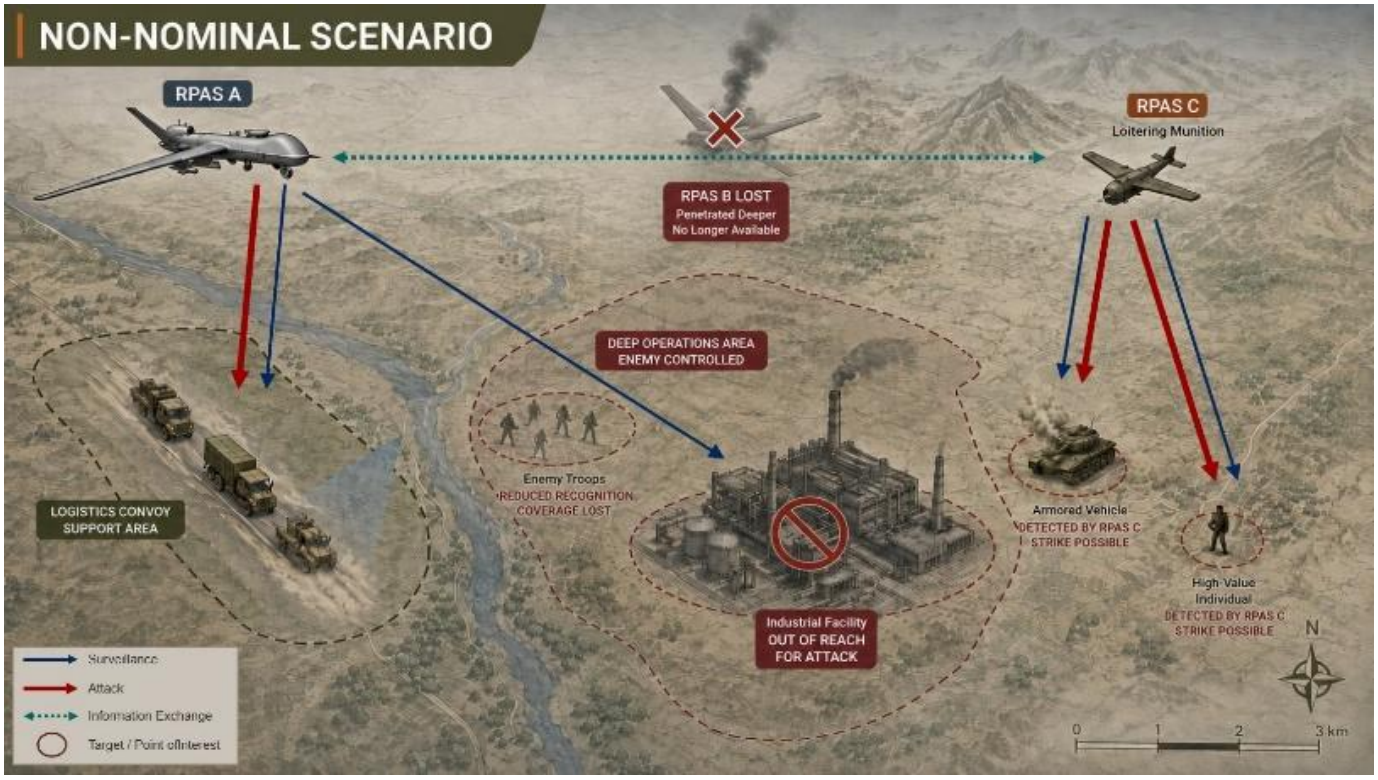


Fig. 3. Non-Nominal Scenario (RPAS B, which had penetrated deeper into enemy territory, was shot down; each RPAS must detect its own targets, resulting in the loss of information about other targets).

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4.6. Step 6: Development of Use Case Diagrams

As presented in Steps 1 and 2, The Remotely Piloted Aircraft System must provide reconnaissance and monitoring capabilities, including border monitoring and the monitoring of the position and movement of opposing troops or hostile elements in areas of interest. The RPAS must also provide attack capability. In non-war situations, the monitoring capability should also support additional activities, contributing to interagency border monitoring and the prevention of illegal activities, such as trafficking, smuggling, illegal extraction of resources, and environmental crimes, including wildfires. The RPAS must also provide attack capability to conduct attacks of opportunity against high-value targets or deny unrestricted use of the airspace, inflicting losses and forcing opposing forces to keep air-defense assets mobilized.

In this step, the capabilities described in the previous paragraph were decomposed into functions, and into subfunctions where appropriate, to develop the Use Case diagram shown in Fig. 4 using Capella (ArcML).

In this diagram, the RPAS performs the functions of taking off, landing, detecting targets, transmitting and receiving target data, entering safe mode (to avoid risks to other aircraft and people on the ground in the event of a failure), using ECM (Electronic Countermeasures), flying in formation, and engaging targets.

Other air and ground reconnaissance and attack vehicles also perform the functions of exchanging target data and engaging targets. Air and ground transport vehicles, in turn, are not capable of engaging targets.

Targets may be enemy troops or various vehicles considered high-value targets, meaning that attacking them is worthwhile either because of the extent of the damage they may inflict on the enemy (important officers and commanders; expensive or difficult-to-replace materiel; critical logistics support; etc.) or because of the tactical advantage to be gained (for example, assisting in the capture of key terrain). Enemy elements (troops and vehicles) are therefore associated with the detection and engagement functions.

Target detection includes the functions of identifying targets and exchanging target data, which may be regarded as subfunctions because they are linked to the main function.

The use of ECM is important for the RPAS and for reconnaissance and attack aircraft to reduce their exposure to enemy fire.

However, given the cost and volume constraints of the Attack RPAS, which require a feasibility analysis of the equipment carried on board, and considering its lower replacement cost and the absence of human lives on board, the RPAS is not assigned the function of employing anti-missile countermeasures. Manned attack aircraft, by contrast, are more expensive to replace and carry crews, which justifies the use of onboard systems that provide this capability.

The ground segment, comprising radars and command centers, is associated with functions involving the exchange of various types of data.

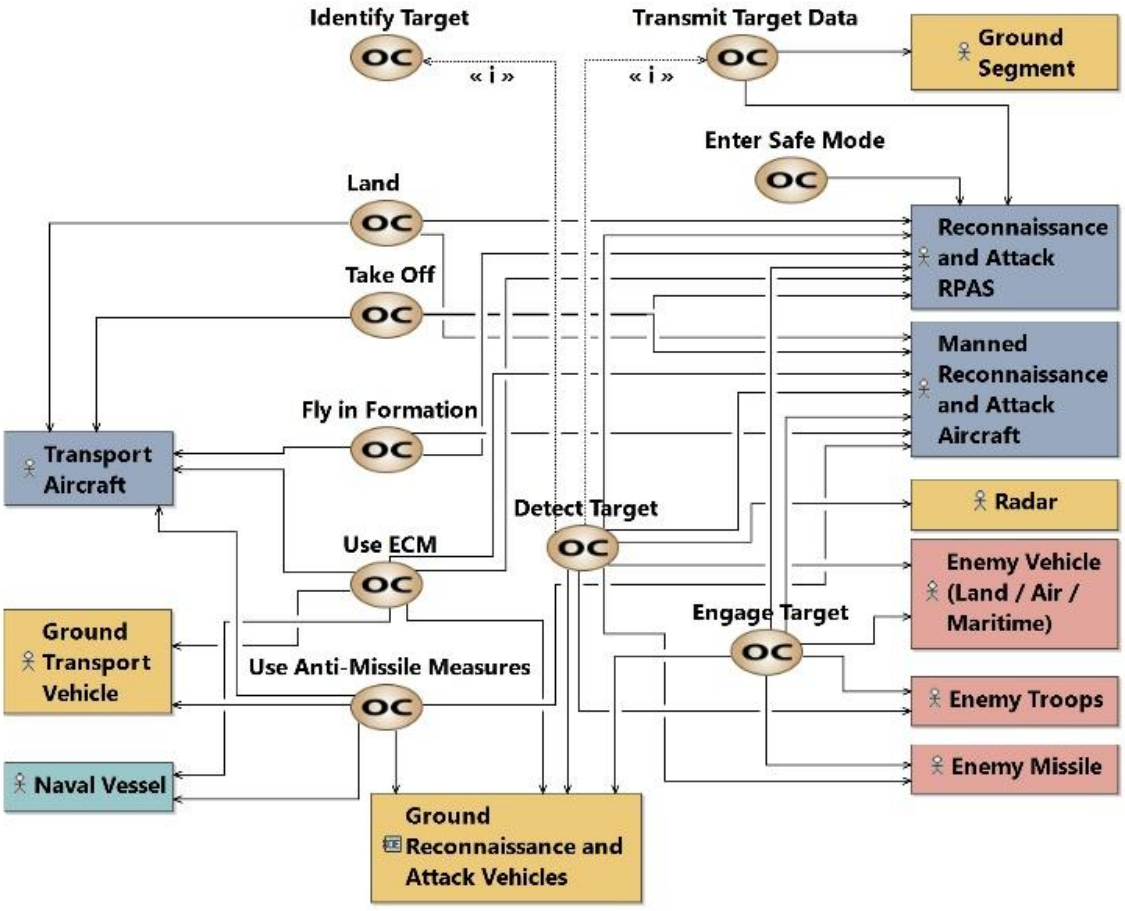


Fig. 4. Use Case Diagram for the Attack RPAS.

4.7. Step 7: System Requirements Elicitation

For the Attack RPAS, system requirements (functional and non-functional requirements) were identified to guide product development. These requirements were modelled using Capella (ArcML). An extract of the resulting diagram, containing four of the main captured requirements, is presented in Fig. 5.

The main functional requirements captured, identifying targets and taking off from unprepared runways up to 50 m long, are related to RPAS performance.

Target identification is the first action the RPAS must perform to satisfy the system mission need, both for reconnaissance and for attack. Short-runway takeoff is particularly important when airfields have been attacked or are unavailable, or when troops operate in areas without robust infrastructure, such as several regions of the Amazon and Central-West Brazil.

Through target identification, the system may support the monitoring and attack of targets by directing fires from other systems operating jointly, including aircraft, artillery, and infantry. In non-war situations, the same identification capability may be used to detect illegal activities, such as the presence of unlawful aircraft or vessels in Brazilian territory or the Brazilian Exclusive Economic Zone, illegal extraction of resources, illegal deforestation, or wildfires.

Short-runway takeoff is important to make the system versatile and enable its effective employment in the combat zone.

Among the non-functional requirements captured, two stand out: communication with legacy systems and safe mode.

Communication with legacy systems is an important interface requirement intended to enable interoperability among systems, allowing them to operate in a Theatre of Operations as a true System of Systems. The new product will therefore complement the resources already available and operate in an integrated manner, effectively adding capabilities to the Brazilian Army and providing new courses of action.

This interface compatibility avoids wasting resources on the acquisition of an entirely new ecosystem of radios and components and, depending on the case, on the recertification of aircraft already in operation because of modifications required to integrate new communication systems, which is very costly. It also avoids the need to train personnel to operate new compatible communication systems.

Thus, although they are not directly linked to mission accomplishment (theoretically, any communication system could meet the bandwidth and transmission-rate requirements needed to exchange target data), interface requirements are important to project feasibility.

Another non-functional requirement concerns safe mode, in which the RPAS shall operate in the event of loss of control or any situation that endangers other aircraft or personnel on the ground. This requirement is intended to comply with flight-safety regulations [28]–[30] and avoid events that may have negative public repercussions.

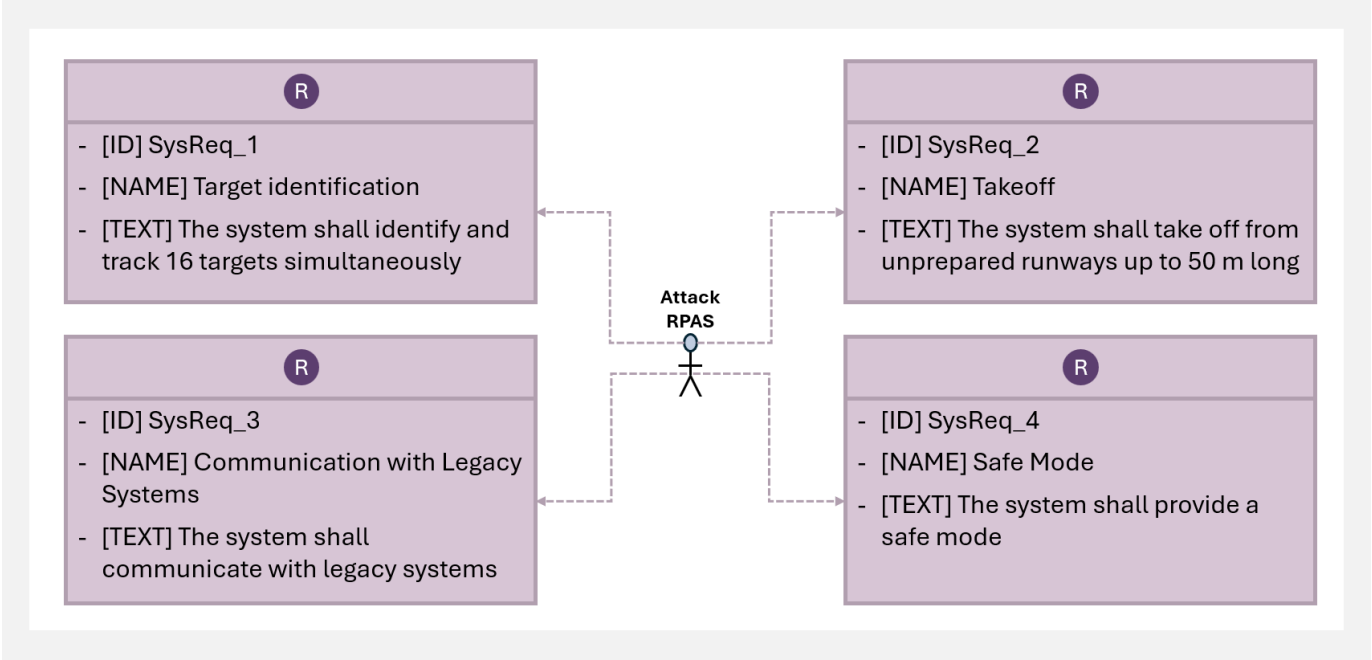


Fig. 5. Extract of the System Requirements diagram.

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5. Results and discussion

During the application of the method proposed in this paper, several strengths and practical observations were identified, as discussed below.

The method was effective in identifying and refining system requirements, finding inconsistencies, verifying the interfaces between the RPAS and legacy systems, examining ergonomics (the interaction between the system and human operators/actors), and identifying new operational requirements.

The models developed in Capella (ArcML) contributed to improving understanding of all the aspects presented and facilitated requirements traceability and documentation consistency; that is, when a requirement or function is changed, all derived requirements or functions should be reviewed.

A structured method for capturing the requirements of an attack-capable RPAS may also support project management by defining the technical documentation to be delivered at each project stage. The iterative nature of the method was also found to enable greater interaction among stakeholders and better use of time.

Regarding the application, this study covered several functions envisaged for the RPAS, including both target-attack functions and area-surveillance and monitoring functions. The same RPAS configuration may therefore support not only wartime scenarios but also non-war scenarios, such as border surveillance against trafficking and smuggling, illegal resource extraction, and environmental crimes.

6. Conclusions

This paper presented a Systems Engineering method focused on the system requirements capture process and applied it to initiate the conceptual study of a system capable of providing the Brazilian Army with an air asset with attack capability for the fulfilment of its constitutional missions, identifying its main requirements.

The use of diagrams benefited the method by making the visualization of the system interacting with its environment, users, and adversarial elements more intuitive, and by improving the understanding of the requirements, thereby providing participants with a clearer and more consistent view of the project.

Because this paper did not intend to complete the conceptual development of the Attack RPAS, the following directions for future work are proposed to support system design

First, it is proposed to conduct the complete conceptual study, presenting architectural alternatives for the Attack RPAS and subsequently analyzing their advantages and disadvantages to provide a stronger basis for concept selection;

Finally, future work may extend the study to the design of an entire family of Reconnaissance and Attack RPAS, with different architectures for different uses and mission characteristics, while maintaining some commonality of components and solutions and analyzing the corresponding commonality metrics.

Conflicts of interest

The authors declare that there are no financial, commercial, political, academic, or personal conflicts of interest related to the conduct and publication of this research.

Author contributions

D. E. Casale: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Supervision, Writing – original draft, Writing – review and editing. **R. C. da Silva**: Investigation, Writing – review. **C. H. N. Lahoz**: Supervision. **L. E. V. Loures da Costa**: Supervision, Funding acquisition.

All authors have read and approved the final version of the manuscript and assume full responsibility for its accuracy, integrity, and originality.

Data availability

The data supporting the findings of this study were already presented in the paper. Additional information is available from the corresponding author upon request.

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