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Benchmarking of Military Systems Applied to an Unmanned Aircraft Project

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Abstract

This paper presented a systematized method for benchmarking military systems and applied it to military attack Unmanned Aircraft Systems (UAS). The study sought to contribute to the development and acquisition of these systems by the Brazilian Armed Forces. The method comprised three stages: selecting the design characteristics for analysis, establishing criteria for system selection, and conducting the benchmarking study. The application compared systems similar to the system under development according to the defined characteristics and selection criteria. It identified the main characteristics of those systems and established a shared understanding among the participants involved in the project. The results showed that the proposed sequence organized the benchmarking process and supported the examination of comparable attack UAS. The study concluded that the method provided a structured basis for benchmarking military systems and supported activities related to the development and acquisition of attack UAS by the Brazilian Armed Forces.

1. Introduction

Military conflicts have traditionally been accompanied by periods of substantial technological advancement aimed at obtaining tactical and strategic advantages on the battlefield. During decisive moments such as these, which may determine the continuity or dissolution of a nation-state and affect the cultural, social, and economic identity of its people, all available resources are employed.

The expansion of social media, access to the Internet, and broader access to information have facilitated the dissemination of information on the use of new technologies and the adaptation of established technologies for new purposes in modern conflicts, thereby bringing the role of engineering in warfare into greater prominence.

In this context, Unmanned Aircraft Systems (UAS) have been widely employed in combat. Their advantages include lower operating costs, an important consideration for sustaining aircraft availability [1], [2]; greater transportability due to their smaller dimensions; lower weight compared with manned aircraft; and reduced risk to personnel [3], [4]. This reduction is particularly relevant in critical operational conditions, including adverse weather [5] and contested airspace where air superiority has not been established. Military UAS may support search and rescue, surveillance, reconnaissance, intelligence, attack, and target identification missions [6]–[9].

For the development of a UAS, as with other systems, it is important to identify the characteristics of comparable existing systems from the earliest project phases. This activity helps establish a shared understanding among stakeholders of the technological possibilities and limitations associated with the intended product and supports the definition of an initial design baseline. In this context, benchmarking can provide relevant support during the early stages of the project by grounding stakeholder expectations before major design decisions are required. Such decisions are inherently complex and may have substantial downstream consequences, since changes introduced early in development can propagate across multiple system characteristics and project constraints [10].

Observation and comparison are part of human nature and are often intuitive. It is difficult to assign an absolute value to something without a reference for comparison. For example, determining whether 45 minutes represents adequate endurance for a surveillance UAS requires knowledge of the values achieved by aircraft in the same category.

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Similarly, determining whether R$ 500,000.00 is excessive for the acquisition of a UAS model requires knowledge of competing systems with similar capabilities.

Accordingly, benchmarking is important for assessing product characteristics and quality, expected performance levels and the costs associated with each performance level [11], as well as for supporting process improvement, organizational restructuring, and knowledge generation [12], [13], being ultimately important to the success of its application [14].

Against this background, this paper presents a systematized method for benchmarking military systems and applies it to military attack UAS, thereby supporting their development and acquisition by the Brazilian Armed Forces

2. Theoretical background

Benchmarking is defined in the literature as a systematic activity for evaluating products, services, and processes with the aim of achieving organizational improvements, rationalizing procedures, and improving understanding of the technological state of a particular field [15]–[17].

In the private sector, one of the most widespread applications of benchmarking is market analysis, including the identification of opportunities and comparison with competitors. Xerox, for example, is recognized as a pioneer because it effectively employed benchmarking to address problems faced by the company in the late 1970s [14]. In the governmental sphere, [18] shows that benchmarking studies are widely used to create public-service quality indicators, enabling the assessment of government actions, improving service to the population, and supporting more effective public policies.

Benchmarking may therefore serve different purposes, including supporting the optimization of an organization's internal processes and strengthening its competitiveness by identifying opportunities for improvement and best practices adopted by competitors [19].

A review of [20]–[23] identifies six types of benchmarking according to the object and scope of comparison:

- Product benchmarking, which uses reverse-engineering principles and may include disassembling competitors' products to understand their operation and identify their components;
- Competitive (or performance) benchmarking, which compares a company's performance level with that of other companies;
- Process benchmarking, which compares a company's practices with those of other companies, whether competitors or not;
- Strategic benchmarking, which compares strategic decisions related to resources, markets, and investments;
- Global benchmarking, which seeks to learn best practices from companies located anywhere in the world;
- Competence benchmarking, which concerns learning and adapting competencies in response to market changes.

As established in the objectives, this paper focuses on benchmarking military systems, classified as product benchmarking, to support the Systems Development Process and anticipate the performance levels that may or may not be achieved and the costs associated with each level, thereby improving preparation for subsequent project stages.

Benchmarking models are available in the literature and, as suggested by [22], may be adapted to the needs and culture of organizations or to the intended objectives, as in [24]. Adapting and employing a structured process for benchmarking military systems to the organizational culture of the Armed Forces may support their development and acquisition, reduce development time, and improve the satisfaction of current and future operational needs of national defense.

3. Method

To guide system benchmarking and provide a structured basis for the study, a method comprising three iterative and not necessarily sequential stages is proposed. The outputs of each stage may support the revision or refinement of the others. The three stages are described below.

The project scope constitutes the initial input to the benchmarking study. It should include information on the system functions; the type of system to be developed, such as a ground vehicle or satellite launch vehicle; the estimated project budget; the target unit cost when multiple units are expected to be produced; and the planned development schedule.

The use of intuitive idea-generation techniques, such as brainstorming [25], is proposed throughout the benchmarking study. These techniques may broaden the understanding of the problem and of the capabilities offered by systems comparable to the System of Interest (SoI). They may also generate insights that contribute to refining the SoI Concept of Operations.

3.1. Step 1: Definition of the design characteristics to be analyzed

Based on the project objectives and stakeholder needs, the design characteristics most relevant to the benchmarking study should be identified. These characteristics may include general system information, such as cost, manufacturer or developer, and country of origin, as well as technical information related to system architecture and performance. Their analysis enables the project team to characterize and compare the systems included in the study. For a surveillance UAS, for example, relevant characteristics may include aircraft endurance, operational range, and payload capacity for carrying cameras and other surveillance equipment. The output of this stage is a justified list of the design characteristics to be examined in the benchmarking study.

3.2. Step 2: Definition of system selection criteria

The selection criteria determine whether a system is suitable for inclusion as a comparative reference in the benchmarking study. Defining these criteria helps improve the consistency and relevance of the comparison by excluding systems that are incompatible with the intended analysis. For example, in fields

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characterized by rapid technological evolution, outdated solutions may be excluded by considering only systems developed after a specified date. The output of this stage is a list of justified criteria for selecting the systems to be included in the comparison.

3.3. Step 3: Conducting the benchmarking study

Based on the activities established in the preceding stages, information should be collected from databases and publicly available online sources on systems comparable to the one under development that satisfy the selection criteria defined in Step 2. A comparative table should then be prepared using the design characteristics identified in Step 1. Specialists from the relevant project disciplines should collaborate in collecting and assessing information related to their areas of expertise. This multidisciplinary analysis allows the systems to be examined in greater detail and contributes to characterizing the current technological landscape.

To complete this stage and conclude the benchmarking study, the team responsible for the study should examine the systems included in the comparison and assess their capabilities and limitations across different cost ranges. Representative performance levels should also be determined to estimate what may or may not be feasible given the available technologies and the project budget. If existing technologies are insufficient to satisfy stakeholder requirements, the team should assess whether those requirements should be revised or whether research and development activities should be initiated to investigate new technologies or approaches capable of achieving the required performance levels.

4. Case study

The application of the proposed method in a benchmarking study within the development project of an attack UAS is presented below. The input information is assumed to be known, and the system is required to perform the following functions:

- Conduct reconnaissance;
- Conduct area surveillance;
- Conduct intelligence missions;
- Identify targets;
- Transmit target information;
- Attack surface and airborne targets.

4.1. Step 1: Definition of the design characteristics to be analyzed

Based on the project objectives and stakeholder priorities, the design characteristics considered most relevant for comparing the systems were defined as follows: UAS designation, manufacturer, country of origin, estimated cost, wing configuration, length, wingspan, height, maximum speed, cruise speed, service ceiling, maximum endurance, operational range, engine type, number of missiles carried, maximum takeoff weight, payload capacity, and operational function.

4.2. Step 2: Definition of system selection criteria

At this stage, the benchmarking study was restricted to reusable aircraft and excluded one-way attack systems, including loitering munitions, which are expended when they strike their targets. This restriction reflected the stakeholders' interest in operating reusable aircraft capable of performing persistent surveillance and engaging multiple targets without the loss of the air vehicle after the first engagement.

Improvised UAS for which no evidence of serial production was identified were also excluded. The stakeholders intended the project to develop a family of UAS for the missions previously described, with performance and reliability exceeding those of field adaptations produced to address immediate operational needs.

The study also excluded jet-powered Unmanned Combat Aerial Vehicles (UCAV), such as the Kratos XQ-58 Valkyrie. Although these aircraft may perform combat missions, their operational concepts, performance envelopes, propulsion systems, and intended roles differ substantially from those of the persistent attack UAS considered in the study. Their inclusion would therefore reduce the comparability of the selected systems and provide limited information regarding the surveillance and attack capabilities required by the stakeholders.

Because attack UAS and their employment doctrines had evolved rapidly during the period examined, the study included only systems that remained in service until at least 2018 or after. This criterion was intended to provide an overview of aircraft representative of relatively recent operational and technological practices, as aeronautical systems may remain operationally relevant for decades when they continue to perform their intended missions satisfactorily. Continued operational service was therefore considered a more appropriate indicator of the relevance of an aircraft to the benchmarking study than its original development or production date.

4.3. Step 3: Conducting the benchmarking study

The consolidated results of the benchmarking study of military UAS are presented in Table I. The data were collected from publicly available sources.

The study indicated that reported acquisition costs may vary substantially according to the onboard sensors, mission equipment, and scope of the acquisition package. Contractual arrangements between buyers and suppliers, industrial or technological offsets, and logistics and support agreements may also affect the final price. Consequently, the exact unit cost of each aircraft could not always be determined from open sources, although the collected values provided an approximate basis for comparison.

During problem definition, the imaging and sensing capabilities required for intelligence, surveillance, and reconnaissance missions should therefore be identified to determine which payloads must be acquired or developed. These decisions have implications for payload-interface

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Table I. Results of the benchmarking study of military UAS.

UAS Name	Manufacturer	Country	Cost (US$ million)	Wing type	Length (m)	Wingspan (m)	Height (m)	Max. speed (km/h)	Cruise speed (km/h)	Service ceiling (km)	Max. endurance (h)	Range (km)	Engine	Missiles	MTOW (kg)	Payload (kg)
MQ-9A Reaper	General Atomics Aeronautical Systems	USA	32	Fixed	11.00	20.00	3.81	482	313	15.24	27	1900	1 × Honeywell TPE331-10 turboprop engine (900 hp)	4 × AGM-114 Hellfire	4760	1700
MQ-9B SkyGuardian	General Atomics Aeronautical Systems	USA	-	Fixed	11.70	24.00	-	390	-	12.20	40	11000	1 × Honeywell TPE331-10 turboprop engine (900 hp)	7 missile hardpoints 9 missile hardpoints (pylons)	5670	2520
Kronshtadt Orion	Kronstadt Group	Russia	13	Fixed	8.00	16.00	3.00	200	120	8.00	24	250	-	4	1000	200
MQ-1C Gray Eagle	General Atomics Aeronautical Systems	USA	8	Fixed	8.50	17.00	2.10	310	250	8.84	30	400	1 × Thielert 2.0L piston engine (165 hp)	4 × AGM-114 Hellfire or 8 × AIM-92 Stinger	1633	488
MQ-1 Predator	General Atomics Aeronautical Systems	USA	40	Fixed	8.22	14.80	2.10	217	165	7.62	24	1100	1 × Rotax 914F piston engine (115 hp)	2 × AGM-114 Hellfire	1020	508
Bayraktar TB2	Baykar	Turkey	6	Fixed	6.50	12.00	2.20	220	130	8.23	27	150[d]	1 × Rotax 912 gasoline piston engine (100 hp)	4 × laser-guided smart munitions	630	150
Bayraktar TB3	Baykar	Turkey	-	Fixed	8.35	14.00	2.60	300	232	9.50	24	2000	1 × TEI PD170/1 × TEI PD200 turbodiesel piston engine (planned)	8	1450	280
Falco Xplorer	Leonardo S.p.A.	Italy	-	Fixed	9.00	18.80	3.80	215	-	9.15	24	-	-	-	1300	350
CH-5 Rainbow	China Aerospace Science and Technology Corp.	China	17	Fixed	11.00	21.00	3.80	300	220	9.00	60[b]	6500	1 × diesel piston engine (330 hp)	16	3300	1000
Aarok	Turgis & Gaillard	France	-	Fixed	14.00	22.00	-	450	-	13.7	24	-	1 × Pratt & Whitney PT6 turboprop engine	-	5500	3000
MQ-8B Fire Scout	Northrop Grumman Corp.	USA	16 – 27.5	Rotary	7.30	8.40[a]	2.96	213	200	6.10	8[c]	200	1 × Rolls-Royce 250 turboshaft engine	-	1430	490
MQ-8C Fire Scout	Northrop Grumman Corp.	USA	33	Rotary	10.60	11.20[a]	3.30	260	-	6.10	15	-	1 × Rolls-Royce 250-C47B turboshaft engine	-	2720	1240

[a] Value refers to main rotor diameter (rotary-wing platform).
[b] 60 h in clean configuration; 30 h with eight AR-1 missiles.
[c] 8 h; 5 h at MTOW.
[d] 150 km at MTOW; 300 km maximum.

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requirements, including load capacity, maximum dimensions, electrical power demand, data interfaces, and the vibration environment to which the equipment will be exposed.

Experience from the conflict between Russia and Ukraine has also demonstrated the vulnerability of UAS operations to electronic warfare, particularly interference with communication and navigation systems. Increasing onboard autonomy may mitigate some consequences of command-and-control link disruption by allowing the aircraft to continue a predefined mission or execute contingency procedures. It does not, however, eliminate other electronic warfare threats, including navigation interference, sensor degradation, or deception. Moreover, autonomous weapon engagement involves technical, legal, and ethical constraints that must be addressed before such capabilities are implemented.

Manufacturers and operators used as information sources do not necessarily adopt identical definitions, measurement conditions, or system configurations. The reported values should therefore be interpreted as indicative rather than as directly equivalent certified performance data. Even so, the values collected from the different sources were generally consistent, although variations were observed among sources and production configurations.

Aircraft of the same model may incorporate different components, structural modifications, mission systems, or software versions without necessarily receiving a new designation. Changes introduced during production or operation may affect reliability, maintainability, weight, and performance. A similar situation occurs in manned aviation, in which aircraft of the same model and version may differ because of incorporated Service Bulletins, repairs, or modifications. Performance parameters such as speed, service ceiling, range, endurance, and maximum takeoff weight may also depend on atmospheric conditions, payload, fuel load, and mission configuration.

Ten of the UAS selected according to the Step 2 criteria were fixed-wing aircraft and two were rotary-wing aircraft. The two rotary-wing systems were derived from airframes originally developed for manned helicopters and subsequently adapted for unmanned operation. The MQ-8C succeeded the MQ-8B and provided greater endurance and payload capacity. The Fire Scout family has supported intelligence, surveillance, reconnaissance, targeting, and maritime operations, while mine-detection capabilities have also been integrated or demonstrated across its different configurations.

The manufacturer of Aarok reported cruise speed exceeding 450 km/h, operational altitude of 9.15 km and service ceiling of 13.7 km, and the capacity to carry nearly 3,000 kg distributed among fuel, weapons, and mission equipment, such as special sensors, radars or radios. These characteristics distinguish it from most systems included in the comparison and justify continued monitoring of its upgraded versions. They should not, however, be interpreted as independently verified operational performance.

Excluding the provisional Aarok data, most attack-capable UAS included in the study had reported service ceilings of up to approximately 10 km. The MQ-9A and MQ-9B were exceptions, with reported maximum altitudes of approximately 15.24 km and 12.2 km, respectively. Both belong to the Medium-Altitude, Long-Endurance category, although this classification also applies to several other fixed-wing systems examined. The MQ-9 models also presented some of the highest maximum and cruise speeds in the dataset. The reported cruise speeds of the other aircraft generally ranged from 120 to 250 km/h.

Most fixed-wing aircraft examined had reported endurance values of approximately 24 hours or more, with some reaching 27 or 30 hours. Higher values were reported for the MQ-9B SkyGuardian and the CH-5 Rainbow. Such endurance allows operators to maintain surveillance over an area of interest for extended periods, although the actual time on station also depends on transit distance, payload, weather, and mission profile.

The rotary-wing aircrafts presented lower reported endurance, ranging from approximately 5 to 15 hours. This characteristic limits their time on station relative to most fixed-wing UAS. However, rotary-wing systems can hover, operate from confined areas, and maneuver with greater flexibility at low speeds, which may provide operational advantages in shipborne, coastal, urban, and localized surveillance missions. Endurance should therefore be assessed in relation to the intended employment scenario rather than as an isolated performance parameter.

Reported range varied substantially, even among fixed-wing aircraft. However, this parameter requires particular caution because open sources may use the term range to describe different quantities, including communication-link range, operational radius, combat radius, ferry range, or maximum travel distance. These values are also affected by altitude, atmospheric conditions, fuel load, payload, and reserve requirements. Direct comparisons should therefore be made only when the sources use equivalent definitions and operating conditions. The highest value identified in the study was approximately 11,000 km for the MQ-9B SkyGuardian.

Range influences military employment because it affects the distance from the operating base at which the aircraft can conduct its missions. A greater range may allow deeper operation within hostile territory, broader coverage, or the use of more distant and protected operating bases. Nevertheless, operational reach also depends on communication architecture, satellite connectivity, airspace access, basing arrangements, survivability, and the availability of alternative recovery locations.

Payload capacity also varied substantially. The Bayraktar TB2 presented a reported capacity of 150 kg, whereas the MQ-9B SkyGuardian could carry approximately 2,155 kg externally and an additional 363 kg internally. The table should explicitly distinguish internal, external, and combined payload capacities to prevent inconsistent comparisons. Aircraft with estimated acquisition costs below US$10 million generally presented payload capacities below 500 kg, and four of the aircraft examined had capacities of 350 kg or less.

Payload capacity has direct implications for the number and

types of sensors, communication systems, weapons, and auxiliary equipment that can be carried simultaneously. Greater capacity may increase mission flexibility, but it should not be treated as an isolated indicator of operational value. The minimum required capacity depends on the employment doctrine, intended targets, weapon characteristics, sensor configuration, required endurance, and stakeholder objectives. A smaller aircraft may remain operationally suitable when its payload is consistent with its intended mission profile.

Finally, most models showed relatively limited dimensional variation. Their lengths were generally between approximately 8 and 11 m, wingspans between 14 and 20 m, and heights between 2.1 and 2.6 m. The Bayraktar TB2 was the smallest fixed-wing aircraft in the dataset, whereas the MQ-9 variants were among the largest. No direct relationship between aircraft dimensions and maximum endurance or range was identified because these performance parameters also depend on aerodynamic efficiency, propulsion, fuel fraction, structural mass, payload, and operating conditions. Nevertheless, the larger aircraft generally presented greater payload capacities.

5. Conclusions

The application of the proposed method enabled the benchmarking study of attack UAS to be conducted in a structured manner and produced information relevant to the development and acquisition of military UAS for the Brazilian Armed Forces. The study identified the main characteristics of comparable systems and contributed to establishing a shared understanding among the project stakeholders. The resulting comparison provided stakeholders, including users and technical personnel, with a clearer and more consistent view of the performance levels and design characteristics associated with currently available technologies.

The method systematized the benchmarking process by defining the stages of the analysis, establishing criteria for selecting the systems included in the comparison, and identifying the design characteristics to be examined. This structure also improved the traceability of the decisions made throughout the study.

A limitation observed during the application was the difficulty of obtaining complete and directly comparable data for all the selected characteristics. This limitation arose partly because performance parameters may vary according to configuration, operating conditions, payload, and the definitions adopted by different sources. The use of multiple publicly available sources partially mitigated these inconsistencies and allowed the study objectives to be addressed, although some values remained indicative rather than directly comparable.

Future work should examine the integration of the method into a broader systems engineering process for the development or acquisition of military systems. Further applications to other system categories and project contexts would also help assess the method's transferability and identify adaptations required for different benchmarking objectives.

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, Data curation, Writing – review and editing; **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 obtained from publicly available online sources, including manufacturers' official websites, technical documents, product specifications, and institutional publications. The data extracted and compiled for the benchmarking analysis are presented in Table I.

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