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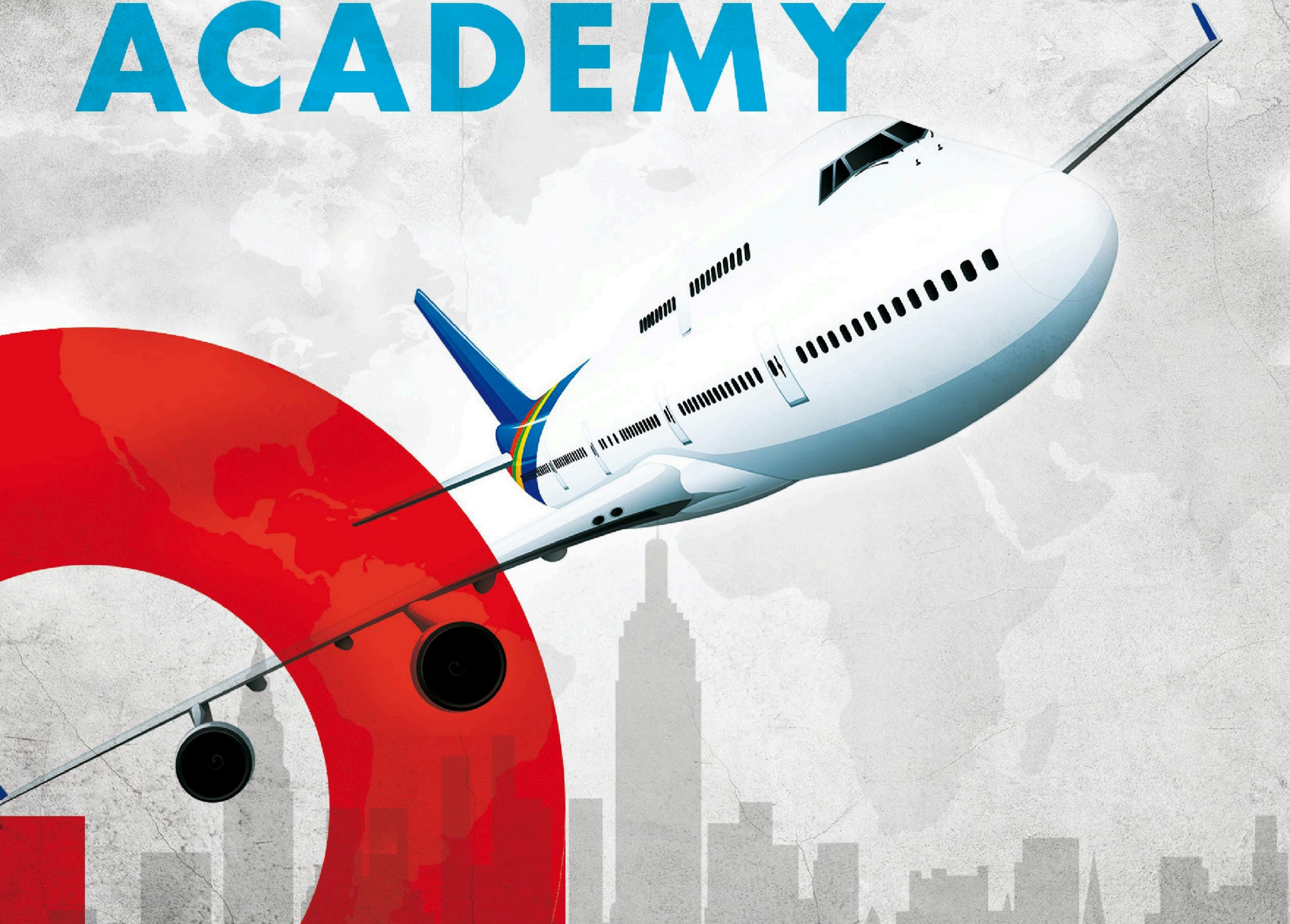

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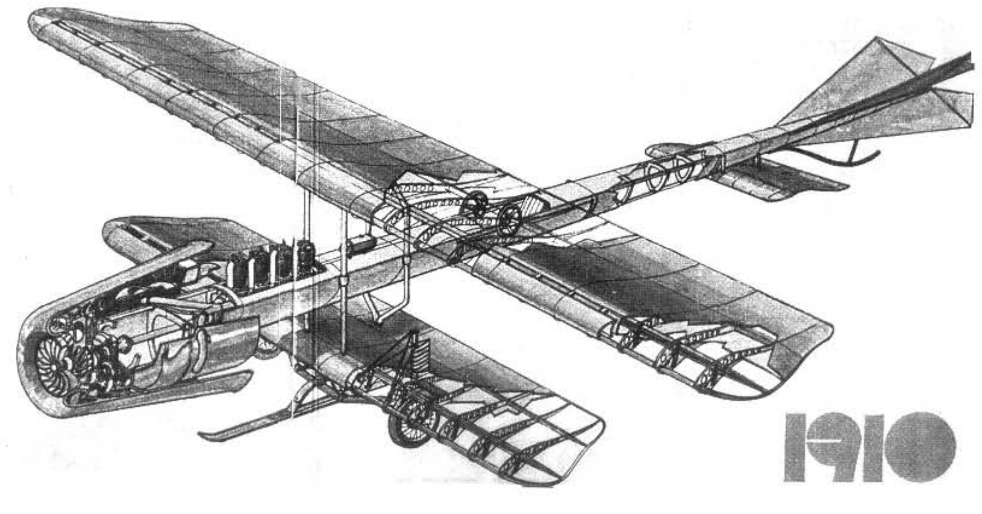

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CONTENTS

STRATEGIC IMPLICATIONS DETERMINED BY THE MASSIVE USE OF LOW-COST DRONES

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Abstract*: This paper analyzes the structural cost asymmetry and strategic implications of the massive use of low-cost drones (e.g. Shahed-136, Geran-2) in the context of the Drone War, using the Ukraine conflict as a case study. We demonstrate that the use of high-performance interception systems (approximately millions of dollars) against low -cost drones (thousands of dollars) creates a cost asymmetry. Being unsustainable in the long run, this can be analyzed as a key economic vulnerability.*

Thus, a rapid review of integrated military doctrines is required for the new layered defense architecture, introducing "Layer 0" and the transition to non-kinetic countermeasure solutions (EW, DEW) and smart artillery.

The research method used is Multiple Cause Comparative Analysis (MCCA), supported by Cost-Effectiveness Modeling (CEM), which allows us to demonstrate that cost asymmetry is not an isolated event but a structural feature of modern warfare.

Keywords*: Cost asymmetry, defense doctrines, C-UAS, electronic warfare, War in Ukraine, Deterrence*

1. INTRODUCTION

The current strategic context on NATO’s Eastern Flank is marked by physical intrusions of drones and fragments of Shahed-136/Geran-2 attack drones [1], especially on the territory of Romania and Poland [2]. Repeated discoveries of attack drone fragments, even if they do not represent a problem of airspace violation (in accordance with international law) [3], can represent a major challenge to the architecture of the collective defense system. These incidents are not simple accidents, but stress tests for collective defense procedures, which can undermine NATO’s deterrence mechanisms.

Integrated Air and Missile Defence Doctrine (NATO IAMD) is based on air superiority and on defence against missiles and aircraft from air strike groups [4]. New types of sub-conventional threats, cheap, easy to mass produce and extremely difficult to detect for opportune neutralisation, establish a new strategic context that defines the sequences of massive use of drones as methods of intimidation, giving them a new role, namely that of *saturation weapons*.

Conventional systems such as Patriot or NASAMS (National Advanced Missile Surface- to-Air Systems) were designed for high-speed and high-value targets [5], not for low-RCS, low-Altitude and low-cost drones. Thus, a cost asymmetry appears as a systemic vulnerability where the defender exhausts his financial resources and ammunition stocks in the face of saturation weapons.

This paper focuses on the argument that addressing the cost asymmetry issue goes beyond the purely economic dimension, constituting a strategic imperative for doctrinal adjustments across all military architectures. While this approach does not entirely eliminate the dilemmas generated by conducting military operations in the context of the *Drone Warfare* model [6], it does contribute significantly to maintaining the shared credibility of deterrence on NATO's Eastern Flank.

2. COMPARATIVE COST ANALYSIS (HARD-KILL vs. SOFT KILL)

The analyzed empirical data on the estimated prices for the analyzed systems are presented in Tables 1 and 2. We note that the prices shown are estimates based on publicly reported production costs or export contracts and may vary depending on the specific configuration [7] [8] [9].

Table 1 - Table with the price and suppliers of attack drones frequently used in Russian attacks

Drone model	**Origin / Manufacturer**	**Estimated unit price (USD)**	**Use**
Shahed-136/ Geran-2	HASA (Iran) and locally assembled	20,000-50,000	Strategic strikes on Ukrainian critical infrastructure
Mohajer-6	Qods Aviation Industry (Iran)	3-5 million.	MALE (ISR/Attack) – especially in the Black Sea area
Lancet-3	ZALA Aero Group (Russia)	Approx. 35,000	Tactical use for precision strikes on high-value targets (artillery, armored vehicles, etc.)
Orion/ Inochodets	Kronstadt (Russia)	20-25 million.	MALE (ISR/Attack) – strategic drone capable of carrying guided munitions
Forpost-R	Ural Civil Aviation Plant (Russia)	5 million.	Reconnaissance, fire adjustment and secondary attacks
Kub -BLA	ZALA Aero Group (Russia)	15,000-25,000	Tactical use, at short distances, intended to destroy ground targets

Table 2 - **Table of prices and suppliers of interception vectors from Allied forces**

System	**Interceptor (Missile)**	**Estimated unit price (USD)**	**Main supplier**	**Use**
NASAMS	AIM-120 AMRAAM	1 -1.2 million.	Raytheon Tech. (USA)	Medium-range air defense
Patriot PAC-3	PAC-3 MSE	4-5 million.	Lockheed Martin (USA)	Defense against ballistic and cruise missiles. Can be used against drones as a final course of action
SAMP/T system	Aster 3O	2-3 million.	MBDA (France, Italy)	Mobile, medium-long range air defense
Skyguard / Oerlikon	Skyranger	5,000-10,000	Rheinmetall (Germany)	Intelligent Projectile (AHEAD), as a low-cost kinetic solution against drones and artillery projectiles

As can be seen, the price of the Shahed-136 (row 1/Table 1) contrasts with that of the interceptor vectors. Due to the cost asymmetry, the market is rapidly moving towards the development of low-cost C-UAS solutions, including electronic warfare (EW) systems and directed energy weapons (DEW), as well as defensive strategies to counter any saturation attack executed by drones.

To highlight the magnitude of that imbalance, we compared the price of the Shahed-136/Geran-2 drone to that of interceptors, in an efficiency indicator: **Interception Cost Asymmetry Ratio**.

Table 3 - Cost Asymmetry Analysis

Threat (Drone)	**Interceptor (Missile/System)**	**Drone cost (USD)**	**Interceptor cost (USD)**	**Asymmetry ratio**
Shahed-136	Patriot PAC-3 MSE	30,000	4,000,000	1:133
Shahed-136	AIM-120 AMRAAM (NASAMS)	30,000	1,200,000	1:40
Shahed-136	Skyranger (AHEAD)	30,000	10,000	3:1 ***(Advantage)***
Shahed-136	EW/DEW/Laser system	30,000	Approx. 100 (marginal price)	300:1 **(Optimum)**

Analyzing the evolution of the Ukraine conflict, it can be deduced that the war based on technological superiority is slowly but surely transforming into a problem of financial resource management. Faced with this new sub-conventional threat, based on the exploitation of the weaknesses of systems designed for high-performance threats, a dual strategic response becomes imperative. The effective integration of solution aimed at urgently addressing cost asymmetry, the adoption of non-kinetic "soft-kill" countermeasures (such as EW, DEW weapons, lasers systems etc.), and a fundamental shift in the offensive operations conduct will require a rapid transformation of air defense doctrines. Such adaptation is essential to enable defense architecture to deliver decentralized, layered and threat-adaptive responses with the evolving operational environment.

3. RESEARCH METHODOLOGY

The most appropriate method to substantiate this strategy is Comparative Qualitative Analysis (CQA), supported by Cost-Effectiveness Analysis (CEA). CQA is a qualitative-empirical method that allows the examination of two or more relevant situations to identify common variables, recurring causes and systemic trends [10].

Based on this method, we demonstrate that cost asymmetry is not an isolated incident, but a structural feature of modern warfare.

To justify the need for doctrinal changes towards low-cost asynchronous threats and the universal support of the type of aerial threat through UAS, we perfomed a comparative study of three types of conflicts and the particularities of the use of drones/UAS depending on the technological development specific to the respective historical stage (table 4).

Table 4

The problem studied	**Focus of the analysis**	**Strategic conclusion**
The war in Ukraine	Usage Rate of Shahed/Geran Drone vs. Interception Success Rate and Cost (Patriot, NASAMS)	Justifies the asymmetry by demonstrating stock depletion and unsustainable operational cost levels.
Nagorno-Karabakh conflict/2020	Bayraktar drones’ impact on conventional armored platforms	It justifies doctrinal transformations and demonstrates the vulnerability of conventional forces to UAS threats, at the operational level.
Use of V-1 rockets in World War II	Britain's defensive response to Nazi V-1 missile attacks (early forms of low-cost and low-RCS threats)	It justifies the generation of alternative solutions and the need for the rapid development of ad-hoc and cheap technologies (cannons, EW) instead of much more expensive fighter jets.

Cost-Effectiveness Modeling [11] is a quantitative method that can be used in defense policy analysis to compare the costs of different alternatives (e.g. air defense systems) in relation to achieving the same objective (e.g. neutralizing the drone threat). Based on it, we mathematically justify the need to cost asymmetry resolves.

Thus, we establish the model variables and the quantification of key variables:

- C_{UAS} – the unit cost of a drone;
- C_{Int} – Unit cost of the interception system;
- C_{EW} – the marginal operational cost of a jamming attack (practically "0" once the system is purchased);
- P_{Kill} – Probability of neutralization/success of each method;
- R_{Ops} – The operation/maintenance rate of each system.

The *Crossover Point* is determined by the number of drones neutralized after which the total cost of an expensive system (kinetic system: NASAMS + number of missiles) exceeds that of a cheaper C-UAS system (non-kinetic: Mobile jamming system + its maintenance).

$$\text{Cost}_{Total}\ (\text{Kinetic}) = N \text{ x } C_{Int} + C_{Systems}\ (\text{Kinetic}) \qquad (1)$$

$$\text{Cost}_{Total}\ (\text{Non-Kinetic}) = N \text{ x } C_{EW} + C_{Systems}\ (\text{Non-Kinetic}) \qquad (2)$$

where "N" represents the number of commitments.

It is observed that for a high volume of engagements (characteristic of drone attacks), solutions with large C_{Int} quickly become exponentially unsustainable compared to C_{EW} solutions. This approach provides a robust justification, combining empirical evidence from real conflicts with a rigorous economics of defense solutions.

Variables:

- C_{UAS} – unit cost of the drone Shahed – approx. 30,000 (USD);
- C_{Int} – Unit cost of the AIM-120 / NASAMS interceptor missile – approx. 1,200,000 (USD);
- C_{EW} – marginal operational cost of a jamming system per engagement – approx. 100 (USD);
- Cost_{System} (Kinetic) – Initial cost of a NASAMS artillery battery – approx. 150,000,000 (USD);
- Cost_{System} (Non-Kinetic) - Initial cost of a high-performance EW system – approx. 20,000,000 (USD)

The total cost of using a system is determined from the initial acquisition cost and the marginal cost per engagement (“N” of engagements). Thus:

$$\text{Cost}_{Total}\ (\text{Kinetic}) = N \text{ x } 1{,}200{,}000 + 150{,}000{,}000 \qquad (3)$$

$$\text{Cost}_{Total}\ (\text{Non-Kinetic}) = N \text{ x } 100 + 20{,}000{,}000 \qquad (4)$$

The mathematical model compares a kinetic (NASAMS) with a non-kinetic (EW) systems.

The *Crossover Point* is the number of commitments (N) at which the total cost of the two equations becomes equal:

$$N \text{ x } 1200000 + 150000000 = N \text{ x } 100 + 20000000 \qquad (5)$$

Solving the equation, we obtain:

$$N \text{ x } 1199900 = 130000000 \qquad (6)$$

$$N = 108.34.$$

We use **109 engagements** (drones used) as the *Crossover Point* value.

Therefore:

- **Under 109 engagements**: The kinetic system is cost-effective due to immediate accuracy, with the higher initial cost of the EW system not yet recouped through missile savings;
- **Over 109 engagements**: The EW system is cost-effective, becoming critical for economic survival as the marginal cost of the missile (approx. $1.2 million) increases linearly towards unsustainability.

4. ANALYSIS AND DISCUSSION: IMPLEMENTATION OF “LAYER 0”

This cost-effectiveness analysis fully justifies the model of attack drone countermeasure scenarios in operations conducted during the Ukraine war in which the threshold of 109 drones is quickly exceeded.

The main operational-strategic consequences are:

1. **Economic exhaustion**: Continuing these operational procedures to combat attack drones leads to a rapid and unsustainable depletion of defense budgets, forcing NATO forces to spend precious resources to neutralize a technologically marginal potential threat;
2. **Stock depletion**: Intensive use of expensive interception vectors with a long production cycle leads to stock depletion, leaving NATO's Eastern operational flank vulnerable to high-value threats (aircraft, cruise missiles etc.);
3. **Decreased credibility of deterrence**: The failure to develop an effective and cost-efficient response to the low-cost threats signals to a potential enemy the existence of exploitable vulnerabilities that may be leveraged in a possible attack.

Following the ongoing analysis, we consider the following immediate solutions to correct the gap caused by this asymmetry are shifting interest towards non-kinetic and low-cost kinetic investments:

- **Advanced electronic warfare solutions**: We consider them to be the fastest alternative to counter attack drones. Investments in jamming systems capable of neutralizing GNSS (Global Navigation Satellite System) components and C2 (Command and Control) of drones offers a high success rate for the ratio of marginal cost vs. number of interceptions;
- **Directed energy weapons and lasers**: The development and integration of systems based on microwaves, very high frequencies, as well as high-power lasers, which are already present in numerous applications and systems, can offer solutions with a cost of approximately "zero" per shot, once the system is purchased;
- **Modern anti-aircraft artillery systems**: The use of modern anti-aircraft artillery systems, with reprogrammable projectiles and high firing rates, can saturate the airspace with strikes much cheaper than a missile, representing the complementary solution for targets that are not affected by EW.

The continued exclusive use of expensive kinetic methods (most of the current doctrinal frameworks applicable to all categories of armed forces) has become an unsustainable strategy in the long term and amounts to a planned financial self-exhaustion by the adversary.

We appreciate that the quantitative results obtained through CEM provide a mathematical and logical basis to support the operational effectiveness depending on the number of engagements of an anti-drone air defense system, for the following approaches:

1. **Economic**: Since C_{Int} (Kinetic) is unsustainable, funds must be allocated for the development of C_{Int} (Non-Kinetic) solutions, which are much cheaper, thus solving the issue of cost asymmetry;
2. **Doctrinal**: Because EW-based C-UAS systems are often decentralized and mobile, operating at low altitude, their large-scale implementation requires doctrinal changes from a centralized architecture to a distributed, multi -layered and integrated C-UAS architecture.

The current NATO IAMD doctrine (updated on 13 February 2025) must be implemented quickly to cover detection and combat gaps at altitudes below 300 m.

The Qualitative Stratification principle, currently adopted, is outdated, unable to cope with low-RCS technologies and the extremely large dispersion of drones. Attack drones can operate at low altitudes (below 300 m) and low speeds (below 200 km/h) and are often unidentified by radars designed with filters to ignore signals from birds, from relief forms in the vicinity of the combat position and other asynchronous jamming signals. This creates detection gaps in the lower layers of defense, being designed to ensure good protection of high-value points (HQ, air bases, missile division positions, other territorial objectives of strategic importance). In the event of a dispersed attack with drones, this can no longer be applied, as drones pose a challenge to current centralized, fixed and semi-mobile air defense systems.

We believe that new doctrinal measures must focus on air density management and multi -domain, multi -layered defense of C-UAS systems, namely:

1. **Development of "Layer 0"**: Creating a level of defense below that provided by IAMD. This will consist of multimodal sensors (optical, thermal, acoustic), mobile EW systems, other small radar systems etc., to compensate for the limitations of conventional radars.
2. **Integration of civil-military warning architectures** (All-Domain Awareness): The recognition that drones cross civil airspace determines the involvement of non-military warning structures, as civil telecommunications operators, air traffic control and even ad-hoc civil-military visual observers (gendarmes, police officers, other agents from the ensuring public order system and even individuals present occasionally in the drones' area of action) having a very important role in providing timely information for creating the Common Operating Picture (COP), in real time;
3. **Decentralized decision-making**: C-UAS systems must be able to engage targets in the shortest possible time, which is impossible under centralized coordination management. These systems must be capable of autonomous or semi-autonomous decision-making to reduce reaction time in the face of drone swarms.

4. CONCLUSIONS: SUSTAINABILITY OF DETERRENCE

This paper justifies the need for a fundamental change in the air defense doctrine of Romania and other NATO armies, with an emphasis on the integration of EW systems and other low marginal cost countermeasures, not as a tactical option but as a strategic necessity imposed by the economic logic of modern warfare.

Cost asymmetry is a form of financial self-depletion planned by the adversary. From an economic and operational point of view, it can lead to a number of vulnerabilities for national and the Alliance security.

We conclude that to maintain the credibility of deterrence on the NATO Eastern Flank, the Ministry of National Defense and NATO must prioritize:

- Massive investments in Electronic Warfare (EW) and Directed Energy Weapons (DEW);
- Adopting a distributed and mobile architecture, capable of protecting not only high-value points but also extended geographical spaces against hybrid threats;
- Updating the legal framework to enable an agile response to sub-conventional threats.

These transformations will ensure not only the protection of national airspace, but also the financial sustainability of deterrence, in the medium and long term.

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THE LEGAL PROTECTION OF MILITARY PARACHUTISTS IN INTERWAR INTERNATIONAL AIR LAW: A CONTRIBUTION FROM ROMANIAN LEGAL DOCTRINE

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DOI: 10.19062/1842-9238.2026.24.1.2

Abstract:*The use of the parachute as a means of rescuing pilots and balloon observers raised, from the outset of military aviation, a fundamental question of international law: may a person descending by parachute be attacked in the air? This article analyses the legal status of military parachutists in the context of the First and Second World Wars, based on the provisions of Article 20 of the Draft Rules of Aerial Warfare adopted by the Hague Commission of Jurists (1922–1923). The author critically examines the criteria proposed by Western legal scholars — Spaight, Riesch, Kroell, Montersi and le Goff — regarding the legitimacy of attacks on aviators and balloon observers parachuting to safety.*

The original contribution consists in proposing a system of four cumulative criteria — the aircraft being disabled from combat, the territory above which the jump occurs, the capabilities of local ground defences, and the self-interest of the belligerents — which more precisely characterise each operational situation than the existing doctrinal formulations, considered either too restrictive or practically inapplicable. The article further demonstrates the contemporary relevance of these criteria through their connection to Additional Protocol I to the Geneva Conventions (1977), Article 42.

Keywords: *international air law, military parachutists, Hague Regulations, law of war, prisoners of war, aerial chivalry, Costeanu*

1. INTRODUCTION

Note on research continuity: This study explicitly builds on the author's previously published research: Deaș, M. (2021), "Historical Landmarks Regarding the Actions of Attacking in the Air of the Aeronautical Personnel that are Saved by Parachuting during the World Conflicts of the XXth Century", Review of the Air Force Academy. Whereas that study provided a historical-descriptive analysis of belligerent practice, the present article extends that research through three new contributions: [1]

(1) a detailed legal-doctrinal analysis of Article 20 of the Hague Commission and of the proposals by Kroell, Montersi and le Goff;

(2) an in-depth examination of each of the four criteria proposed by Costeanu;

(3) an assessment of the contemporary relevance of these criteria with reference to Additional Protocol I to the Geneva Conventions (1977), Art. 42.

With all attempts at regulation by the Hague Commission of Jurists, one fundamental question persists: "Must an observer or a pilot be attacked during the parachute descent?" In order to answer this properly, a brief history of the use of the parachute as a rescue means in wartime and the practice of the belligerents towards this procedure are required.

The development of military aviation during the First World War raised a question of international law without precedent: what is the legal status of the aviator or balloon observer who, forced to abandon his aircraft, descends by parachute? May he be attacked while still in the air? Or does the protection accorded to the shipwrecked sailor - enshrined in international conventions - apply by analogy to this "aerial shipwrecked" person?

The Hague Commission of Jurists attempted to address these questions through Article 20 of the Draft Rules of Aerial Warfare (1922–1923), but its formulation proved insufficient. Legal scholars - James Spaight, Riesch, Kroell, Mario Montersi and Marcel le Goff - proposed alternative interpretations and redrafts, none succeeding in reconciling the practical requirements of military operations with humanitarian principles.[2]

This article, originally published in the Aeronautics and Navy Magazine in September–October 1943 by Slt. par. Alexandru Costeanu, Doctor of Law and parachutist officer in the Romanian Air Force, brings an original perspective: that of a practitioner combining legal training with direct operational experience. Costeanu proposes a system of four cumulative criteria for determining the legitimacy of the attack, going beyond both the Hague Commission text and Kroell's proposal.

2. THE BALLOON OBSERVERS AND THE PILOTS

2.1. Balloon observers and the rescue parachute

Throughout the entire conflict, balloon observers had parachutes at their disposal. Whenever these balloons came under attack - typically carried out using incendiary rounds - the aircraft would ignite, forcing the crew to leap from the burning balloon using their parachutes in order to survive.[3]

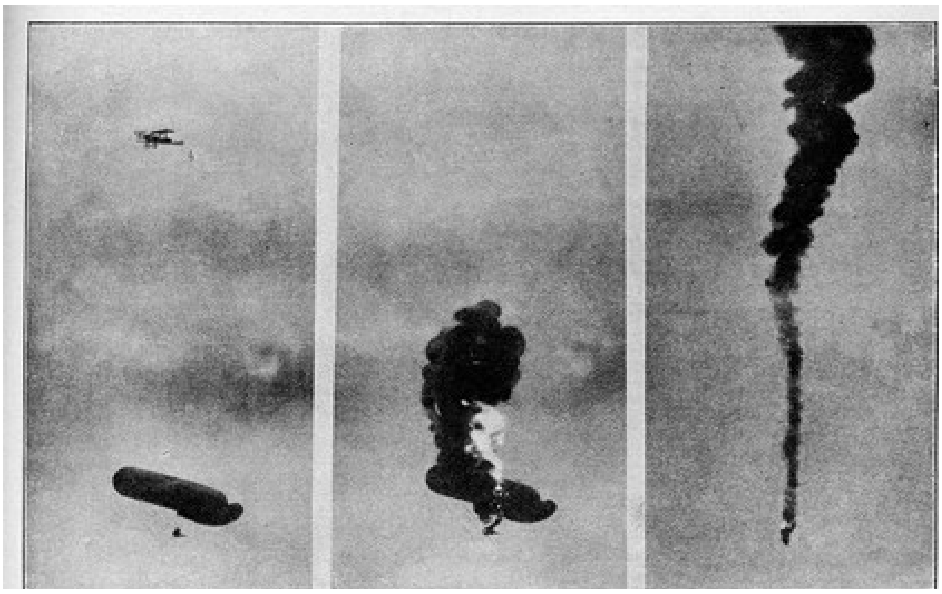

FIG. 1 A biplane shooting successfully at a tethered "kite" balloon flying below, First World War[5]

On numerous occasions, however, the flaming balloon would collapse and plummet rapidly, landing directly on top of the observer who had already jumped, setting the parachute ablaze and ultimately resulting in the jumper's death. This is precisely why, in certain countries such as France, the practice of using parachutes among balloon observers had gradually fallen out of favor toward the final stages of the war.[4]

In the closing stages of the war, both German and French forces developed parachute systems capable of safely lowering the entire gondola along with its equipment, the crew member, and all collected reconnaissance data whenever the balloon was set alight. Under these circumstances, targeting the descending gondola became a justified military action - both because the destruction of the equipment on board represented a significant setback for the enemy, and because the observer, once he reached the ground with his records, posed a potential threat through the intelligence he could relay to his commanders.

2.2. Cases documented: the French attack order and American chivalry

While Riesch arrives at conclusions that faithfully reflect the stances adopted by the warring parties regarding pilots and balloon observers who relied on parachutes to escape, Spaight goes a step further by referencing specific documented incidents from the First World War.[6]

To begin with, a directive issued to a French aerial reconnaissance unit:

"The plane No. 1 will attack the balloon first. If it fails, plane No. 2 will also attack. If plane No. 1 succeeds, then plane No. 2 will attack the observers who save themselves with the parachute. If planes No. 1 and 2 succeed, then plane No. 3 will attack the observers."[7]

French Corporal Leverrier sustained a gunshot wound to the head while abandoning his burning balloon by parachute. Sergeant Mathieu, who was similarly targeted by enemy aircraft during his descent, managed to survive the ordeal on 17 March 1917. A German aviator directed repeated short bursts of fire at the helpless observer who had abandoned the balloon. The British air forces responded in kind, as Captain H.G. Watson of the Australian Flying Corps targeted the suspension lines connecting the descending soldier to his parachute. Captain Rickenbacker, by contrast, chose to hold his fire when faced with a pilot who had bailed out of a stricken aircraft.[8]

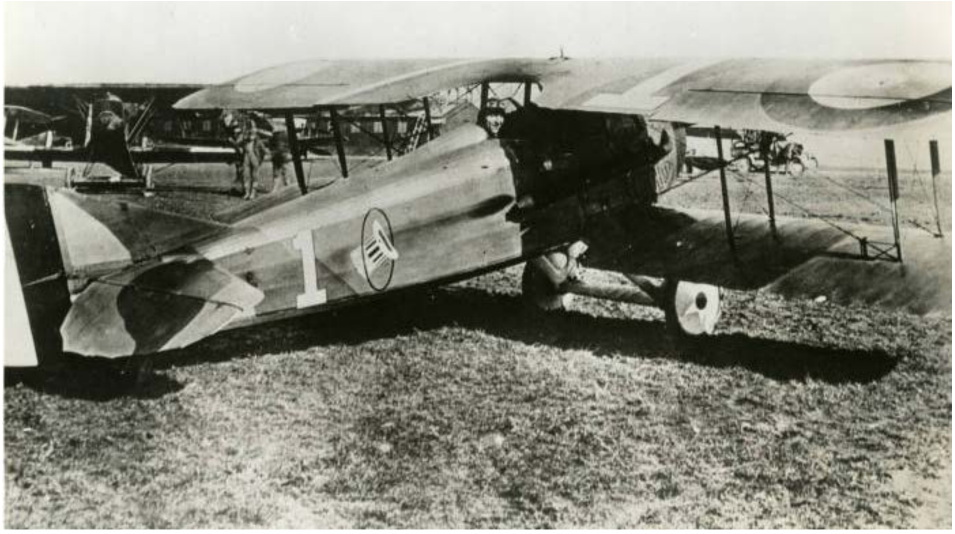

FIG. 2 Captain Rickenbacker's SPAD XIII — chivalry and self-restraint in aerial combat[9]

2.3. Riesch's conclusion: absence of a uniform legal framework

Riesch summarises the legal situation precisely: in the absence of rules of international law expressly addressing the legitimacy of attacking aviators or balloon observers descending by parachute, the warring parties of the First World War found themselves uncertain about the appropriate course of action they were expected to take.

"The conduct of the belligerents was inconsistent. Some aviators attacked the parachutists without inquiring into the reasons that had led them to that situation, even resorting to tracer and incendiary cartridges to fire upon the unfortunate airmen and balloon observers; others simply riddled the canopy of those attempting to save themselves with bullets. It can be said that the majority of aviators during the First World War spared their opponents who were descending by parachute."[10]

3. THE LEGAL FRAMEWORK: ARTICLE 20 OF THE HAGUE COMMISSION (1922–1923)

3.1. The text and limits of Article 20

The Hague Commission of Jurists (1922–1923) adopted Article 20 of the Draft Rules of Aerial Warfare, which prohibits attacks on persons on board an aircraft that can no longer be used. Costeanu criticises the formulation "aircraft that can no longer be used" as being simultaneously too precise and insufficient.[11]

FIG. 3 The_Hague Conference 1922[12]

Too precise, because it excludes cases that deserve the same treatment; insufficient, because it cannot be practically verified in aerial combat conditions. From 1915, French and English intelligence services began launching agents by parachute behind German lines - a wholly different category that created additional uncertainty.

This particular provision covers merely a quarter of all instances involving parachute descents undertaken for survival purposes, leaving the remaining three quarters without any legal protection. Only one specific scenario is explicitly addressed in the Hague Commission's text - that of an aircraft rendered unable to continue fighting - and this accounts for just a fraction of the actual situations encountered in practice.

3.2. Kroell's proposal and its limitations

Kroell proposes a new formulation: " No individual who abandons an aircraft by means of a parachute in order to preserve their life may be made the target of an attack." Costeanu acknowledges that this formulation is more comprehensive, but criticises it on the grounds of practical inapplicability.[13]

The purely subjective criterion of purpose (saving life vs. military action) leaves complete freedom of judgement to those called upon to apply it, since the distinction cannot be objectively verified either by aviators or by ground troops.

Paradoxically, Kroell's proposal may lead to more paratroopers being attacked, not fewer, precisely because the subjective criterion offers no reliable standard.

3.3. Montersi, le Goff and the maritime law analogy

Mario Montersi and Riesch argue through analogy with shipwrecked sailors: the crew saving itself by parachute must be assimilated to shipwrecked sailors and enjoy immunity during the descent. Marcel le Goff subscribes to Kroell's position, but introduces an important operational nuance:

"Solo jumps from an aircraft that has not been disabled in combat are to be regarded with suspicion, and those who perform them may be neutralized; descents carried out by multiple individuals simultaneously invariably constitute sufficient grounds for engagement and elimination."[14]

Costeanu observes that the maritime law analogy is partially valid but has limits: in air law, the principle that a ship is sunk only after the safety of the crew has been ensured cannot be applied. The conditions of aerial combat are fundamentally different from naval ones.[15]

4. THE ORIGINAL CONTRIBUTION: THE FOUR-CRITERIA SYSTEM

Facing the shortcomings of both Article 20 and Kroell's proposal, Costeanu contends that no single standard is sufficient to determine when attacking aviators descending by parachute may be considered lawful, and that multiple criteria are instead required in order to more precisely distinguish between the various operational circumstances that may arise:

- The combat status of the aircraft at the time of the incident;
- The geographic area over which the descent takes place;
- The available means of ground-based defense in the vicinity;
- The strategic interests of the parties involved in the conflict.

4.1. Criterion 1 - The combat status of the aircraft at the time of the incident

The first criterion - whether the aircraft was visibly taken out of combat - is closest to the Hague Commission text. If the plane crashes into flames immediately after the jump, it is clearly an apparatus out of combat. If the aircraft continues to fly apparently intact, the jump becomes suspicious. The difficulty remains that many intermediate situations cannot be distinguished from outside.

4.2. Criterion 2 - The geographic area over which the descent takes place

Costeanu introduces a key distinction neglected by earlier doctrine: the location of the jump radically determines the legal situation. If the jump is made above the parachutist's own territory, the enemy will almost always attack, because the saved aviator can resume combat. A trained pilot is harder to replace than an aircraft - making the attack militarily legitimate, even if it appears inhumane.

Should the individual descending by parachute find himself deep within hostile territory, the opposing force will typically refrain from engaging him either from the air or from the ground - and will be even less inclined to do so when the opportunity to take him prisoner presents itself. Capturing him alive carries greater strategic value than eliminating him outright, since prisoners can be interrogated and put to work, thereby augmenting the productive capacity of the capturing nation. What shields the parachutist in such circumstances is not any sense of battlefield honor, but rather the cold pragmatic reasoning of the adversary.[17]

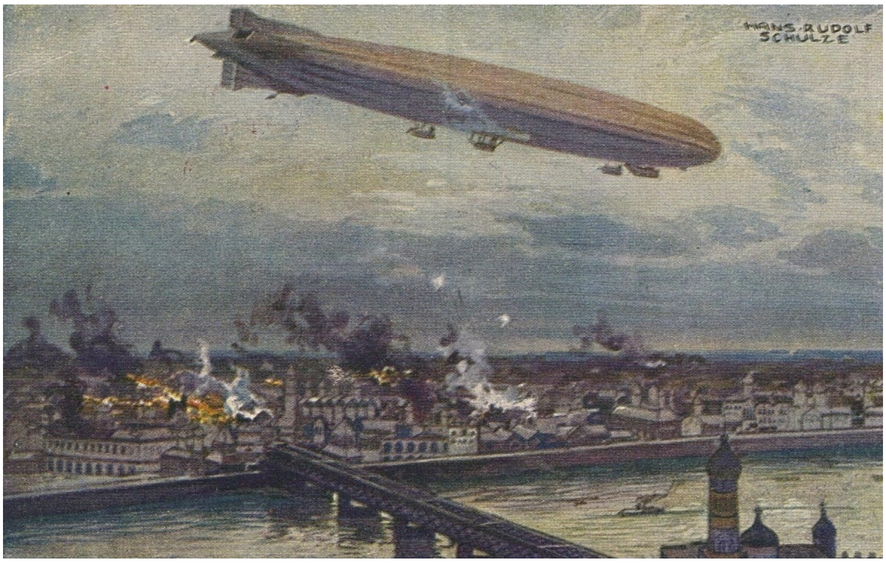

FIG. 4 The German airship Schuette Lanz SL2 bombed Warsaw in 1914[16]

4.3. Criterion 3 - The available means of ground-based defense in the vicinity

The third criterion concerns the concrete capacity of ground forces to capture the parachutist. If local defence is organised and the certainty of capture is high, aerial attack is counterproductive. If, conversely, the parachutist can land in uncontrolled zones or steer the parachute towards his own lines - increasingly possible with manoeuvrable parachutes - the attack becomes justified.

Infantry units on the ground consistently open fire on enemy airmen with little regard for legal or ethical considerations, driven by an incomplete understanding of the unfolding situation, an absence of humanitarian awareness, and uncertainty surrounding where the descending individual will eventually land. A single weapon discharging somewhere along the line is sufficient to trigger a chain reaction, prompting the entire front to unleash a barrage of fire upon the person attempting to save himself.[18]

4.4. Criterion 4 - The strategic interests of the parties involved in the conflict

The fourth criterion is, in Costeanu's view, the most practically important. Chivalry and humanitarianism play a very small role in the operations of modern war. The determining factor is military opportunity: the capture of a trained pilot, capable of providing valuable intelligence, is often preferable to killing him in the air.

This leads Costeanu to a striking paradox, formulated with remarkable lucidity: the improvement in the treatment of parachutists during the Second World War compared to the First was caused not by moral or humanitarian progress, but by the progress of local defence organisation and the "higher understanding of self-interest" - namely, that capturing a living enemy aviator yields more value than shooting him as he descends.

5. OPERATIONAL PARTICULARITIES

5.1. The distinct situation of balloon observers

Costeanu draws an analytical distinction between the aviator and the balloon observer. Captive balloons operate generally above their own territory; the observer who jumps will almost certainly land in friendly lines.

The attack is therefore militarily justified: an observer who has spent time aloft may have noted troop movements and enemy intentions which, once communicated, could be very dangerous to the adversary.[19]

Matters grow considerably more complex when a balloon is ripped loose by adverse weather conditions and swept across into hostile territory - in such a scenario, targeting the observer who abandons the balloon becomes wholly unjustifiable, given that he poses no offensive threat whatsoever and has no feasible means of making his way back to friendly lines. From the very moment he leaps, he is effectively nothing more than a prisoner of war.

5.2. Air battles above the contact lines

When aerial combat unfolds directly over the front lines, even if opposing aircraft choose not to engage the parachutist while he remains airborne, the moment he nears the ground he is met with a barrage of fire from the infantry stationed below. No legal norm can control this behaviour in practice.[20]

5.3. Air battles over the sea

When the aerial battle is fought far out at sea, away from any coast or fleet, attacking parachutists is unjustified - they will perish in the waves regardless. When an enemy fleet is nearby and can recover survivors, the attack becomes legitimate again. In air law, one cannot apply the maritime principle that a ship is sunk only after the safety of its personnel has been ensured.

CONCLUSIONS

It follows, therefore, that no single standard alone is adequate for determining when engaging airmen who are saving themselves by parachute is lawful and when it is not - rather, a combination of multiple criteria must be taken into account:

- The combat status of the aircraft at the time of the incident;
- The geographic area over which the descent takes place;
- The available means of ground-based defense in the vicinity;
- The strategic interests of the parties involved in the conflict.

Such criteria are incapable of establishing with complete certainty when it is appropriate to engage airmen who have abandoned their aircraft by parachute; however, they serve to more accurately characterize each individual situation without narrowing the range of applicable cases - or rather, where some may limit its scope, others act to broaden it.

One might level the charge that we have set aside humanitarian and ethical considerations entirely. Such a criticism would not be without merit; however, it must be stated plainly and without ambiguity that morality, notions of battlefield honor, and humanitarian principles carry very little weight in the conduct of modern warfare. There is little reason to attribute to them a significance they simply do not possess?[21]

Incidents involving attacks on personnel descending by parachute occurred with greater frequency during the First World War than in the Second. This shift can be attributed to advances in the organization of ground-based defenses and a heightened appreciation of strategic self-interest - securing the capture of an enemy airman in order to extract valuable intelligence proved far more beneficial to the nation than the largely impulsive urge to open fire on him while still airborne.

The relevance of this analysis extends beyond the interwar period. Additional Protocol I to the Geneva Conventions (1977), Article 42, prohibits attacks on persons parachuting from a disabled aircraft, extending protection beyond the 1923 Hague Commission formulation. The fundamental distinction introduced in contemporary law - between parachutists saving themselves and those launched on military operations - corresponds precisely to the criteria proposed by Costeanu in the pages of the Aeronautics and Navy Magazine in 1943.

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NEW DEFENCE CONCEPTS OF EUROPEAN STATES IN THE UAS ERA

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Abstract: *The European security environment has entered a phase of accelerated transformation, driven by the return of high-intensity conventional warfare combined with the widespread use of emerging technologies. The war in Ukraine has demonstrated that military superiority is no longer defined exclusively by mass, firepower, or maneuver, but by the ability to rapidly integrate information, technology, and action across all operational domains. In this context, Europe has begun to develop new defence concepts, often generically described as „defensive lines”. However, these initiatives cannot be properly understood through simple historical analogies, but must be analyzed as adaptive, multi-domain systems in which UASs, distributed sensors, and digital networks play a central role. The fundamental question is not whether Europe is building „new lines of defence”, but whether these concepts are sufficient to counter a determined adversary capable of waging hybrid and attrition warfare.*

Keywords: *UAS, defensive lines, European Defence Readiness, drone wall, C-UAS*

1. INTRODUCTION

The transition from classic concepts of territorial defence to defence models based on a systemic approach, integrating military, economic, technological, and informational dimensions, represents a fundamental doctrinal shift in how Europe perceives security in the medium and long term. In the 20th century, defensive structures were built around fortifications, defensive depth, and force concentration, elements designed to slow down and defeat conventional attacks, based on the idea of relatively stable fronts and extended campaigns. These models required centralized control and a predictable operational rhythm, in which fortifications functioned as static „shields”, conceptually separated from the manoeuvring of forces. The new European initiatives, on the other hand, are oriented toward systematic defence, characterized by the integration of technological, doctrinal, and operational capabilities into a coherent and adaptive system. This involves early and continuous detection of threats, deterrence and delay of the adversary, precision strikes at low cost, and conservation of friendly forces for the decisive phases of the conflict. In this model, physical fortifications and traditional infrastructure are no longer central elements, but multipliers of the effects generated by UAS (Unmanned Aircraft System), distributed sensors, and high-precision fire systems.

Obstacles are not designed to permanently stop an attack, but to create favourable time windows for operational response, increasing the overall resilience of the defensive system.

In this way, defence is no longer conceived as a set of passive structures designed for static protection of the territory, but as an active component of the operational system, capable of generating information and decisive effects in an environment characterized by speed, uncertainty, and constant challenges. The transition from static fortifications to dynamic architectures is based on the integration of defence systems such as radars, C-UAS capabilities, and electronic warfare means as elements that support the decision-making process and enable the engagement of the adversary through coordinated fire in multiple operational domains [1].

This evolution reflects not only a technological change, but also a conceptual one: defence is no longer linear or static, but is becoming a multidimensional and reactive system, capable of integrating data collected by autonomous platforms, prioritizing threats, and optimizing the use of resources in real time. Faced with this reality, Europe has launched programs to strengthen its ground and air defence, often presented in public discourse as *„new lines of defence”* [2]. These initiatives include both physical elements: obstacles, fortifications, and military infrastructure, as well as advanced technological components, such as UAS, distributed sensors, C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) networks, and electronic warfare capabilities. In this way, the new *„lines of defence”* are no longer just walls or fortifications, but adaptive architectures that combine physical, digital, and technological tools to support rapid decision-making and coordinated action in a rapidly changing, sophisticated, and unpredictable operational environment.

However, the proliferation of emerging technologies and the multiplication of national initiatives raise fundamental questions about the strategic coherence and operational effectiveness of these efforts. The integration of UAS and autonomous systems promises a significant increase in surveillance, response, and force economy capabilities, but at the same time introduces new vulnerabilities related to network dependency, the electromagnetic spectrum, and industrial resilience.

Based on these premises, the article aims to analyse new European defence concepts from the perspective of the transformation of modern warfare, with a focus on the role of UAS and associated technologies. The main objective is to assess the extent to which these initiatives contribute to credible deterrence and real defence capabilities. In this sense, the paper does not seek to provide an exhaustive overview of all existing programs, but rather to identify structural trends, advantages, and limitations of the current European strategic direction.

Therefore, the research is based on a qualitative, conceptual and doctrinal analysis, using open sources and official documents relevant to the field of defence and security. NATO and European Union doctrinal documents, institutional reports, specialized academic studies, as well as analyses published by security think tanks are analysed. This approach is complemented by an analysis of the main defence initiatives developed by various European states, with the aim of highlighting the main directions and concepts that will form the basis of a defence system adapted to the requirements of contemporary warfare.

The methodology adopted does not seek to provide a detailed assessment of the technical performance of individual systems, but rather to examine how they are integrated into broader defence architectures, particularly within C4ISR structures. The emphasis is on the relationship between technology, doctrine, and organizational adaptability, which are considered essential factors for the effectiveness of new defence concepts in a constantly contested and multi-domain operational environment.

2. EUROPEAN INITIATIVES AND FUTURE DIRECTIONS

As the European security environment continues to evolve under pressure from conventional and hybrid threats, EU member states have begun to outline strategic programs that serve not only to strengthen their defensive posture, but also to create real mechanisms for deterrence and long-term operational resilience.

In order to move from fragmented and reactive initiatives to a coordinated, multi-domain strategy focused on real, interoperable, and sustainable capabilities, the EU has come up with legislative proposals to increase the level of European defence readiness: European Defence Readiness 2030. This commitment aims to strengthen the response capacity and resilience of European states by 2030. The document responds to the strategic challenges posed by Russia's war of aggression against Ukraine and the changing global security environment, emphasizing the need for Europe to become *„more sovereign, more responsible for its own defence and better equipped to act and deal autonomously and in a coordinated way with immediate and future challenges and threats”* [3]. This strategic framework also highlights the importance of a strong European defence industrial base capable of producing and supplying equipment at a scale and pace appropriate to operational needs and deterrence objectives for 2030. Strengthening technological and industrial capabilities is considered essential to reduce external strategic dependencies and support European defence cooperation projects.

This plan to enhance European defence readiness proposes four main strategic projects designed to strengthen the European Union's ability to anticipate and respond to emerging security threats by 2030. The first initiative: European network of anti-drone measures *(„drone wall”),* renamed the European Drone Defence Initiative, aims to develop a state-of-the-art interoperable system for both countering and operational use of unmanned aircraft systems. It aims to create a multi-layered network capable of detecting, tracking, and neutralizing hostile drones, while integrating advanced UAS platforms to enable precision strikes. The initiative is based on lessons learned from the conflict in Ukraine and is closely related to the proposal to create a drone Alliance with Ukraine, designed to support technological and industrial cooperation in this field. At the same time, the initiative has another use, allowing the capabilities developed to be applied in civilian contexts, such as border protection or emergency and disaster management. The program is expected to be launched in the first quarter of 2026, reach initial operational capability by the end of that year, and become fully operational by the end of 2027 [4].

A second project, Eastern Flank Watch, is designed to strengthen land defence capabilities, counter-UAS, border and critical infrastructure protection, military mobility, and strategic support capabilities, thereby creating a rapid response mechanism and coordinated resilience at the EU level. The leaders of the countries located on this border: including Finland, Sweden, Poland, Estonia, Latvia, Lithuania, Romania, and Bulgaria, have called for the prioritization of European funding for this initiative, arguing that they are *„on the front line”* of direct and long-term threats posed by Russia and that a coordinated, multi-domain operational approach is essential for common security [5].

Air Defence Shield (European Air Shield) is the third priority project of the EU for European Defence Readiness 2030 and represents a collaborative effort by EU member states to create an integrated air and missile defence shield covering the entire spectrum of air threats: ballistic missiles, cruise missiles, aircraft, UAS, and drone swarms, creating a layered and interoperable architecture to protect the Union's territory against conventional and complex air threats. This project aims not only to strengthen sensors and kinetic systems, but also to ensure interoperability with NATO structures, thus addressing both traditional gaps and issues highlighted by recent conflicts [6].

The Defence Space Shield project, recently renamed European Space Shield (ESS), is the fourth European initiative to strengthen situational awareness and protect critical space infrastructure. Its main purpose is to protect the EU and its member states against emerging threats in space: from jamming communications and navigation signals to intercepting or disrupting civilian and military satellites. ESS integrates orbital object monitoring, satellite communications protection, and interoperability with command and control systems, providing real-time data for decision support and coordination of multi-domain operations. In addition, the project aims to maintain Europe's technological and strategic competition in space by developing autonomous capabilities and reducing dependence on external suppliers. This initiative reflects lessons learned from the conflict in Ukraine, where space has become a decisive domain for intelligence gathering and precision strike coordination [7].

These strategic projects are designed to function as a coherent set of capabilities covering land, air, sea, cyber, and space domains, and are planned to include both technological components and collaborative procurement and production mechanisms between member states. Overall, the strategic framework aims not only to close capability gaps, but also to strengthen Europe's strategic autonomy through joint deterrence and defence projects.

There are other defence initiatives, such as the Polish Eastern Shield project, launched in 2024, which involves fortifying a 700 km stretch of the border with Belarus and the Russian exclave of Kaliningrad with anti-mobility obstacles (anti-tank ditches, dragon's teeth, 5 m smart fences), over 100 bunkers and fortifications, minefields, fortified bridges, and integrated C-UAS systems, with completion planned by 2028 [8]. Key components of this upgrade should include UAS detection and classification systems, such as low-altitude radars, optoelectronic systems, and passive sensors for receiving UAS data transmissions. Counter-UAS (C-UAS) measures must cover stationary/mobile jamming, kinetic and non-kinetic neutralization, and at the same time, integration with command and control must be achieved to enable real-time situational assessment and transnational data sharing with other Baltic states [9].

Another relevant example of a regional defence initiative is the Baltic Defence Line (BDL), a coordinated system of fortifications and defensive capabilities on the border of Estonia, Latvia, and Lithuania. Designed as a set of multi-layered positions, it includes anti-vehicle obstacles, trenches, reinforced bunkers, observation posts, and sensors, as well as integrated ISR systems such as UAS. The BDL aims to slow down and channel the advance of an attacking force, providing crucial time for the arrival and deployment of NATO forces under Article 5. Compared to the traditional defensive system, this line functions as a *„battlefield shaping”* mechanism, extending operational depth and increasing the costs of an invasion for the aggressor. With three planned echelons of resistance and integrated interoperability with allied command structures, the BDL reflects both the need for deterrence through denial and adaptation to the geographical constraints of NATO's eastern flank, where short distances and proximity to Russian borders require proactive and flexible defensive solutions. [10].

The United States Army Europe and Africa (USAREUR-AF) command has also initiated the Eastern Flank Deterrence Line (EFDL), a new US-NATO concept for countering Russian threats through improved land capabilities and military-industrial interoperability. Initially focused on the Baltic states, the EFDL defines precise requirements for common launchers (offensive/defensive, optionally autonomous), low-cost standardized ammunition, universal fire control systems, and online coordination augmented by AI (artificial intelligence) systems with the ultimate goal of launching the most cost-effective ammunition relative to the target [11].

We must also mention Operation Eastern Sentry, a NATO activity launched on September 12, 2025, as a direct response to repeated incursions by Russian drones into Polish airspace (September 9-10, 2025), invoked under Article 4 and continuing Operation Baltic Sentry (January 2025). Announced by NATO Secretary General Mark Rutte and SACEUR Gen. Alexus G. Grynkewich, the operation integrates fighter jets, helicopters, transporters, anti-aircraft systems, surveillance aircraft, and frigates, plus innovative anti-drone technologies with the primary goal of enhancing NATO's (air, sea, ground) to intercept Russian drones entering allied airspace, moving from separate national efforts to a unified operational policy across the entire eastern flank, from the Baltic Sea to the Black Sea [12].

Overall, the defensive architecture taking shape on the eastern flank is not a mosaic of disparate initiatives, but rather the expression of a systemic transformation in the way Europe conceives its security. The programs brought together under European Defence Readiness 2030: European Drone Defence Initiative, Eastern Flank Watch, European Air Shield, and European Space Shield represent the foundation of the new European approach, focused on early detection, sensor-effector integration, and information superiority. They are complemented, without confusion, by parallel initiatives such as the Eastern Shield, the Baltic Defence Line, and the NATO Eastern Flank Deterrence Line concept, each with its own distinct role: national defensive infrastructure, regional fortifications, and multi-domain deterrence architecture. Together, these projects mark the transition from static defence to a distributed, adaptive, and digitally connected defence capable of responding not only to a conventional attack but also to the dynamism of hybrid and attrition warfare.

3. THE ROLE OF UAS IN NEW DEFENCE CONCEPTS

Unmanned aircraft systems are a central element of new European defence concepts, constituting one of the main sources of innovation and operational efficiency in contemporary conflicts. Their integration into the defensive architecture reflects a fundamental paradigm shift, in which superiority is no longer determined exclusively by large and expensive platforms, but by the ability to quickly process and exploit information in support of decision-making and action.

Some of the most important missions of UAS remain surveillance and reconnaissance, which substantially reduce operational uncertainty and maintain an accurate overall picture at both the tactical and operational levels, as demonstrated by the widespread use of ISR drones in the war in Ukraine, where they have become a central component of modern military operations and have been used in record numbers for continuous monitoring of the battlefield.

At the same time, integrating data collected by unmanned aerial platforms into C4ISR networks helps shorten the sensor-to-shooter information flow, decisively reducing the time between detection and engagement and facilitating accelerated decision-making under operational pressure. The integration of multi-sensor fusion into C-UAS architectures is one of the essential developments in modern drone defence, as small, slow, and low-signature drones are increasingly difficult to detect with a single type of sensor. The effectiveness of current air defence depends on the real-time correlation of data from radar, RF sensors, and electro-optical systems, each with distinct advantages and limitations, which means that using them in isolation can lead to both delays and high false alarm rates. In this context, an adequate infrastructure for interoperability is needed, allowing C-UAS systems to process and merge data from multiple sources into a single, coherent, and actionable picture.

Such approaches are already being applied in Ukraine, where the „Delta” ecosystem combines diverse sources of information to accelerate the detection, classification, and engagement of enemy drones, reducing errors and increasing operational response speed in complex combat conditions [13]. Therefore, multi-sensor fusion is not just a technical optimization, but the basis of a modern defensive architecture that allows C-UAS systems to respond quickly to a wide range of threats.

At the same time, the significant increase in drone threats has necessitated the development of defensive solutions that use UAS themselves in counter-UAS roles as part of a layered air defence. The operational experience gained in Ukraine, where MEROPS shot down over a thousand Russian Shahed drones and other similar systems, has reinforced the platform's reputation as an effective tool for countering asymmetric air attacks, highlighting its cost-effectiveness in the context of a conflict characterized by the intensive use of inexpensive air munitions. The rapid acquisition of the system by Poland and Romania, as well as the implementation of an accelerated multinational training program, reflect the adaptation to the lessons learned from the Ukrainian conflict and the inclusion of these types of systems in the regional defence architecture, where they complement the Eastern Flank Deterrence Line concept by providing a scalable and effective low-altitude air defence capability [14].

In addition to these established functions, new European defence concepts attribute to UAS an expanded set of complementary roles, transforming them into a structural element of these defensive architectures. Thus, UAS are increasingly used as aerial communications nodes, extending coverage and providing redundancy to tactical networks in contested environments or areas where ground infrastructure is vulnerable. In many cases, UAS platforms are equipped with electronic warfare capabilities, enabling them to jam, disrupt, or identify enemy electromagnetic sources, thereby helping to protect their own systems and degrade enemy command and control capabilities. The evolution of loitering drones and the adaptation of FPV (First Person View) drones have also expanded the role of UAS in executing low-cost precision strikes, providing the ability to generate rapid lethal effects adapted to tactical needs. Logistically, drones can be used to transport ammunition, medical equipment, or critical packages to dispersed units, reducing the exposure of supply lines.

In conclusion, in Europe's defensive architecture, UAS cannot be used simply as surveillance tools or as sensors integrated into the rapid engagement chain, but as multifunctional platforms that increase operational resilience, accelerate decision-making, multiply tactical options, and contribute to the creation of a distributed, adaptable defence capable of progressively degrading the adversary's potential across the entire spectrum of conflict.

4. THE DEFENCE INDUSTRY AND SUSTAINABILITY

A long-term conflict cannot be sustained by advanced prototypes or isolated initiatives, but requires robust, scalable, and resilient industrial capabilities able to produce large volumes of equipment at a pace compatible with the intensity of modern operations. Europe still faces structural difficulties in this area. Although the European Union has launched programs dedicated to increasing the production of ammunition and missiles, such as the Act in Support of Ammunition Production (ASAP), these were designed primarily as a response to the urgent need to replenish depleted stocks and support Ukraine, not as a tool for a profound transformation of the industrial base.

ASAP has allocated over €500 million to expand production capacities for explosives, powders, projectiles, and missiles, with the goal of reaching an annual volume of 2 million shells by the end of 2025, but the Commission's report acknowledges that supply bottlenecks and external dependencies remain significant [15].

Independent assessments show that the problem runs deeper than production rates. According to analysis by the International Institute for Strategic Studies, European industrial capabilities suffer from market fragmentation, lack of standardization, chronic underinvestment since the Cold War, and bottlenecks in supply chains, from powders and explosives to microelectronics and critical subassemblies. Even where technological expertise exists, production rates are limited by the reduced capacity of small suppliers and external dependencies for strategic raw materials [16].

Furthermore, although Eastern European countries have embarked on ambitious industrial expansion programs, their growth is insufficient given the nature of contemporary conflicts, which are characterized by massive consumption of ammunition, drones, and counter-UAS systems. The experience in Ukraine shows that modern warfare involves the daily use of thousands of drones, millions of cartridges, and tens of thousands of shells, levels that European industry cannot yet sustain autonomously and consistently. In this context, recent EU programs, such as the Readiness Roadmap 2030, highlight the need to strengthen supply chains, integrate the European defence market, and create a permanent mechanism for scale production capable of supporting both current operations and preventive rearmament [17].

Thus, the issue of European defence sustainability is not only technological, but primarily industrial: Europe can innovate, but it struggles to produce. In the absence of scalable production capacity for UAS, ammunition, and C-UAS systems, the conceptual advantages of new defensive architectures are likely to remain incomplete, and dependent on external suppliers such as the United States, Israel, or South Korea, which compromises the goal of European strategic autonomy.

CONCLUSIONS

Europe's new *„lines of defence”* do not represent a return to the defensive models of the past, but rather an attempt to adapt the lessons of modern warfare into a credible defensive architecture. UAS and associated technologies are not miracle solutions, but they are essential multipliers in an operational environment dominated by speed, information, and precision.

At present, Europe cannot be considered fully prepared for a high-intensity conflict with a militarily comparable adversary. However, the continent is clearly moving in the right direction, both conceptually and doctrinally, integrating the changes that contemporary warfare has brought with it.

The fundamental change lies in recognizing that modern defence can no longer be static, linear, or exclusively conventional. New European concepts emphasize adaptability, distributed technology, economy of force, and the integration of humans, machines, and artificial intelligence, reflecting a shift from a logic of massing forces and equipment to one of connectivity, resilience, and rapid decision-making.

However, although the strategic direction is clearly the right one, the current level of coherence, interoperability, and capabilities remains insufficient to guarantee credible deterrence. Most C-UAS and defence modernization projects are still in the early stages of implementation, dependent on medium and long-term funding, and are constrained by European industrial and doctrinal fragmentation.

In the absence of accelerated integration within NATO IAMD and C4ISR, as well as clear command and control mechanisms at the allied level, there is a risk that these initiatives will remain means of strengthening local defence rather than decisively changing the balance of power in a large-scale confrontation.

Therefore, Europe is not prepared for a high-intensity conflict on its eastern flank, but for the first time since the Cold War, it is on a realistic strategic path to adapt to modern warfare. The success of this transition will depend on the ability of European states to transform these *„new lines of defence”* from fragmented and predominantly national initiatives into an integrated, interoperable, and credible at the allied level, capable of combining emerging technology with increased industrial capacity alongside political will and effective military coordination within the EU, but also within NATO.

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GEOMETRIC MODELING AND AERODYNAMIC ANALYSIS OF THE RR LENTUS MOTOR GLIDER

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Abstract: *This research presents a systematic aerodynamic evaluation of the RR Lentus motor glider through a digital reverse engineering workflow. Due to the absence of proprietary manufacturer data, the study focuses on reconstructing a high-fidelity digital twin to predict flight behavior and stability characteristics. The methodology integrates geometric acquisition via photogrammetry with specialized design tools, utilizing winghelper for structural visualization and xflr5 for computational fluid dynamics (CFD) analysis based on the vortex lattice method (VLM). The analysis follows a dual-stage approach: a 2D analysis of the NACA 4407 and NACA 0009 airfoils to determine section polars, followed by a comprehensive 3D simulation of the full aircraft assembly. Key performance metrics, including the total lift-to-drag ratio (*C_l/C_d*) and longitudinal stability derivatives, were quantified under international standard atmosphere (ISA) conditions. Furthermore, a detailed mass-moment analysis was conducted to localize the center of gravity (CG) at 33% of the mean aerodynamic chord (MAC), ensuring a balanced flight envelope. The findings provide a technical baseline for the aerodynamic validation of high-performance RC gliders, demonstrating the efficacy of open-source simulation tools in academic UAV research.*

Keywords: *analysis, reverse engineering, WingHelper, XFLR5, Vortex Lattice Method.*

Symbols and acronyms:

C_l	Lift coefficient	VLM	Vortex Lattice Method
C_d	Drag coefficient	Re	Reynolds number
C_l/C_d	Lift-to-drag ratio	UAV	Unmanned Aerial Vehicle
C_L	Total lift coefficient	MAC	Mean aerodynamic chord
C_D	Total drag coefficient	AoA (α)	Angle of Attack
C_L/C_D	Total lift-to-drag ratio	MTOW	Maximum Take-Off Weight
CG	Center of gravity	ESC	Electronic Speed Controller
RC	Radio Control	CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics	OEM	Original Equipment Manufacturer
NACA	National Advisory Committee for Aeronautics	ISA	International Standard Atmosphere

1. INTRODUCTION

The study of contemporary radio-controlled (RC) aircraft necessitates a shift from observational testing toward theoretical validation. This research focuses on the RR Lentus, a high-performance motor glider developed by Multiplex specifically for thermal soaring and slope soaring applications. According to manufacturer specifications, the aircraft incorporates an advanced airfoil design that facilitates a broad dynamic flight envelope and controlled landings through a four-flap "butterfly" (crow) configuration [1].

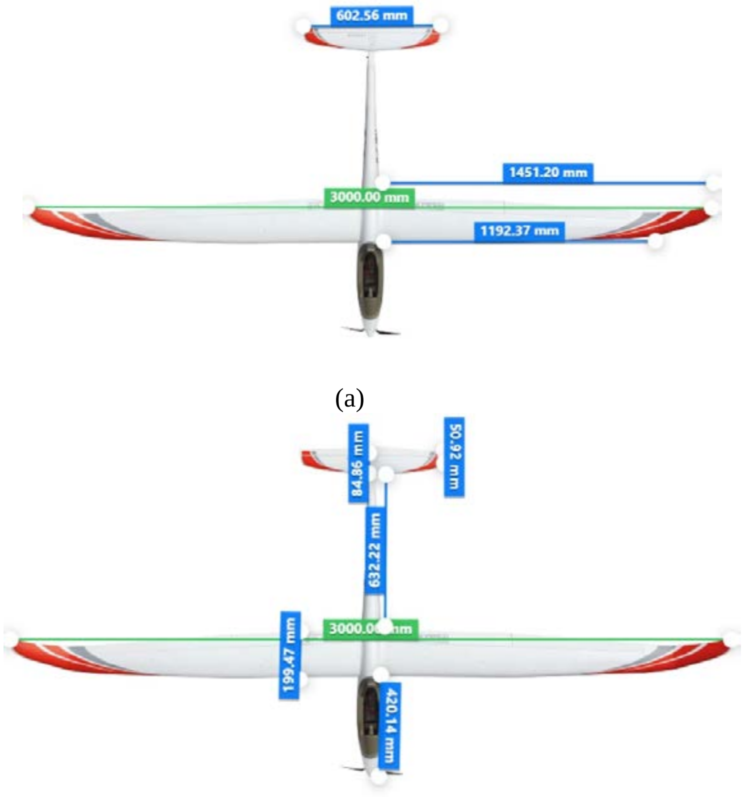
In its standard Ready-for-Radio (RR) iteration, the model is equipped with a ROXXY brushless power system optimized for 3S LiPo configurations, utilizing six Hitec HS-65HB servos to actuate the primary control surfaces: elevator, rudder, ailerons and flaps. While Multiplex provides this baseline operational parameters-along with options for aerotow releases or retractable landing gear, the full suite of aerodynamic coefficients remains proprietary and is not publicly documented.

The primary objective of this study is to address this informational deficit by synthesizing the missing technical parameters through high-fidelity simulation. Moving beyond the general descriptions provided by the manufacturer, this paper adopts a reverse engineering methodology. By digitizing the physical geometry of the airframe and performing a computational analysis within the XFLR5 environment, we aim to establish a quantitative baseline for the aircraft's longitudinal stability and aerodynamic efficiency.

2. METHODOLOGY AND GEOMETRIC RECONSTRUCTION

A precise digital replica of the RR Lentus was engineered to ensure the accuracy of the subsequent aerodynamic evaluations. Given that proprietary CAD data is unavailable, the model was reconstructed using an integrated three-phase workflow: photogrammetry for geometric capture, structural definition and the final aerodynamic modeling.

2.1 Geometric acquisition. To facilitate the 3D reconstruction, the model's geometry was first mapped using ImageOnline (Fig. 1) [2]. A top-down photographic analysis, calibrated against the 3000 mm wingspan, allowed for the precise identification of chord lengths and sweep angles at multiple stations, forming the structural basis of the simulation model.

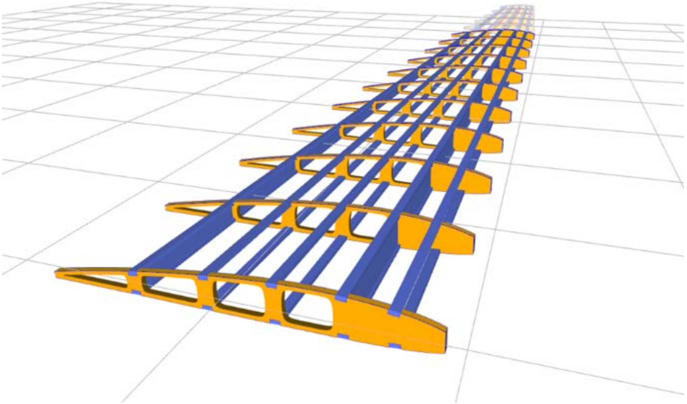


(a)

(b)

FIG. 1 Geometric acquisition and dimensioning using ImageOnline

2.2 Structural and propeller modeling. Based on the extracted measurements, the wing geometry was visualized using WingHelper [3]. This software allowed for the definition of the aerodynamic surfaces, including the dihedral angles and the placement of control surfaces (Fig. 2). The wing employs a classic rib-and-spar construction. The aerodynamic profile is defined by a series of ribs, generated according to the NACA 4407 coordinates [4], featuring lightening holes to optimize the strength-to-weight ratio. The primary aerodynamic loads are carried by a dual-spar system (upper and lower caps connected by shear webbing) running spanwise, designed to resist bending moments during flight.



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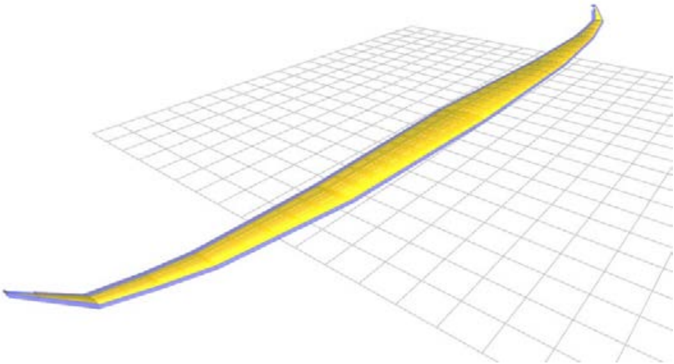

(b)

FIG. 2 3D Wing reconstruction in WingHelper

2.3 Aerodynamic model construction. Constructing the analysis model in XFLR5 [5] represented the most complex stage of the workflow. Based on the previously captured spatial data, the simulation model was synthesized by defining the aircraft's aerodynamic components, including the wing, empennage surfaces and fuselage body, to ensure an accurate representation of the physical airframe.

The wing geometry was built in XFLR5 by entering the chord lengths and positions obtained from the image calibration. Since exact technical drawings were unavailable, the sweep angles and the dihedral seen in Fig. 3 were approximated based on top and front-view photographs. The red line in the 3D view shows the airfoil section, while the wireframe mesh defines the surfaces where the software calculates lift.

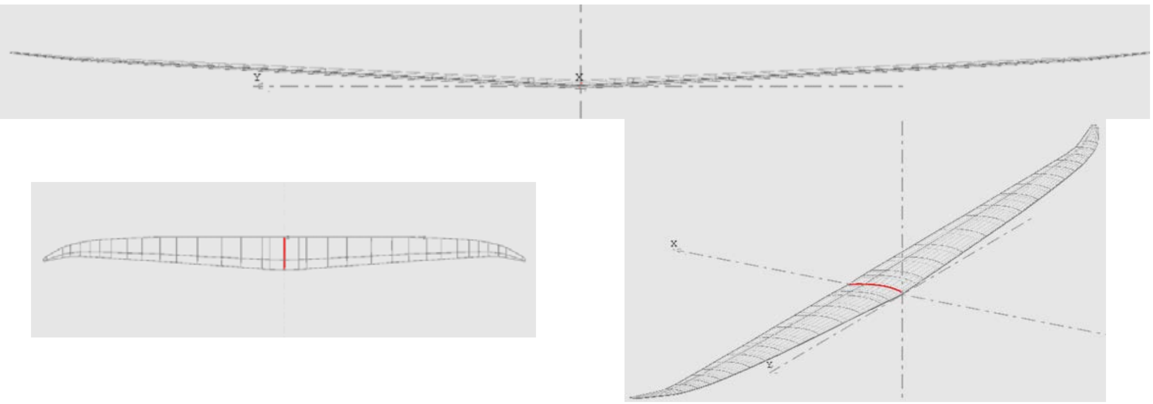

FIG. 3 XFLR5 geometric model of the wing assembly showing front, top and isometric views

A similar process was used for the horizontal stabilizer, as shown in Fig. 4. The span and chord were set according to the digitized measurements, while the overall shape was adjusted to match the visual proportions of the RR Lentus. This model uses a symmetrical profile to ensure the tail remains neutral during flight, which is essential for longitudinal balance.

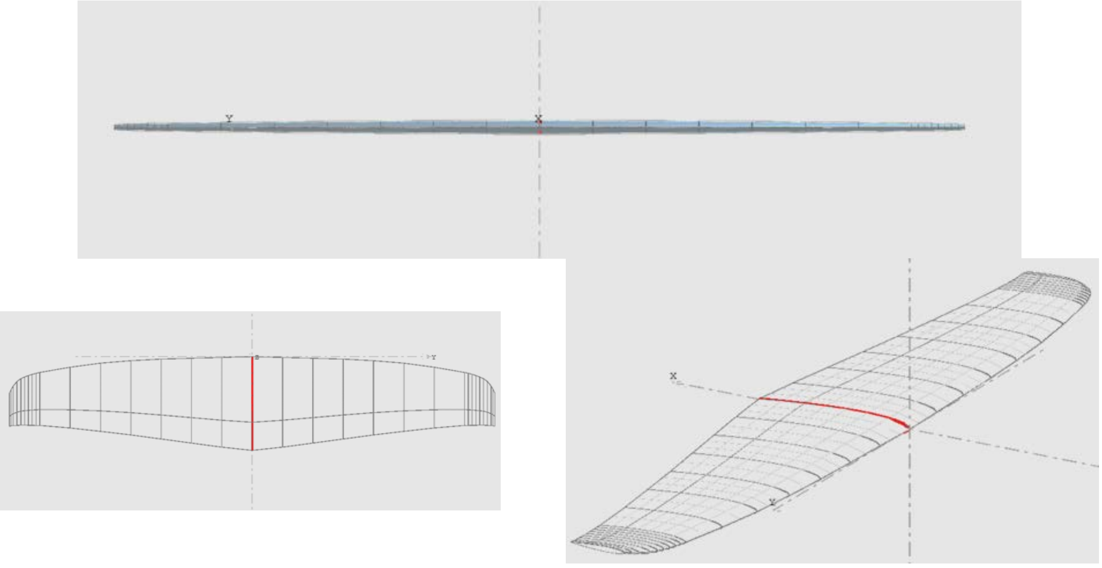

FIG. 4 3D visualization of the elevator assembly in XFLR5, showing the front, top and isometric views

The vertical fin was modeled by defining its height and taper ratio in the XFLR5 geometry editor, as seen in Fig 5. The sweep of the leading edge was approximated to follow the aircraft's scale appearance. This surface provides the necessary directional stability to keep the glider aligned with the airflow during thermal turns.

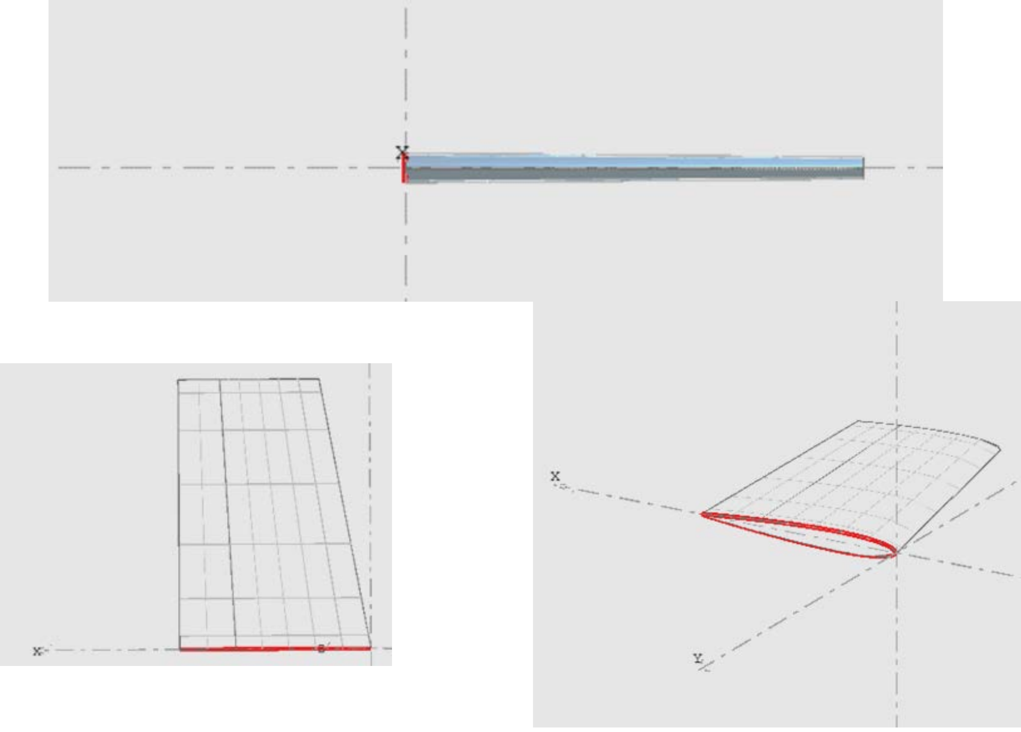

FIG. 5 3D visualization of the fin assembly in XFLR5, showing the front, top and isometric views.

Figure 6 shows the fuselage body, which was created using a series of circular and elliptical cross-sections. These sections were scaled and positioned to replicate the streamlined shape of the real motor glider. Although the fuselage produces very little lift, including it in the model is important for a more realistic estimate of the total drag.

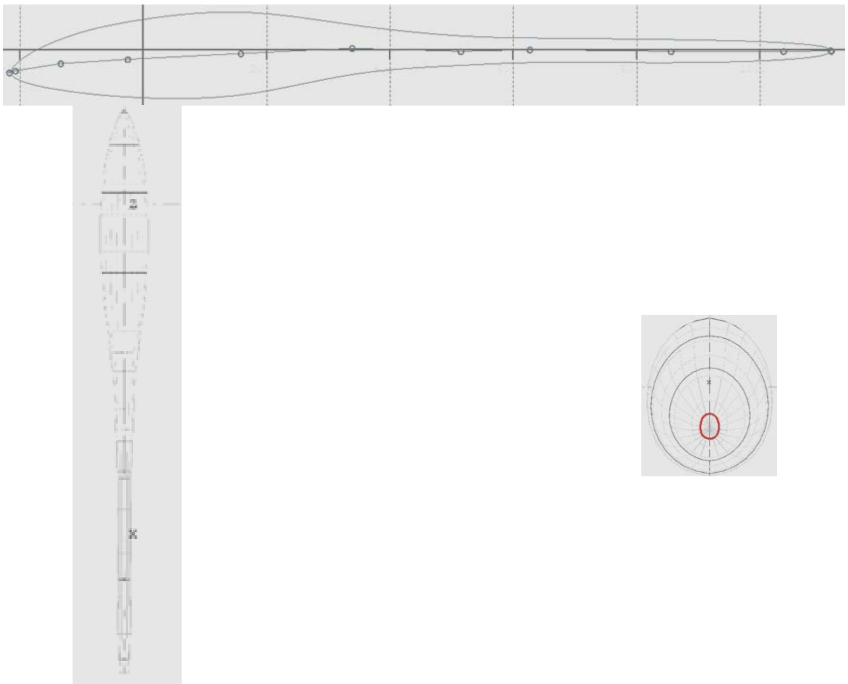

FIG. 6 3D visualization of the body assembly in XFLR5, showing the front, top and isometric views.

The final stage of the geometric reconstruction is the integrated aerodynamic model shown in Fig. 7. This complete digital twin combines the main wing, the empennage and the fuselage into a single computational entity. This unified configuration is used to perform the 3D analysis, allowing for the simulation of complex interactions

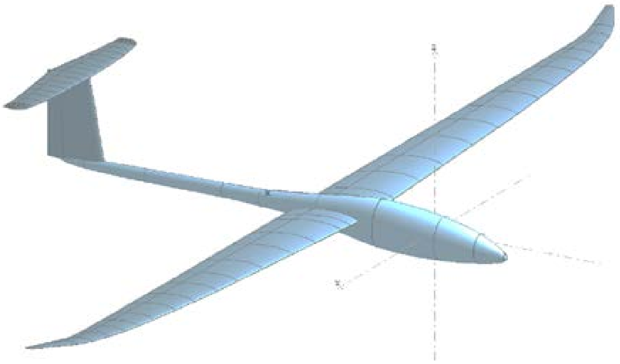

FIG. 7 Complete aerodynamic model definition in XFLR5

3. AERODYNAMIC ANALYSIS

Utilizing the XFLR5 analytical suite, this study evaluated the lift, drag and stability derivatives of the aircraft. The simulation environment was configured to reflect International Standard Atmosphere (ISA) conditions, providing a controlled baseline for the aerodynamic results.

Table 1. Initial conditions for aerodynamic analysis [6, 7].

Parameter	Value	Parameter	Value
Speed	10 m/s	Viscosity	1.46 x 10^{-5} m^2/s
Air density	1.225 kg/m^3	Method	3D/VLM
AoA interval	-15°÷ 15°, Δ=1°	Reynolds number	108,904 (109,000)
Temperature	15°C	Mach number	0.030 Mach
Aerodynamic airfoils	NACA 4407 (asymmetric) NACA 0009 (symmetric)	MAC	159.37 mm

3.1 Airfoil selection and characteristics. The aerodynamic optimization of the RR Lentus relies on the selection of distinct airfoils for its lifting and stabilizing surfaces. For the main wing, a NACA 4407 (Fig. 8) (modified) was implemented, providing the necessary lift through its 4% camber and 7% thickness to excel in thermal duration flights. This allows for high-alpha maneuvers without the risk of a premature stall. For the empennage, NACA 0009 symmetrical airfoils were adopted [4]. The adoption of a symmetrical section ensures that the stabilizers remain aerodynamically neutral at a 0° angle of attack, preventing unwanted pitching moments and providing a stable reference for the aircraft's longitudinal trim.

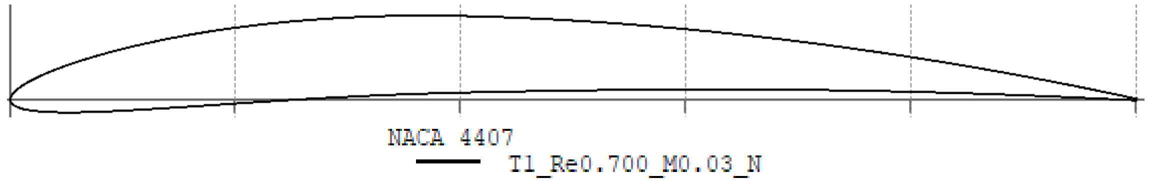

FIG. 8 NACA 4407 airfoil geometry

Analysis of the main wing airfoil NACA 4407

The aerodynamic performance of the main wing is characterized by the polar curves generated in XFLR5.

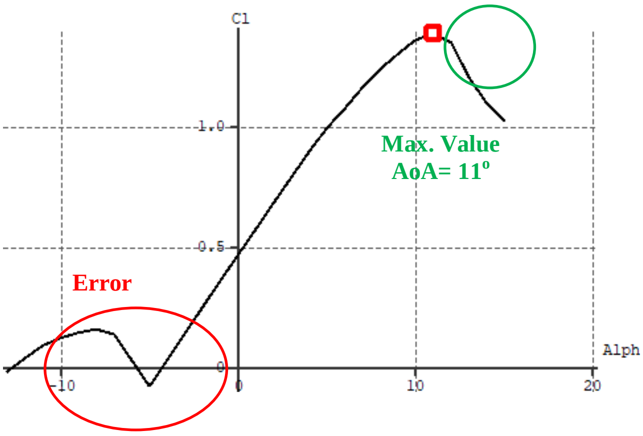

FIG. 9 2D Polar (C_l) for NACA 4407 airfoil computed in XFLR5

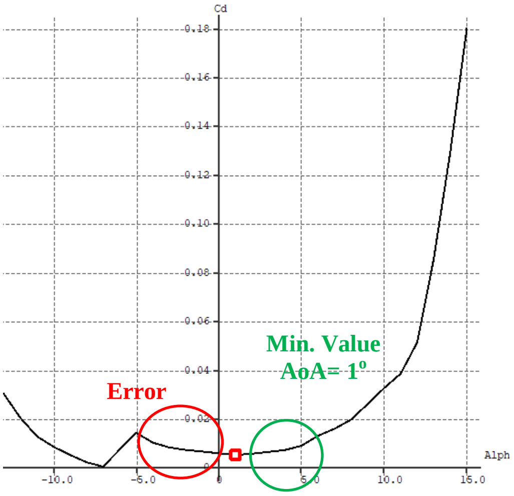

FIG. 10 2D Polar (C_d) for NACA 4407 airfoil computed in XFLR5

Figure 9 illustrates the lift coefficient (C_l) as a function of the angle of attack (α). The curve exhibits a linear behavior typical of cambered airfoils, reaching a maximum lift coefficient (C_{lmax}) of approximately 1.4 at a critical angle of 11°, which represents the stall point.

Figure 10 presents the drag polar, where the low-drag region covers the intended cruising range.

Analysis of the Stabilizer Airfoil (NACA 0009)

The horizontal stabilizer utilizes the symmetrical NACA 0009 (Fig. 11) airfoil to ensure neutral handling characteristics [8, 9].

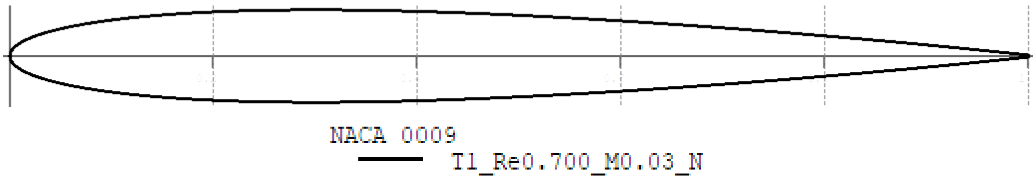

FIG. 11 NACA 0009 airfoil geometry

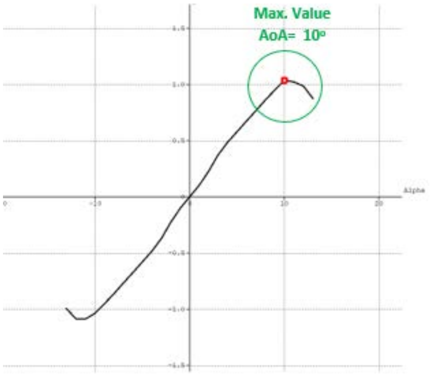

FIG. 12 2D Polar (C_l) for NACA 0009 airfoil computed in XFLR5

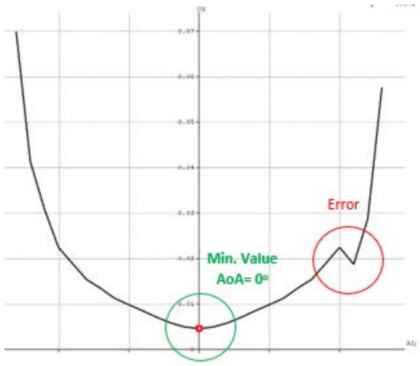

FIG. 13 2D Polar (C_d) for NACA 0009 airfoil computed in XFLR5

As shown in Fig. 12, the lift curve passes directly through the origin ($Cl=0$ at $\alpha=0$), confirming that no unintended lift is generated at a neutral angle.

Figure 13 demonstrates that the minimum drag coefficient is also achieved at this 0^{o} position.

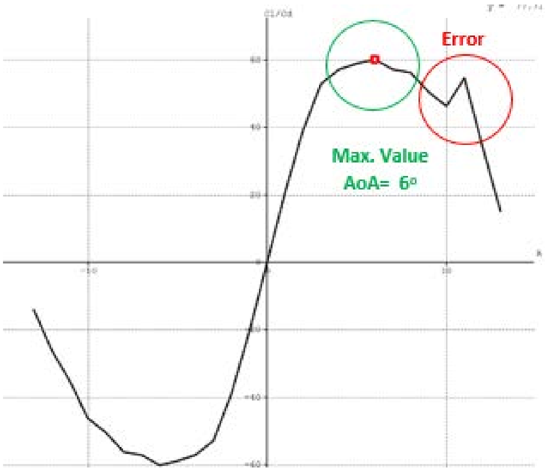

FIG. 14 2D Polar (C_l/C_d) for NACA 0009 airfoil computed in XFLR5

The linear lift slope observed in Fig. 14 ensures predictable pitch authority, allowing for precise control inputs.

3.2 Aerodynamic efficiency (3D wing analysis). The flow visualization in XFLR5 reveals the formation of wingtip vortices and the downwash distribution across the span captured at a fixed angle of attack 5°. However, the irregular behavior of the streamlines at certain chord stations suggests a need for mesh refinement (Fig. 15). To achieve higher numerical convergence and eliminate artificial turbulence, the panel density should be increased and the geometric transitions between the wing segments must be further smoothed to ensure a continuous aerodynamic surface.

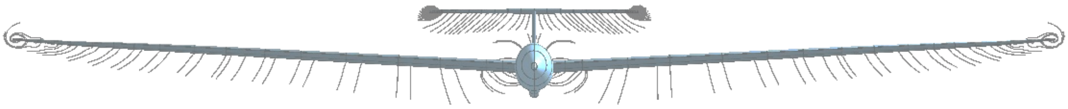

FIG. 15 Visualization of 3D streamlines and wake-vortex distribution for the RR Lentus at a 5° angle of attack in XFLR5

3.3 Longitudinal stability and center of gravity. To establish a reliable baseline for stability, the aircraft's Center of Gravity was derived through a detailed mass-moment analysis of all internal components. By integrating the weights and positions of the motor, battery and servos, the CG was localized at 33% of the chord length relative to the leading edge, it can be seen in Fig. 16. This placement follows the conventional rule for stable RC gliders, providing the necessary restoring moments required for a predictable flight envelope.

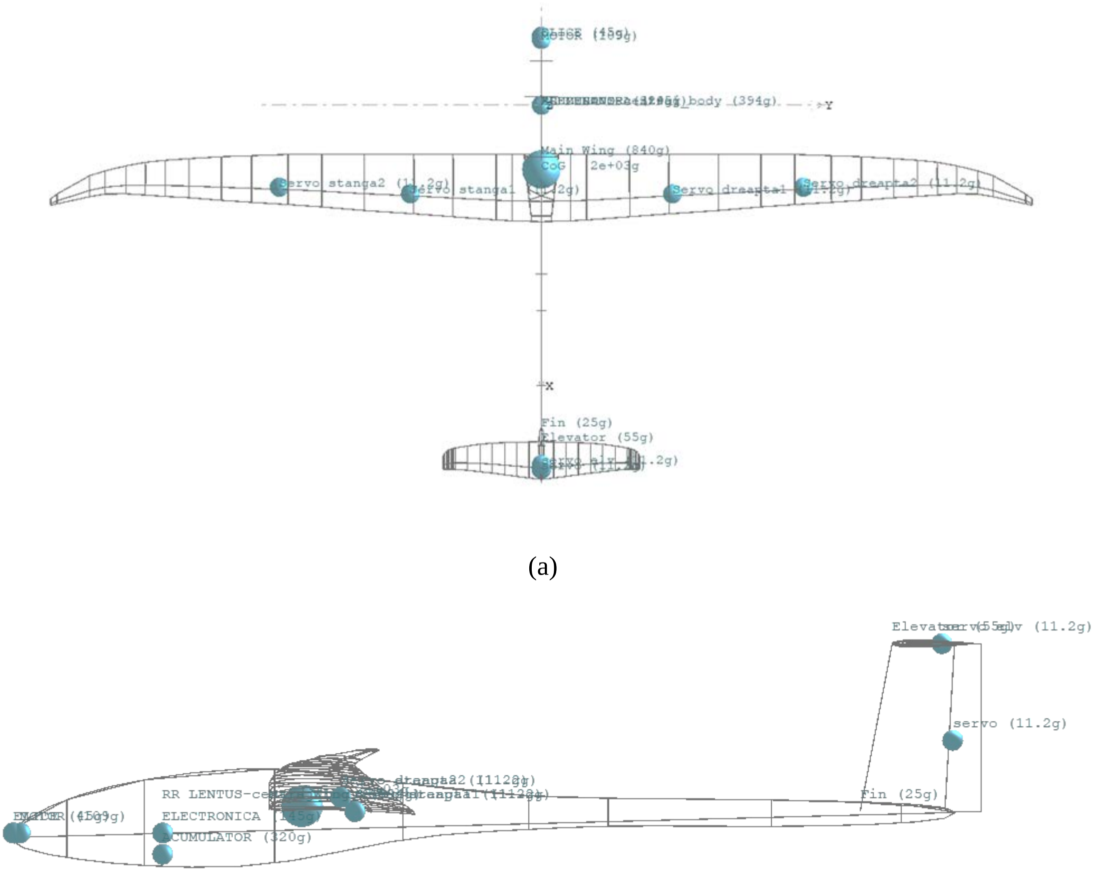

FIG. 16 Mass distribution and center of gravity for the RR Lentus: (a) top view and (b) side view

Table 2. List of components and masses

No.	Component	Mass (g)	Type
1	Body (20%)	394	Elapor
2	Main wing (42%)	840	Elapor
3	Fin (2%)	25	Elapor
4	Elevator (3%)	55	Elapor
5	Battery	320	LiPo
6	Electric motor	109	ROXXY brushless
7	Propeller	45	Folding
8	Servo motors (x6)	11.2	HS-65HB
9	Electronics	145	Wiring, ESC, FC, transceiver
TOTAL		2000	

3.4 Full aircraft aerodynamic analysis. The 3D simulation provides a comprehensive evaluation of the complete airframe's performance, accounting for the interaction between lifting surfaces and the resulting aerodynamic forces.

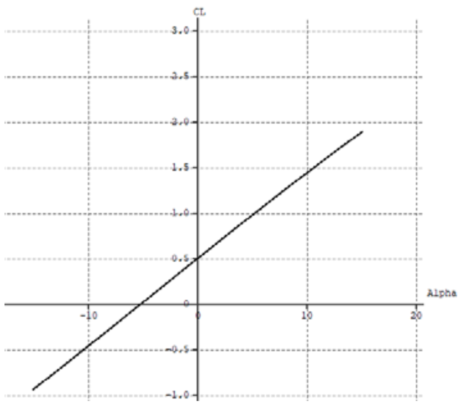

FIG. 17 Variation of lift coefficient (C_L) with angle of attack (α)

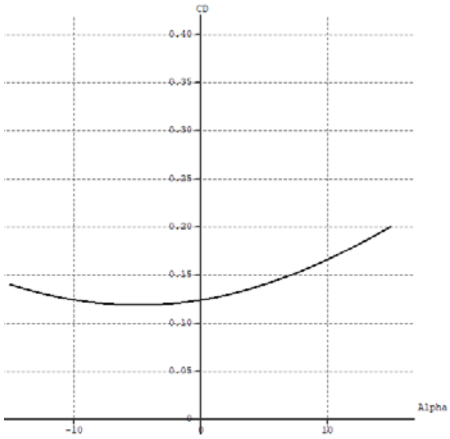

FIG. 18 Variation of drag coefficient (C_D) with angle of attack (α)

Figure 17 illustrates the variation of the total lift coefficient (C_L) as a function of the angle of attack. The curve demonstrates a consistent linear progression within the operational flight envelope, validating the wing's lifting capability. Figure 18 depicts the total drag coefficient (C_D), which represents the effect of parasitic drag (surface friction and form drag) and induced drag. The parabolic nature of this curve highlights the increase in aerodynamic resistance at higher angles of attack, a phenomenon specific to finite wings.

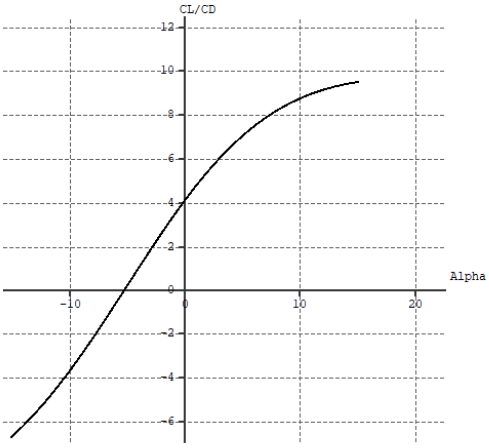

FIG. 19 Variation of lift-to-drag ratio (C_L/C_D) with angle of attack (α)

Figure 19 provides the global lift-to-drag ratio curve, indicating the overall aerodynamic efficiency and the maximum potential gliding range of the RR Lentus.

CONCLUSIONS

This study successfully validated the aerodynamic design and flight characteristics of the RR Lentus motor glider through a comprehensive digital modeling and simulation workflow.

By utilizing ImageOnline for precise geometric extraction, the aircraft was meticulously reconstructed component by component-integrating the main wing, horizontal and vertical stabilizers and the fuselage body-within the XFLR5 environment.

The computational analysis was strategically divided into two phases: initially generating 2D polar curves to evaluate the isolated performance of the NACA 4407 and NACA 0009 airfoils, followed by a full 3D simulation of the complete aerodynamic assembly. The findings confirm that the specific wing configuration yields high aerodynamic efficiency essential for thermal soaring, while the carefully calculated mass balance guarantees inherent longitudinal stability.

Despite these positive outcomes, certain methodological limitations within the simulation framework must be acknowledged. The primary constraint stems from the aerodynamic evaluation relying on XFLR5, an open-source solver based on the Vortex Lattice Method (VLM). While highly effective for preliminary design and standard flight envelopes, this numerical approach is susceptible to convergence artifacts and exhibits reduced accuracy when predicting complex viscous flows, particularly at high angles of attack or in near-stall conditions.

To enhance the precision of future aerodynamic assessments, subsequent research should transition from basic VLM tools to professional-grade Computational Fluid Dynamics (CFD) software capable of accurately modeling flow separation and turbulence. Furthermore, the theoretical 2D airfoil performance and the 3D polar data generated in this study could be physically verified through wind tunnel testing of scaled wing sections. Ultimately, the research would benefit significantly from instrumenting the actual RC aircraft with onboard telemetry sensors. Gathering live data would allow for a direct empirical correlation between the simulated flight parameters and the real-world dynamic behavior, a methodology highly consistent with advanced UAV aerodynamic research [10, 11, 12].

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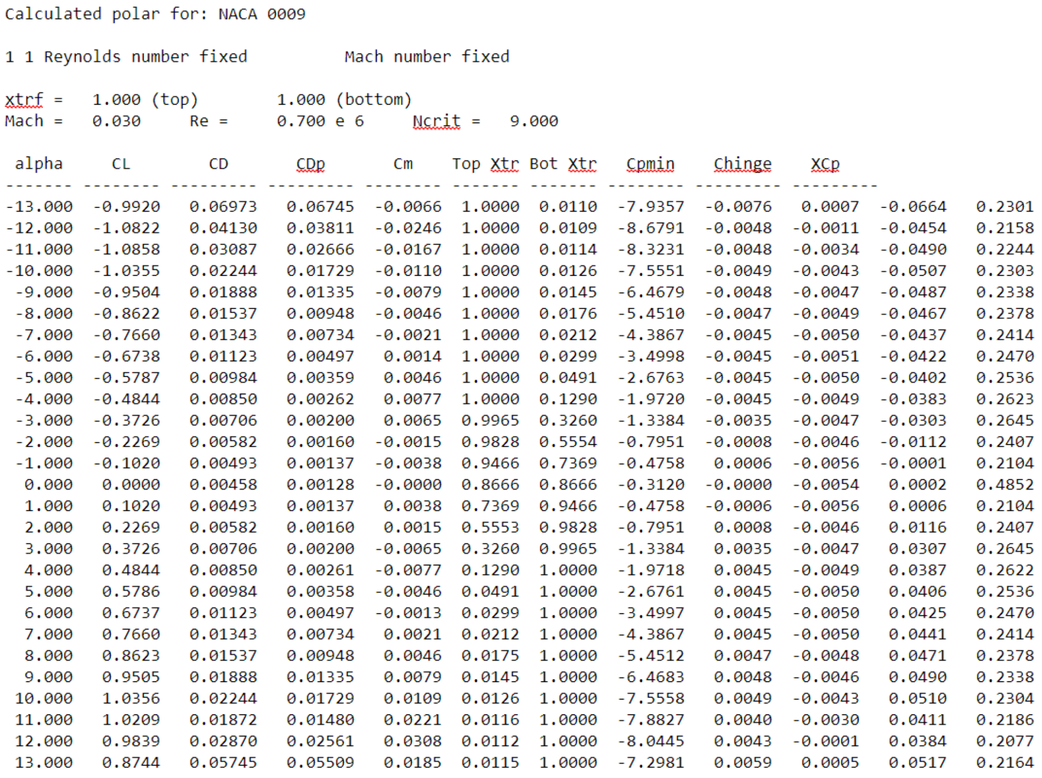
ANNEXES

Annex 1. Calculated Polars for NACA 0009 Airfoil



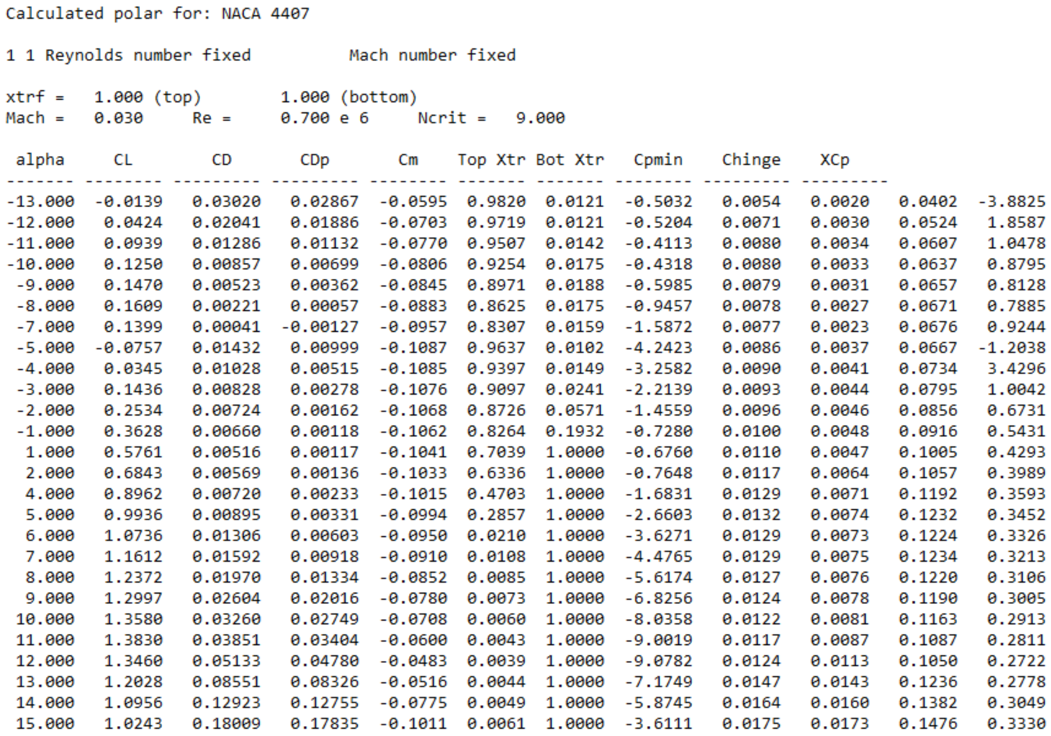
```
Calculated polar for: NACA 0009

1 1 Reynolds number fixed          Mach number fixed

xtrf =   1.000 (top)        1.000 (bottom)
Mach =   0.030     Re =     0.700 e 6     Ncrit =   9.000

 alpha     CL        CD       CDp       Cm     Top Xtr  Bot Xtr   Cpmin    Chinge     XCp
------- -------- --------- --------- -------- -------- -------- -------- --------- ---------
-13.000  -0.9920   0.06973   0.06745  -0.0066   1.0000   0.0110  -7.9357   -0.0076   0.0007   -0.0664   0.2301
-12.000  -1.0822   0.04130   0.03811  -0.0246   1.0000   0.0109  -8.6791   -0.0048  -0.0011   -0.0454   0.2158
-11.000  -1.0858   0.03087   0.02666  -0.0167   1.0000   0.0114  -8.3231   -0.0048  -0.0034   -0.0490   0.2244
-10.000  -1.0355   0.02244   0.01729  -0.0110   1.0000   0.0126  -7.5551   -0.0049  -0.0043   -0.0507   0.2303
 -9.000  -0.9504   0.01888   0.01335  -0.0079   1.0000   0.0145  -6.4679   -0.0048  -0.0047   -0.0487   0.2338
 -8.000  -0.8622   0.01537   0.00948  -0.0046   1.0000   0.0176  -5.4510   -0.0047  -0.0049   -0.0467   0.2378
 -7.000  -0.7660   0.01343   0.00734  -0.0021   1.0000   0.0212  -4.3867   -0.0045  -0.0050   -0.0437   0.2414
 -6.000  -0.6738   0.01123   0.00497   0.0014   1.0000   0.0299  -3.4998   -0.0045  -0.0051   -0.0422   0.2470
 -5.000  -0.5787   0.00984   0.00359   0.0046   1.0000   0.0491  -2.6763   -0.0045  -0.0050   -0.0402   0.2536
 -4.000  -0.4844   0.00850   0.00262   0.0077   1.0000   0.1290  -1.9720   -0.0045  -0.0049   -0.0383   0.2623
 -3.000  -0.3726   0.00706   0.00200   0.0065   0.9965   0.3260  -1.3384   -0.0035  -0.0047   -0.0303   0.2645
 -2.000  -0.2269   0.00582   0.00160  -0.0015   0.9828   0.5554  -0.7951   -0.0008  -0.0046   -0.0112   0.2407
 -1.000  -0.1020   0.00493   0.00137  -0.0038   0.9466   0.7369  -0.4758    0.0006  -0.0056   -0.0001   0.2104
  0.000   0.0000   0.00458   0.00128  -0.0000   0.8666   0.8666  -0.3120   -0.0000  -0.0054    0.0002   0.4852
  1.000   0.1020   0.00493   0.00137   0.0038   0.7369   0.9466  -0.4758   -0.0006  -0.0056    0.0006   0.2104
  2.000   0.2269   0.00582   0.00160   0.0015   0.5553   0.9828  -0.7951    0.0008  -0.0046    0.0116   0.2407
  3.000   0.3726   0.00706   0.00200  -0.0065   0.3260   0.9965  -1.3384    0.0035  -0.0047    0.0307   0.2645
  4.000   0.4844   0.00850   0.00261  -0.0077   0.1290   1.0000  -1.9718    0.0045  -0.0049    0.0387   0.2622
  5.000   0.5786   0.00984   0.00358  -0.0046   0.0491   1.0000  -2.6761    0.0045  -0.0050    0.0406   0.2536
  6.000   0.6737   0.01123   0.00497  -0.0013   0.0299   1.0000  -3.4997    0.0045  -0.0050    0.0425   0.2470
  7.000   0.7660   0.01343   0.00734   0.0021   0.0212   1.0000  -4.3867    0.0045  -0.0050    0.0441   0.2414
  8.000   0.8623   0.01537   0.00948   0.0046   0.0175   1.0000  -5.4512    0.0047  -0.0048    0.0471   0.2378
  9.000   0.9505   0.01888   0.01335   0.0079   0.0145   1.0000  -6.4683    0.0048  -0.0046    0.0490   0.2338
 10.000   1.0356   0.02244   0.01729   0.0109   0.0126   1.0000  -7.5558    0.0049  -0.0043    0.0510   0.2304
 11.000   1.0209   0.01872   0.01480   0.0221   0.0116   1.0000  -7.8827    0.0040  -0.0030    0.0411   0.2186
 12.000   0.9839   0.02870   0.02561   0.0308   0.0112   1.0000  -8.0445    0.0043  -0.0001    0.0384   0.2077
 13.000   0.8744   0.05745   0.05509   0.0185   0.0115   1.0000  -7.2981    0.0059   0.0005    0.0517   0.2164
```

Annex 2. NACA 4407 2D Airfoil Analysis



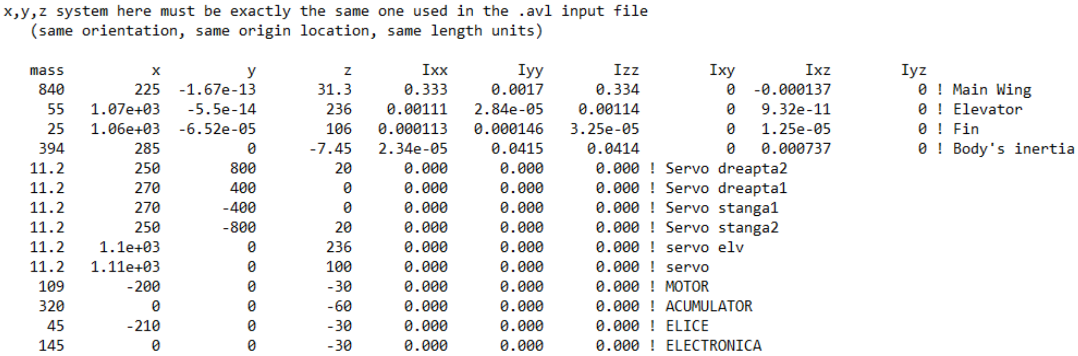
```
Calculated polar for: NACA 4407

1 1 Reynolds number fixed          Mach number fixed

xtrf =   1.000 (top)        1.000 (bottom)
Mach =   0.030     Re =     0.700 e 6     Ncrit =   9.000

 alpha     CL        CD       CDp       Cm     Top Xtr  Bot Xtr   Cpmin    Chinge     XCp
------- -------- --------- --------- -------- -------- -------- -------- --------- ---------
-13.000  -0.0139   0.03020   0.02867  -0.0595   0.9820   0.0121  -0.5032    0.0054    0.0020    0.0402  -3.8825
-12.000   0.0424   0.02041   0.01886  -0.0703   0.9719   0.0121  -0.5204    0.0071    0.0030    0.0524   1.8587
-11.000   0.0939   0.01286   0.01132  -0.0770   0.9507   0.0142  -0.4113    0.0080    0.0034    0.0607   1.0478
-10.000   0.1250   0.00857   0.00699  -0.0806   0.9254   0.0175  -0.4318    0.0080    0.0033    0.0637   0.8795
 -9.000   0.1470   0.00523   0.00362  -0.0845   0.8971   0.0188  -0.5985    0.0079    0.0031    0.0657   0.8128
 -8.000   0.1609   0.00221   0.00057  -0.0883   0.8625   0.0175  -0.9457    0.0078    0.0027    0.0671   0.7885
 -7.000   0.1399   0.00041  -0.00127  -0.0957   0.8307   0.0159  -1.5872    0.0077    0.0023    0.0676   0.9244
 -5.000  -0.0757   0.01432   0.00999  -0.1087   0.9637   0.0102  -4.2423    0.0086    0.0037    0.0667  -1.2038
 -4.000   0.0345   0.01028   0.00515  -0.1085   0.9397   0.0149  -3.2582    0.0090    0.0041    0.0734   3.4296
 -3.000   0.1436   0.00828   0.00278  -0.1076   0.9097   0.0241  -2.2139    0.0093    0.0044    0.0795   1.0042
 -2.000   0.2534   0.00724   0.00162  -0.1068   0.8726   0.0571  -1.4559    0.0096    0.0046    0.0856   0.6731
 -1.000   0.3628   0.00660   0.00118  -0.1062   0.8264   0.1932  -0.7280    0.0100    0.0048    0.0916   0.5431
  1.000   0.5761   0.00516   0.00117  -0.1041   0.7039   1.0000  -0.6760    0.0110    0.0047    0.1005   0.4293
  2.000   0.6843   0.00569   0.00136  -0.1033   0.6336   1.0000  -0.7648    0.0117    0.0064    0.1057   0.3989
  4.000   0.8962   0.00720   0.00233  -0.1015   0.4703   1.0000  -1.6831    0.0129    0.0071    0.1192   0.3593
  5.000   0.9936   0.00895   0.00331  -0.0994   0.2857   1.0000  -2.6603    0.0132    0.0074    0.1232   0.3452
  6.000   1.0736   0.01306   0.00603  -0.0950   0.0210   1.0000  -3.6271    0.0129    0.0073    0.1224   0.3326
  7.000   1.1612   0.01592   0.00918  -0.0910   0.0108   1.0000  -4.4765    0.0129    0.0075    0.1234   0.3213
  8.000   1.2372   0.01970   0.01334  -0.0852   0.0085   1.0000  -5.6174    0.0127    0.0076    0.1220   0.3106
  9.000   1.2997   0.02604   0.02016  -0.0780   0.0073   1.0000  -6.8256    0.0124    0.0078    0.1190   0.3005
 10.000   1.3580   0.03260   0.02749  -0.0708   0.0060   1.0000  -8.0358    0.0122    0.0081    0.1163   0.2913
 11.000   1.3830   0.03851   0.03404  -0.0600   0.0043   1.0000  -9.0019    0.0117    0.0087    0.1087   0.2811
 12.000   1.3460   0.05133   0.04780  -0.0483   0.0039   1.0000  -9.0782    0.0124    0.0113    0.1050   0.2722
 13.000   1.2028   0.08551   0.08326  -0.0516   0.0044   1.0000  -7.1749    0.0147    0.0143    0.1236   0.2778
 14.000   1.0956   0.12923   0.12755  -0.0775   0.0049   1.0000  -5.8745    0.0164    0.0160    0.1382   0.3049
 15.000   1.0243   0.18009   0.17835  -0.1011   0.0061   1.0000  -3.6111    0.0175    0.0173    0.1476   0.3330
```

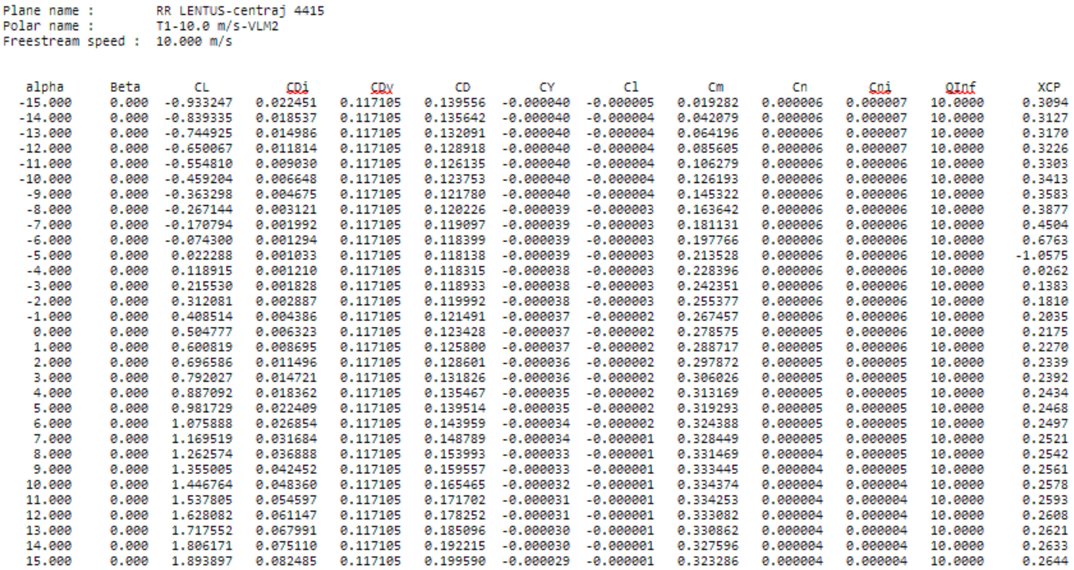
Annex 3. Mass and inertia distribution



```
x,y,z system here must be exactly the same one used in the .avl input file
   (same orientation, same origin location, same length units)

   mass          x          y          z        Ixx        Iyy        Izz        Ixy        Ixz         Iyz
    840        225  -1.67e-13       31.3      0.333     0.0017      0.334          0  -0.000137           0 ! Main Wing
     55   1.07e+03   -5.5e-14        236    0.00111   2.84e-05    0.00114          0   9.32e-11           0 ! Elevator
     25   1.06e+03  -6.52e-05        106   0.000113   0.000146   3.25e-05          0   1.25e-05           0 ! Fin
    394        285          0      -7.45   2.34e-05     0.0415     0.0414          0   0.000737           0 ! Body's inertia
   11.2        250        800         20      0.000      0.000      0.000 ! Servo dreapta2
   11.2        270        400          0      0.000      0.000      0.000 ! Servo dreapta1
   11.2        270       -400          0      0.000      0.000      0.000 ! Servo stanga1
   11.2        250       -800         20      0.000      0.000      0.000 ! Servo stanga2
   11.2    1.1e+03          0        236      0.000      0.000      0.000 ! servo elv
   11.2   1.11e+03          0        100      0.000      0.000      0.000 ! servo
    109       -200          0        -30      0.000      0.000      0.000 ! MOTOR
    320          0          0        -60      0.000      0.000      0.000 ! ACUMULATOR
     45       -210          0        -30      0.000      0.000      0.000 ! ELICE
    145          0          0        -30      0.000      0.000      0.000 ! ELECTRONICA
```

Annex 4. 3D Analysis of the Balanced Model



```
Plane name :         RR LENTUS-centraj 4415
Polar name :         T1-10.0 m/s-VLM2
Freestream speed :   10.000 m/s


   alpha      Beta       CL        CDi       CDv        CD         CY         Cl         Cm         Cn        Cni       QInf       XCP
 -15.000     0.000  -0.933247  0.022451  0.117105  0.139556  -0.000040  -0.000005  0.019282  0.000006  0.000007  10.0000     0.3094
 -14.000     0.000  -0.839335  0.018537  0.117105  0.135642  -0.000040  -0.000004  0.042079  0.000006  0.000007  10.0000     0.3127
 -13.000     0.000  -0.744925  0.014986  0.117105  0.132091  -0.000040  -0.000004  0.064196  0.000006  0.000007  10.0000     0.3170
 -12.000     0.000  -0.650067  0.011814  0.117105  0.128918  -0.000040  -0.000004  0.085605  0.000006  0.000007  10.0000     0.3226
 -11.000     0.000  -0.554810  0.009030  0.117105  0.126135  -0.000040  -0.000004  0.106279  0.000006  0.000006  10.0000     0.3303
 -10.000     0.000  -0.459204  0.006648  0.117105  0.123753  -0.000040  -0.000004  0.126193  0.000006  0.000006  10.0000     0.3413
  -9.000     0.000  -0.363298  0.004675  0.117105  0.121780  -0.000040  -0.000004  0.145322  0.000006  0.000006  10.0000     0.3583
  -8.000     0.000  -0.267144  0.003121  0.117105  0.120226  -0.000039  -0.000003  0.163642  0.000006  0.000006  10.0000     0.3877
  -7.000     0.000  -0.170794  0.001992  0.117105  0.119097  -0.000039  -0.000003  0.181131  0.000006  0.000006  10.0000     0.4504
  -6.000     0.000  -0.074300  0.001294  0.117105  0.118399  -0.000039  -0.000003  0.197766  0.000006  0.000006  10.0000     0.6763
  -5.000     0.000   0.022288  0.001033  0.117105  0.118138  -0.000039  -0.000003  0.213528  0.000006  0.000006  10.0000    -1.0575
  -4.000     0.000   0.118915  0.001210  0.117105  0.118315  -0.000038  -0.000003  0.228396  0.000006  0.000006  10.0000     0.0262
  -3.000     0.000   0.215530  0.001828  0.117105  0.118933  -0.000038  -0.000003  0.242351  0.000006  0.000006  10.0000     0.1383
  -2.000     0.000   0.312081  0.002887  0.117105  0.119992  -0.000038  -0.000003  0.255377  0.000006  0.000006  10.0000     0.1810
  -1.000     0.000   0.408514  0.004386  0.117105  0.121491  -0.000037  -0.000002  0.267457  0.000006  0.000006  10.0000     0.2035
   0.000     0.000   0.504777  0.006323  0.117105  0.123428  -0.000037  -0.000002  0.278575  0.000005  0.000006  10.0000     0.2175
   1.000     0.000   0.600819  0.008695  0.117105  0.125800  -0.000037  -0.000002  0.288717  0.000005  0.000006  10.0000     0.2270
   2.000     0.000   0.696586  0.011496  0.117105  0.128601  -0.000036  -0.000002  0.297872  0.000005  0.000005  10.0000     0.2339
   3.000     0.000   0.792027  0.014721  0.117105  0.131826  -0.000036  -0.000002  0.306026  0.000005  0.000005  10.0000     0.2392
   4.000     0.000   0.887092  0.018362  0.117105  0.135467  -0.000035  -0.000002  0.313169  0.000005  0.000005  10.0000     0.2434
   5.000     0.000   0.981729  0.022409  0.117105  0.139514  -0.000035  -0.000002  0.319293  0.000005  0.000005  10.0000     0.2468
   6.000     0.000   1.075888  0.026854  0.117105  0.143959  -0.000034  -0.000002  0.324388  0.000005  0.000005  10.0000     0.2497
   7.000     0.000   1.169519  0.031684  0.117105  0.148789  -0.000034  -0.000001  0.328449  0.000005  0.000005  10.0000     0.2521
   8.000     0.000   1.262574  0.036888  0.117105  0.153993  -0.000033  -0.000001  0.331469  0.000004  0.000005  10.0000     0.2542
   9.000     0.000   1.355005  0.042452  0.117105  0.159557  -0.000033  -0.000001  0.333445  0.000004  0.000005  10.0000     0.2561
  10.000     0.000   1.446764  0.048360  0.117105  0.165465  -0.000032  -0.000001  0.334374  0.000004  0.000004  10.0000     0.2578
  11.000     0.000   1.537805  0.054597  0.117105  0.171702  -0.000031  -0.000001  0.334253  0.000004  0.000004  10.0000     0.2593
  12.000     0.000   1.628082  0.061147  0.117105  0.178252  -0.000031  -0.000001  0.333082  0.000004  0.000004  10.0000     0.2608
  13.000     0.000   1.717552  0.067991  0.117105  0.185096  -0.000030  -0.000001  0.330862  0.000004  0.000004  10.0000     0.2621
  14.000     0.000   1.806171  0.075110  0.117105  0.192215  -0.000030  -0.000001  0.327596  0.000004  0.000004  10.0000     0.2633
  15.000     0.000   1.893897  0.082485  0.117105  0.199590  -0.000029  -0.000001  0.323286  0.000004  0.000004  10.0000     0.2644
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THE INFLUENCE OF THE INHOMOGENEITY OF AL ALLOYS ON THE TRANSMISSION OF STRUCTURAL CHARACTERISTICS IN CASTINGS

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Abstract: *The paper studies the influence of chemical and structural inhomogeneity of aluminum alloys on the mechanisms of formation and transmission of microstructural characteristics in castings. The phenomena of micro- and macrostructural segregation and the non-uniform distribution of intermetallic phases are also analyzed.*

Initial inhomogeneities are correlated with the appearance of areas with different mechanical properties, which can favor the initiation of internal defects and reduce the operational performance.The results emphasize the importance of controlling solidification processes in order to minimize segregations and obtain an uniform microstructure, with a direct impact on improving the mechanical properties of aluminum alloy castings.

Keywords: *aluminum alloys, inhomogeneity, structural characteristics*

1. INTRODUCTION

Cast aluminum alloys are highly sensitive to variations in casting conditions. This sensitivity leads to the appearance of chemical and structural inhomogeneities [1].

Deviations from the chemical composition of the alloy, the cooling rate, the thermal gradient or the casting conditions lead to the appearance of chemical segregations, randomly distributed intermetallic phases or to variations in morphology or crystal size [2, 3].

The transmission of heredity in cast parts depends on the evolution of the solidification front and the interaction between the solid and liquid phases [4, 5]. Initial inhomogeneities can lead to the development of areas with different mechanical properties, which leads to the appearance of internal defects (porosity, inclusions or solidification cracks) [4, 6, 7].

2. METHODS

For the proposed study, samples were taken from an Al-Si-Mg aluminum alloy bar that was continuously cast and a piece obtained by casting from that bar.

In order to highlight the hereditary transmission of inhomogeneity, microscopic analysis was used.

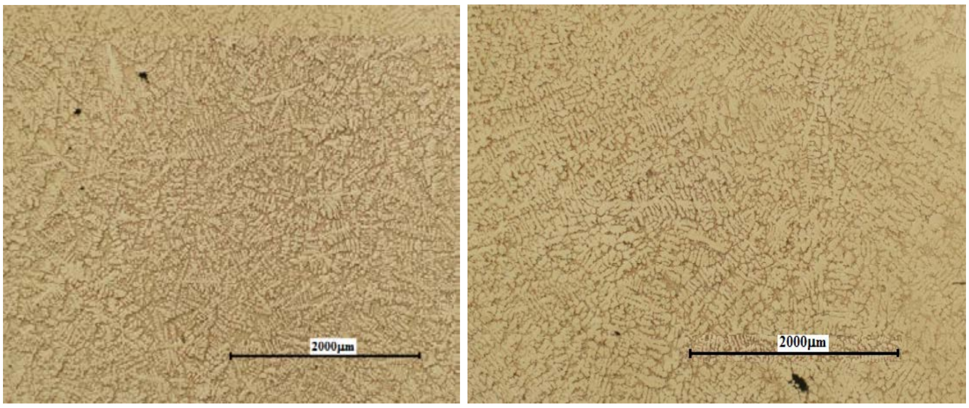
The samples (taken both from the bar and from the cast piece) were properly prepared for the analysis of structural characteristics by optical microscopy. Within this, the following were evaluated: the shape and dimensions of the dendrites and of the α crystals, the characteristics of the defects at the limits of the dendrites and the morphology of the phases or constituents.

On polished and unetched samples, the characteristics of the α solid solution dendrites were analyzed at a magnification of 25x. The aim was also to highlight the shape and size of the dendrites in each sample and, at the same time, a comparative analysis between the samples was also made. The results found are presented in table 1 and Fig. 1.

Table 1. Shape and dimensions of α solid solution dendrites at 25x magnification

No.	Sample	Dendrites' shape	Average dendrite dimensions [µm]		Observations
			lenght	thickness	
1	Cast piece	elongated	1500	300	Very similar to those in the bar
2	bar	elongated	1300	300	

The comparison of the dendrite characteristics between the continuously cast bar and the parts that were cast from it is very important. As it can be seen from table 1 and figure 1 there is a significant similarity of the dendrite characteristics from the cast part and the bar used in the load. This resemblance indicates that for some reason the cast bars used in the load have inherited, to a large extent, their structural characteristics to the parts obtained subsequently by casting.



a) b)

FIG. 1. Appearance of the shape and dimensions of the dendrites in the structure. Unetched samples: a) - cast part; b) - bar semi-finished product; Magnification: 25x

The shape and size of the α solid solution crystals were also studied at a magnification of 100x. The results of the study are presented in table 2 and Fig. 2.

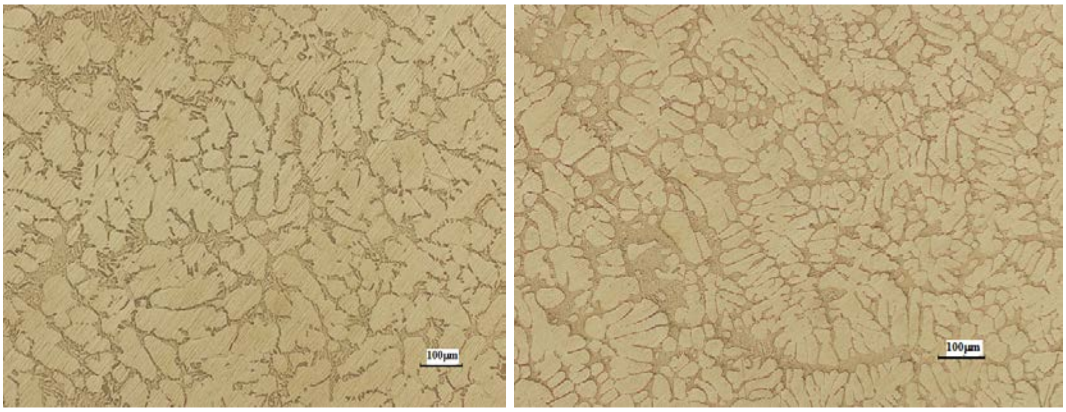
Table 2. Shape and dimensions of α solid solution crystals at 100x magnification

No.	Sample	Crystal shape	Average crystal sizes [µm]		Observations
			lenght	thickness	
1	Cast piece	elongated	150	60	Very similar to those in the bar
2	bar	elongated	120	40	

The analysis of the intersection of the dendrite branches with the sectioning plane of the sample indicates that the α solid solution crystals present characteristics correlated with those of the dendrites, i.e. the transmission of structural characteristics, as a hereditary phenomenon, is pronounced.

In this context, only void-type defects were analyzed, which can essentially be contraction microporosities (micro-shrinkage), porosities due to gases or other causes.

As can be seen in Fig. 1, at the limits of the α solid solution dendrites, porosity-type defects are present, in larger quantities and sizes, both for the castings and for the bars used in the load.

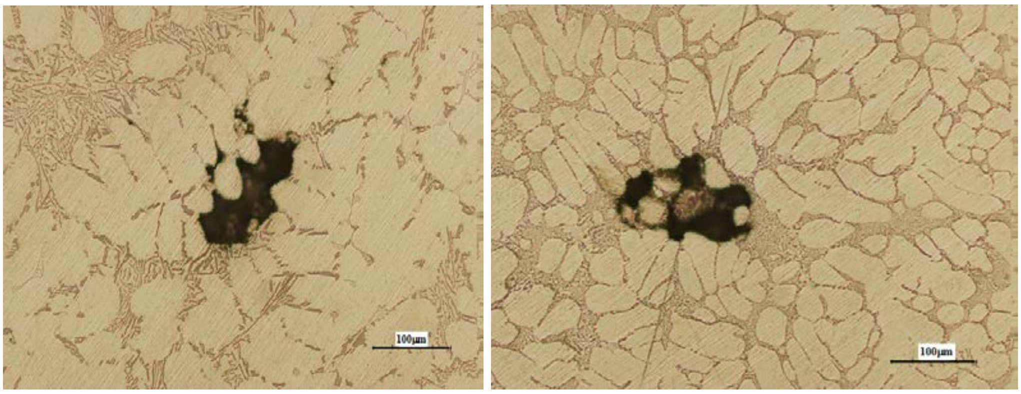


a) b)

FIG. 2. Shape and dimensions of crystals in the structure. Unetched samples: a)-cast part; b)-bar semi-finished product; Magnification: 100x

For a clearer observation of the shape and dimensions of the porosities, the study was carried out on polished and unetched samples at 200x magnification. Indicative images of the shape of the porosities are presented in Fig. 3.

In Fig. 3.a and 3.b, the porosities are predominantly microshrinkage porosity, so they are due to shrinkage during solidification and have much larger dimensions reaching up to 200µm. It is important to note that they have similar dimensions and shapes in the cast parts and in the bars used as a load. This fact confirms the hereditary transmission of the structural characteristics of the bars to the cast parts.



a) b)

FIG. 3. Shape and dimensions of bordering defects (microshrinkage porosity). Unetched samples: a) -cast part; b)-bar semi-finished product; Magnification: 200x

Following the dendritic segregation process, at the limit of the α solid solution dendrites, towards the end of solidification, a series of elements with lower solubility in the solid solution than in the liquid alloy (Fe, Mg, O, Sb, C, etc.) are concentrated.

These can form eutectic phases or compounds (intermetallic or stoichiometric) with properties different from those of the solid solution and therefore with an important influence on the overall properties of the cast parts.

The shape that these borderline phases take is closely linked to the shape of the α solid solution dendrites. On polished and unetched samples, such borderline phases can be observed, easily distinguishable from Si separations.

The reason is related to the different cooling rates during solidification. The cast pieces solidified with lower cooling rates, which allowed a more pronounced evolution of the segregation phenomenon and thus a more important quantitative development of the borderline phases.

The effect of the bordering phases could also be determined by following the behavior of the material during preparation in order to study the structure through optical microscopy. There are borderline phases with very high hardness, much higher than the α solid solution, which when grinding with abrasive materials can fragment and detach from the alloy, generating apparent pores, or having destructive effects on the neighboring areas. These phases can have the same behavior during the mechanical machining operation by chipping causing difficulties related to ensuring the quality required for the processed surfaces through these operations.

In order to better highlight the shape and composition of the adjacent phases of the α dendrites, an electron microscopy study (SEM and SEM-EDS) was carried out on samples taken from the castings obtained using continuously cast bars.

Figures 4 and 5 show the aspects of the borderline phases at higher magnifications than those provided by optical microscopy. Areas where phases other than Si can be observed were selected from the samples (especially 1000x at 5000x magnifications).

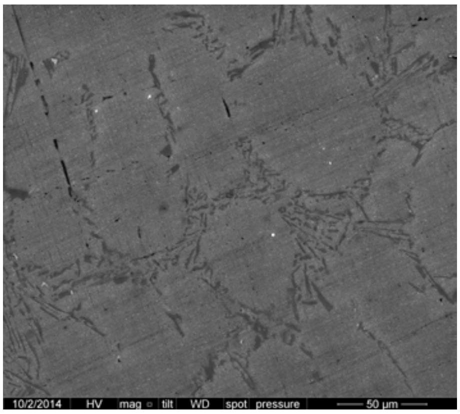


FIG.4. Appearance of the structure at 1000x magnification: cast part

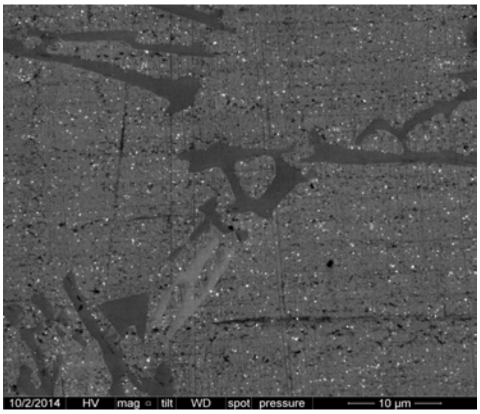


FIG.5. Appearance of the structure at 5000x magnification: cast part

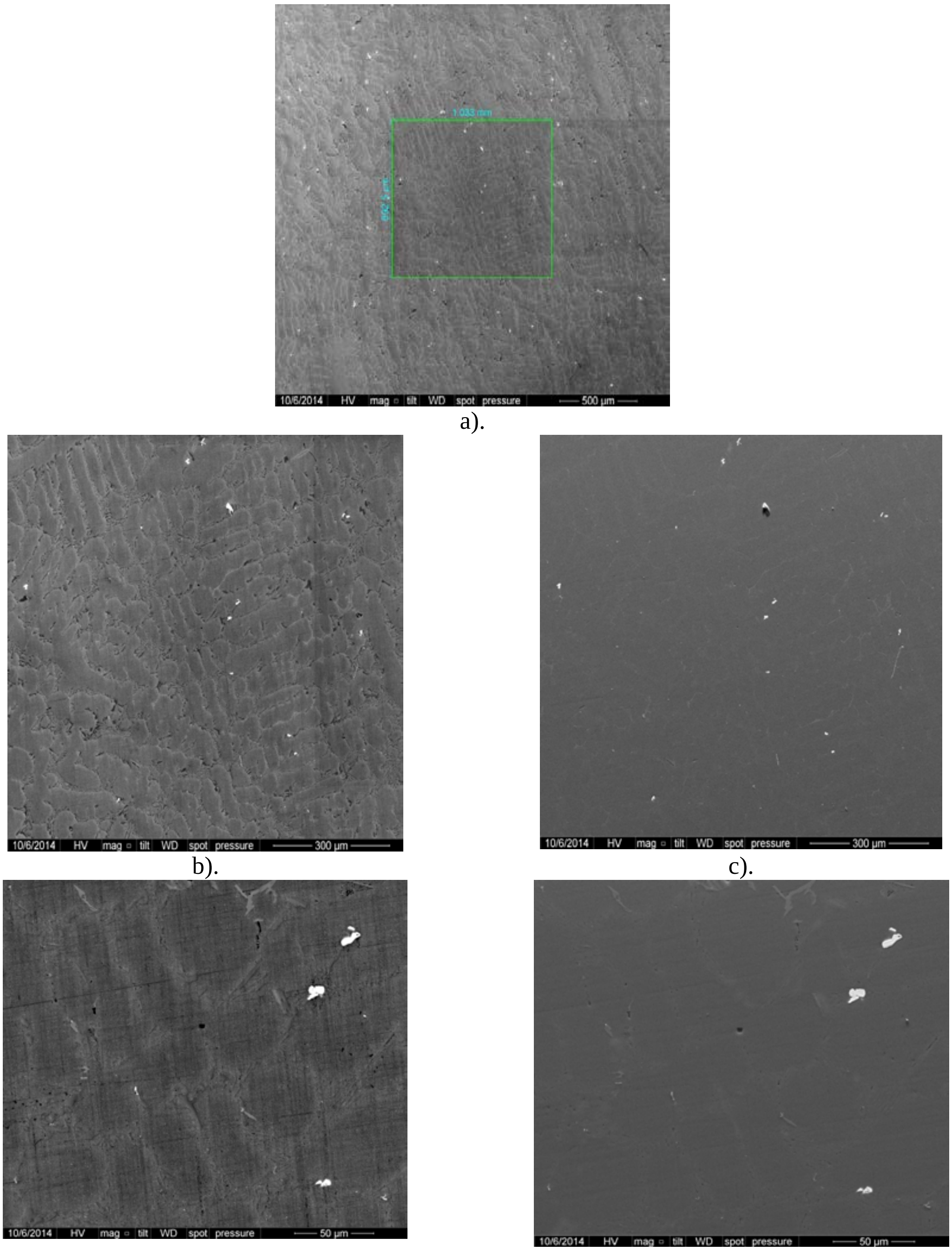
The study showed that the borderline phases have acicular (light gray), polyhedral shapes combined with acicular (dark gray), compact polyhedral and equiaxed agglomerations. Through their shape and properties, these phases can greatly influence the mechanical and technological properties of the material.

To validate the conclusions drawn, we also identified the chemical nature of the borderline phases by SEM electron microscopy with EDS.

Thus, an area was selected from the surface of the samples on which the average chemical composition was first determined by the electron microscope and then the surface distribution of the elements identified in the chemical composition was determined. The selected areas were studied at magnifications of: 250x and 1000x respectively. These are presented in Fig.6. The average chemical compositions of the areas selected in the study, expressed in weight percentages (%Gr) and in atomic percentages (%At) are shown in table 3 and figure 6 respectively.

Table 3. Average chemical composition in the areas selected for study presented in Fig. 6

No.	Piece type/area	Chemical comp. expressed in	Chemical element								
			C	O	Mg	Al	Si	Sb	Ti	Fe	Total
3	250x	%Gr	0,00	1,20	1,00	87,61	9,65	0,17	0,14	0,23	100
		%At	0,00	2,01	1,10	87,40	9,25	0,04	0,08	0,11	100
4	1000x	%Gr	0,19	1,24	0,94	86,63	9,88	0,72	0,25	0,15	100
		%At	0,42	2,09	1,04	86,59	9,49	0,16	0,14	0,07	100

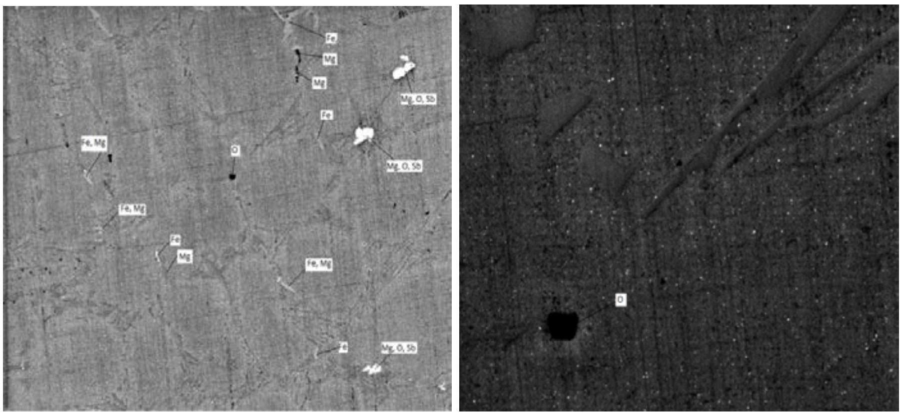


a).

b). c).

d). e).

FIG.6. Appearance of the area studied by SEM microscopy with EDS for the piece: a) general image of the area at 100x magnification; b) image of the selected area created by secondary electrons, 250x magnification; c) image of the selected area created by backscattered electrons, 250x magnification; d) image of the selected area created by secondary electrons, 1000x magnification; e) image of the selected area created by backscattered electrons, 1000x magnification



a) b)

FIG. 7. Chemical nature of the borderline phases in the case of the cast part: a) the area studied at 1000x magnification; b) the area studied at 5000x magnification

From the analysis of the elements distribution in the studied areas, it was possible to establish the specific locations where each of them is found in higher than average concentration, thus identifying the chemical nature of the borderline phases (figure 7).

The non-uniformities in the chemical compositions given in table 3 are due to the fact that the areas chosen for the study are located in the regions where the effects of dendritic segregation are maximal (dendrite limits).

CONCLUSIONS

The following conclusions can be drawn from the analysis of the studied microscopies:

1. The chemical nature of the phases bordering the α solid solution dendrites is complex. In relation to the local conditions of agglomeration of the elements following the dendritic segregation process, they can be grouped into various associations: Mg-Al, Fe-Mg-Al, C-O-Al, O-Al, Fe-Al, Mg-O-Sb;
2. In the piece cast from the bar, the amount of borderline phases is large. At the same time, associations are present between the bar and the piece. These phases are agglomerations of the Mg-O-Sb, O-Al type.
3. The presence of phases such as Mg-O-Sb, as well as others with O (C-O-Al, O-Al) indicates an inadequate preparation of the alloy before casting by specific metallurgical treatments (degassing, filtration).
4. In the borderline phases, the coexistence of eutectic compositions with intermetallic compounds of the respective elements is possible.

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MAES AS A DATA-DRIVEN TRAINING PLATFORM: DAYLIGHT HIGH-LOAD OPERATION WITH PHOTOVOLTAIC SUPPORT

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Abstract: *This paper presents a short experimental episode based on the MAES prototype - Mobile Module for Ensuring Energy Autonomy from Sustainable Sources, interpreted as a data-driven training platform for tactical energy autonomy [1]. The analysis goes one step further than previously published research by focusing on daylight operation under high three-phase load and significant photovoltaic contribution. During the analyzed interval, MAES supplied an AC load of approximately 11-12 kW, while the photovoltaic subsystem generated between 4.0 and 5.1 kW instantaneously. The measured data show that solar input reduced the battery discharge power from values close to 12 kW, typical for operation without photovoltaic production, to approximately 7.2-7.9 kW. The paper also integrates short-term energy balance screenshots, which indicate that cloudy days affected solar yield and reduced the expected photovoltaic contribution. The results confirm the usefulness of MAES as a living laboratory for military technical education and as a basis for further development of predictive autonomy models integrating load, PV production, battery state of charge and operational constraints.*

Keywords: *MAES, data-driven training platform, photovoltaic support, LiFePO4 storage, tactical energy autonomy, VRM monitoring, energy management, military education*

1. INTRODUCTION

Deployable military infrastructures increasingly depend on reliable, monitored and adaptable energy systems. Command posts, communication nodes, field sensors and radar-related applications require stable power supply, while the logistical cost and acoustic signature of diesel generators remain important operational limitations. In this context, hybrid systems combining photovoltaic generation, electrochemical storage, inverter-based conversion and remote monitoring can support both operational resilience and applied technical education.

From the perspective of operational energy, deployable infrastructures should be considered not only as consumers of electricity, but as mission systems whose effectiveness depends on resilient power supply, fuel economy and real-time energy awareness. NATO identifies energy security as a relevant dimension of Allied resilience, because disruptions in energy supply can affect both national security and military operations [2]. Consequently, command posts, communication nodes and radar-related systems require energy solutions that reduce dependence on continuous generator operation while preserving operational continuity.

Military microgrids respond to this requirement by combining conventional generators, photovoltaic sources, energy storage, efficient loads and intelligent power management. NATO Energy Security Centre of Excellence materials indicate that microgrids integrating diesel generators, renewable sources, efficient consumers and intelligent management have demonstrated fuel-saving potential for deployed camps [3].

NATO smart-energy initiatives also show that photovoltaic systems, solar trailers and hybrid microgrid demonstrators can be used in deployed military environments, provided that their limitations regarding irradiance, available surface, orientation and maintenance are properly understood [4].

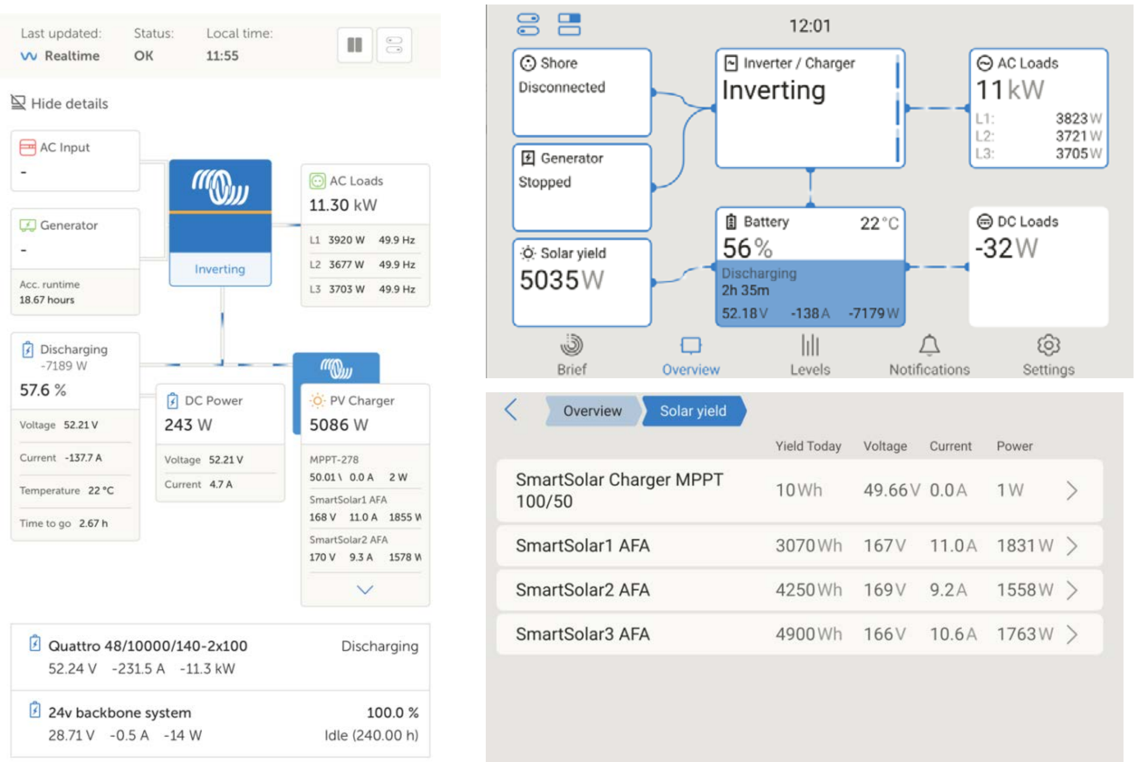
Recent microgrid research confirms the importance of distributed generation, storage, control strategies and information technologies for resilient energy systems [5]. In the military field, tactical microgrids are discussed as a means to reduce fuel demand, improve electrical resilience and lower acoustic or thermal signatures [6], while broader defence-energy approaches emphasize the need for architectures able to combine resilience, autonomy and operational planning [7]. In this context, MAES can be interpreted as a small-scale deployable military microgrid and as a data-driven platform for future predictive energy management.

The MAES prototype was previously introduced as a mobile energy autonomy solution based on renewable generation and battery storage. The present paper does not repeat the complete architectural description of the prototype. Instead, it provides a concise experimental episode based on real monitoring data, focusing on daylight operation under high load and partial photovoltaic support.

The main objective is educational. MAES is considered not only as an energy platform, but also as a living laboratory. Students can observe the relationship between AC load, photovoltaic production, battery discharge, state of charge and estimated autonomy. Such a training context is particularly relevant for modern military technical education, which increasingly requires the use of digital platforms, real data and applied experimentation [8, 9].

2. EXPERIMENTAL CONTEXT AND MONITORED VARIABLES

The analyzed episode corresponds to daylight operation with a high three-phase load.



Last updated: Realtime
Status: OK
Local time: 11:55

AC Input: -
Generator: -
Acc. runtime 18.67 hours
Discharging -7189 W
57.6 %
Voltage 52.21 V
Current -137.7 A
Temperature 22 °C
Time to go 2.67 h

AC Loads 11.30 kW
L1 3920 W 49.9 Hz
L2 3677 W 49.9 Hz
L3 3703 W 49.9 Hz

DC Power 243 W
Voltage 52.21 V
Current 4.7 A

PV Charger 5086 W
MPPT-278
50.01 V 0.0 A 2 W
SmartSolar1 AFA
168 V 11.0 A 1855 W
SmartSolar2 AFA
170 V 9.3 A 1578 W

Quattro 48/10000/140-2x100 Discharging
52.24 V -231.5 A -11.3 kW

24v backbone system 100.0 %
28.71 V -0.5 A -14 W Idle (240.00 h)

12:01
Shore: Disconnected
Generator: Stopped
Solar yield: 5035 W
Inverter / Charger: Inverting
AC Loads: 11 kW
L1: 3823 W
L2: 3721 W
L3: 3705 W
Battery 22 °C
56 %
Discharging
2h 35m
52.18 V -138 A -7179 W
DC Loads: -32 W

	Yield Today	Voltage	Current	Power
SmartSolar Charger MPPT 100/50	10 Wh	49.66 V	0.0 A	1 W
SmartSolar1 AFA	3070 Wh	167 V	11.0 A	1831 W
SmartSolar2 AFA	4250 Wh	169 V	9.2 A	1558 W
SmartSolar3 AFA	4900 Wh	166 V	10.6 A	1763 W

FIG. 1 (a) Daylight MAES dashboard under high AC load and PV contribution (b) Overview display showing PV support and battery discharge; **(**c) MPPT-level solar production values during the daylight test

The system operated in inverter mode, with the AC input disconnected and the generator stopped. Consequently, the load was supplied by the combined contribution of photovoltaic generation and the LiFePO4 battery bank. The available screenshots include the main Cerbo GX/VRM dashboard, overview pages, MPPT-level solar yield pages and short-term energy balance charts.

The relevant monitored variables are AC load, instantaneous PV power, battery state of charge, battery discharge power and, where available, MPPT voltage and current. These variables are sufficient for a preliminary operational interpretation because they allow the net battery burden to be assessed during high-load operation. From a didactic point of view, they also allow students to calculate the share of solar contribution and to compare ideal autonomy calculations with real operating conditions.

Figures 1.a-c present three distinct screenshots used as experimental evidence. They were kept as separate figures in order to allow flexible arrangement in the final version of the paper and to preserve the visibility of solar production values, especially the PV Charger, Solar Yield and MPPT-level power indicators.

3. INSTANTANEOUS PHOTOVOLTAIC SUPPORT UNDER HIGH LOAD

The values in Table 1 show that the photovoltaic subsystem supplied between approximately 37% and 46% of the instantaneous AC load. The clearest operating point is at 11:55, when the AC load was 11.30 kW, PV production was 5.086 kW and the battery discharge power was approximately 7.189 kW. Therefore, almost 45% of the instantaneous demand was covered by solar generation.

Table 1. Instantaneous values extracted from MAES daylight monitoring

Time	AC Load (kW)	PV Power (kW)	Battery SOC (%)	Battery Power (kW)	PV Share (%)	Observation
11:37	~11.0	4.055	63	-7.943	36.9	high load, partial PV support
11:39	~12.0	4.834	63	-	40.3	PV production close to 5 kW
11:55	11.30	5.086	57.6	-7.189	45.0	clear reduction of battery burden
12:01	~11.0	5.035	56	-7.179	45.8	stable PV + battery operation

This result is relevant because, in operation without solar production, a similar load requires the battery bank to supply almost the entire power demand. In the daylight case, the PV subsystem reduces the net battery burden by roughly 4-5 kW. This translates into longer autonomy, lower discharge stress and reduced need for generator intervention under favorable solar conditions.

The graphical representation in FIG. 2 compares the AC load, measured PV production, battery discharge and battery state of charge. The upper textual title was deliberately removed from the graph; the explanatory title is kept only in the caption below the figure, in accordance with the Review of the Air Force Academy template requirements for figure captions.

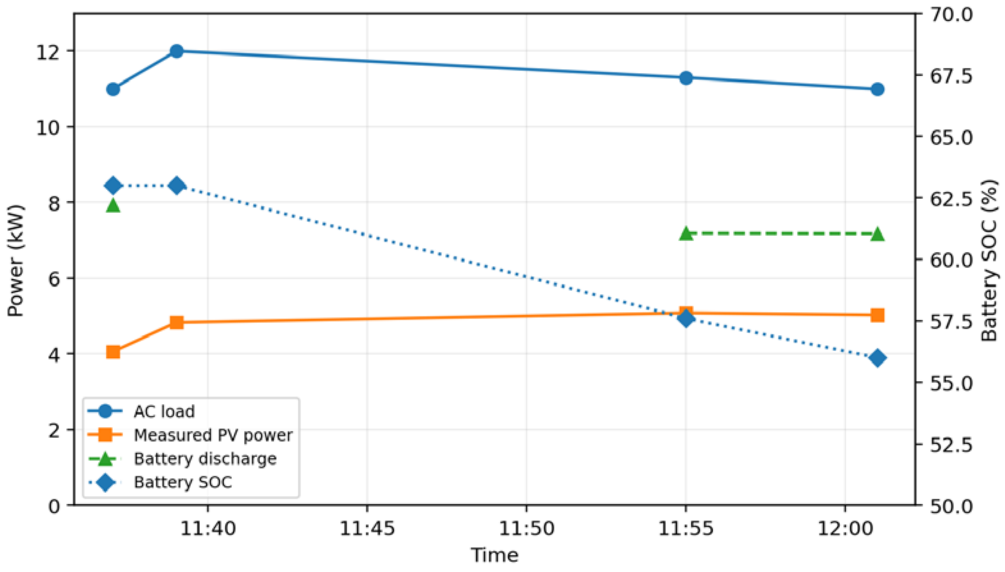


FIG. 2. AC load, measured PV production, battery discharge and SOC during daylight high-load operation

4. SHORT-TERM ENERGY BALANCE AND CLOUDY-DAY INFLUENCE

Instantaneous measurements are useful for explaining the energy flows at a given moment, but the operational relevance of MAES also depends on energy balance over longer intervals. The VRM monitoring screenshots provide several interval-based views in which consumption, solar yield and battery state of charge are displayed simultaneously. These views are particularly useful for teaching because they show how daily energy availability depends on both load profile and weather conditions.

Table 2. Short-term energy balance from VRM screenshots

Monitoring interval	Consumption (kWh)	Solar yield (kWh)	Interpretation
27-28 May	65.4	42.4	high consumption; PV covered a significant part
28-30 May	31.6	32.5	solar yield comparable to consumption
30 May-1 Jun	1.4	21.7	low load; favorable battery recovery
1-2 Jun	1.9	4.1	cloud-affected day with modest surplus

The analyzed interval contained several cloudy periods. Consequently, solar production was lower than what would normally be expected under fully clear-sky conditions for the installed photovoltaic capacity. This explains why, in some intervals, solar yield remained below consumption even though the platform was operating during daylight hours. Conversely, when the load was reduced, even limited solar production was sufficient to increase or maintain the battery state of charge.

2026-05-27 04:10 to 2026-05-28 19:
To AC Input 0 kWh
From AC Input 0 kWh
Generator 0 kWh
Consumption 65.4 kWh
Solar 42.4 kWh

2026-05-28 19:24 to 2026-05-30 10:
To AC Input 0 kWh
From AC Input 0 kWh
Generator 0 kWh
Consumption 31.6 kWh
Solar 32.5 kWh

2026-05-30 10:38 to 2026-06-01 01:
To AC Input 0 kWh
From AC Input 0 kWh
Generator 0 kWh
Consumption 1.4 kWh
Solar 21.7 kWh

2026-06-01 01:52 to 2026-06-02 17:
To AC Input 0 kWh
From AC Input 0 kWh
Generator 0 kWh
Consumption 1.9 kWh
Solar 4.1 kWh

FIG. 3 a-d. Energy balance for 27 May -1 June interval

4. EDUCATIONAL AND OPERATIONAL INTERPRETATION

The main educational value of this episode is that students can work with real data instead of idealized values. For the 11:55 operating point, they can calculate the PV contribution as 5.086 kW divided by 11.30 kW, resulting in approximately 45%. They can also observe that the remaining power demand is covered by the battery bank and that the overall system remains in inverter mode, with the generator stopped and the AC input disconnected.

This type of analysis supports applied training in renewable energy, power electronics, battery management, energy logistics and operational planning. It can also be connected to data-driven decision support. The interpretation of measured data, alarms, state of charge and load profiles is consistent with broader approaches in which operational information is transformed into decision support indicators [12].

From an operational perspective, the daylight scenario confirms that the hybrid PV-battery architecture is more flexible than a storage-only or generator-only solution. Under solar input, the battery discharge rate is reduced, autonomy is extended and the generator start can be delayed. This is relevant for mobile command posts, communication nodes and radar-related applications, where continuity of supply and reduction of acoustic signature are important operational requirements [13].

5. CONCLUSIONS

This paper presented a concise daylight operating episode of the MAES prototype under high load and significant photovoltaic contribution. The measured data show that, for an AC load of approximately 11-12 kW, instantaneous PV production of 4-5 kW can cover up to about 45% of the power demand and can reduce the battery discharge power to approximately 7.2-7.9 kW.

The interval-based screenshots further show that MAES operation must be interpreted not only through instantaneous power values, but also through short-term energy balance. During cloudy days, solar yield was affected and could not always cover consumption, even though it still reduced the energy deficit. When consumption was low, even modest solar production contributed to battery recovery.

The results confirm the role of MAES as a data-driven training platform and as a practical basis for future predictive autonomy models. Such models should integrate solar forecast, measured PV production, load profiles, battery state of charge, temperature effects and BMS constraints in order to support tactical energy planning for deployable military infrastructures.

ACKNOWLEDGMENT

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THE ETIC PERSPECTIVE ON TURKS. SYMBOLIC INTERACTIONISM: ARABS, GREEKS, EUROPEANS AND TURKIC PEOPLE

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Abstract: *In anthropological studies, the etic perspective represents the exogenous (external) perspective i.e. the alterity's ways of perceiving Turks. Various interactions in various contexts lead to multiple perceptions on someone's identity – this external view is crucial in completing the identity puzzle, according to symbolic interactionism. Turks' neighbours (Arabs, Greeks, Europeans per se and the Turkic people) interact with Turks and define them according to geographical and cultural proximity, but also to other events they encounter, such as ideological interactions or coercive interactions.*

Keywords: *Turks, etic perspective, symbolic interactionism, alterity, Arabs and Turks, Greeks and Turks, Europeans and Turks, Turkic people and Turks*

1. INTRODUCTION

“Symbolic interactionism is a matter of substance” [1], explaining the way in which “self and environment define each other by means of symbolic communication”, in other words, as scholar George Herbert Mead explains, to know what the others are is useful in understanding what we are [2]. Symbolic interactionism describes *taking the role of other* as a necessity in identity construction, under the statement that others' *perceptions* on us help us understand ourselves.

The identity portrait of Turks cannot be completed, according to constructivism, in the absence of others' perceptions on Turks.

We shall analyse the case of Turks from the lenses of other peoples, based on the interactions between them. These peoples are: the Arabs, Greeks, Europeans as an entirety and Turkic people as Turks' alterity. All of them are Turks' neighbours, but also all of them have had different interactions with Turks.

Symbolic interactionism is exceedingly based on *perceptions*, which are difficult to be quantified or presented in their wholeness. Therefore, this analysis is meant to be comprehensive, rather than exhaustive.

2. SYMBOLIC INTERACTIONISM

Symbolic interactionism accentuates the importance of relations between actors in creating *identities*. Its development has been influenced by *pragmatism*, especially in relation with the ideas of *reality construction* and the importance of language in *naming* and *defining objects* – as one of the most important processes that occur in the thinking of a human being, according to John Dewey [3].

Largely, symbolic interactionism is described as the *conversation* between actors, by means of *language*. In this case, language is not reduced to its main meaning (words); it is a rather inclusive and broad concept used with reference to the *communication* (verbal and non-verbal) with which actors respond to each other step by step. Language and communication are, therefore, *civilising*, an instrument for the construction of civilisations and communities [4]. The appeal to language is broad: it *symbolises* the entity through which individuals interact. In its absence, individuals cannot fulfil their *human condition*, cannot bring it to its *ultimate aim*, therefore would not be able to differentiate from other existing entities [4]. This communication between actors was placed under the umbrella of symbolic interactionism, described as "the most *human* and *humanising* activity". If we understand humans as *social* creatures – in need of synergy rather than solitude or isolation, than we can understand symbolic interactionism as a process without which communities would not be able to exist (because it creates ties between people). In other words, *to humanise* means to bring to a *superior* level of existence and self-perception [4].

To provide a better understanding of this theoretical framework, we can as well provide a definition of what symbolic interactionism is opposed to – that is *isolation*. The opposite of *isolation* is *human.*

Communities *humanise* themselves by overrunning *idioglossia*, i.e. by exceeding their own specific way of being, thinking and communicating (*identity*, largely) which is unintelligible to others, by adding the others' way of being, thinking and communicating in relation to them [4].

The three essential parts of symbolic interactionism are, therefore, related to *meaning*, *language* and *thinking* [4]. Meaning is *how* an entity *understands* or *interprets* the other entity – in what terms. Accordingly, "humans act towards the others on the basis of the meanings they assign to those people". This interpretation is mainly based on (previous) personal experience. The matter which might arise is in relation to the number of *realities constructed*. Nevertheless, there is only *one reality*, but differently *perceived* and tackled. The ones who perceive the others as similar might be more inclined towards establishing *connections*, while all the others might act in the opposite way and create *distance* [4]. The paradox is that the *concrete* reality is nothing else than the gathering of *abstract* perceptions. In other words, for some, reality is when their perception is shared and multiplied, when it is "*tested*". When perceptions are different and they meet, their clash might set distance between the entities, but they are enclosed in that one reality anyway and cannot surpass it [4]. Because nobody really know what reality is, people cannot live into thinking that reality is nothing – can something be nothing and still be – and they set meanings to it, to fill that empty space because they search for meaning. That is why the idea of *nothing* is hard to be described by people, who do not know what nothing really *is*. Nothing cannot *be. Because if it is, that it is not nothing;* and this is how the need of sense is born and operates. So they do not just respond to events, they first of all encounter them, interpret them and then respond to them, according to their interpretation – because in its absence, events would be *nothing*, just like *reality*.

To sum up, reality is constructed by meaning. But meaning is also constructed, rather than "pre-existent" and it comes from language. People cannot think (emit ideas) in absence of a set of symbols to help them conceptualise. Meanings are, thence, the result of *emotions* added to an object as a result of human interaction. In other words, meanings are associations between *objects* and *symbols* – that is "*symbolic naming*", (a translation). People know as much as they name. In other words, a symbol is nothing else than "a stimulus to which a meaning and value" are added [4]. A very important point in symbolism is represented by the subconscious.

Very many of the correlations and meanings are to some extent settled in the subconscious, filtered by the environment in which people live, leading to the formation of "*default assumptions*", especially in relation to aspects which are different from the *common sense* [4].

The importance of the *subconscious* is emphasised and revealed when attributing meanings to the others, filtering them by *thinking*. But in order to be able to define the other, people must first of all be able to define themselves, process which happens through "*self-talk*" or "*minding*" – "*thinking* becoming an inner *conversation*". The phenomenon of anticipating others' reactions, for example, cannot come in the absence of social *interaction* and is facilitated by *imitation*: *taking the role of the other*. This can turn into a self-coercive mechanism, in a way that thinking about what the others might think or how they would react determines people's actions. The essence of this phenomenon is that unlike the expectations of being able to understand the others, the ones who people actually understand better are still themselves. In other words, the *self* is defined not as much by *itself*, but by taking the role of the other. The unknown or missing pieces of the inside cannot be taken from the inside, only from its outside to complete the *equation* i.e. *the self*. This is, once again, based on certain assumptions and perceptions – people thinking and "imagining how they look to the others", defined as "the *looking glass-self*" [4].

In *linguistic* terms, we can interpret this as "speaking the *language* of others", where language is an inclusive term for not only communicating, but also thinking and imagining. This can also be explained through "Speak a new *language* so that *the world* will be a new world" (Mevlana Jalal ad-Din Rumi), i.e. the language of others comes with an entire reality of the others. Therefore, the chronology of the self is more likely "I am because I can speak, express, think" etc. and not "I can speak, express, think because I am". Moreover, people cannot fully be *them-selves* in the absence of the interaction with *the others* and the self is thence, unlimited – it fluctuates and changes accordingly. People anticipate themselves as they anticipate the others' acts.

The meeting point is that we are the others, we are an alterity – there are two selves – an objective and a subjective self, this is how people can become their own strangers or stranger to themselves. The *subjective self* or "*the I*" cannot be predicted, the more people try to label it or explain it, the more it becomes stranger as a means of self-protection: "you can never know your *I* because once it is known it becomes your *me*" – i.e. the *objective self*, created by role-taking. The *subjective self* determines the *objective self*, because "there is no <<me>> at birth" [4].

It is to be noted that identity creation and fulfilment based on interactions complete the *portray* of Turks by adding attributes, this time filtered not by Turks themselves, but rather by the people with whom they interact.

The Turkish society is therefore *socially constructed*, rather on a subjective than objective basis, as the "product of shared symbols, events and social interactions transmitted across generations" [5].

There are four main principles of symbolic interactionism: action is based on the (subjective) *meanings attributed* to certain objects, interactions take place "in a social and cultural *context*", "meanings originate from *interactions* with others" and "meanings are created and recreated through a *process of interpretation* that happens whenever the interaction with others happens" [4].

Accordingly, the self-image is developed through interactions, based on the "*generalised other*", i.e. on the expectations, responses and attitudes of the other people [4].

To put the four principles in one, we can state that there is a context where interaction takes place, each actor undergoes a process of interpretation and therefore, generates meanings.

If we consider Turks' interactions with other people, we have to take into consideration the degree of *(cultural) proximity* between Turks and the peoples they interact with: the closer the people and the culture, the more difficult to tell some attributes apart; the more *exotic* the people, the *harsher* the differences.

Therefore, an *ideal* interaction to be interpreted would be exotic enough to differentiate them, but not too exotic so that the cultural gap is not too wide.

Nevertheless, since the main pillars of our topic are "*perception*", "*symbol*", "*context*", "*construction*", "*interpretation*", "*meanings*" etc. the term *ideal* cannot be tackled due to its belonging to another group of determinants.

Therefore, the condition stated above regarding a form of ideal interaction cannot be completely addressed.

Due to the geostrategic location, Turks have encountered many interactions with the *alterity*, starting from the independence against the Juan-Juans in the VI^th^ century – which set the starting point in the ideologically-charged interactions of Turks with other people, due to the fact that it symbolises their wish for independence put in action.

Coercive interactions followed a long path in history, since very many interactions of Turks with other peoples were based on *conflicts* – battles in the pre-Ottoman and Ottoman period, expansionist policies in the Ottoman period, threat of losing territories after the First World War etc.

In those cases, conflict was, symbolically, a *necessary harm* for the construction or preservation of identity, and more importantly, it served as a material means for reaching an immaterial aim – an *instrumentalisation* of a *means*, not an aim in itself.

The nature of the context led to a rather *forced interaction* between people, when parties were acting so that to defend their beliefs.

In the case of countries, "taking the role of other" is, to some extent, similar to people taking the role of other people, due to one essential aspect: it can never actually happen and take place materially, but rather metaphorically. Nevertheless, in the case of countries, it is rather difficult to attempt to "take the role of other", due to the fact that unlike people, countries cannot *move*, change environment etc. – i.e. they cannot adopt purely material measures. Nevertheless, they can still imitate other countries, inspire from their actions and patterns.

In the case of the Mesopotamian culture, the very first *symbolic* interactions for meeting the alterity took place in the *context* of battles, after which the victorious party took whatever precious objects of heritage they wanted from the defeated party and brought them to their own lands" [6] as a means of appropriating the other's culture.

3. ARABS AND THE TURKS

As we mentioned, Arabs are not only bordering Türkiye, but also are ideologically close to them due to several meeting points, especially in the Ottoman period, due to them having similar (religious) beliefs.

3.1 Ideological interactions

One of the most important interactions of Turks with Arabs is related to the ideological dimension – that is the conversion of Turks to Islam.

Historically, Turks' conversion from paganism to Islam took place in the VIII^th^ and X^th^ centuries [7] and changed the course of actions in their history.

According to the philosophy of religion, "Islam is the most cogent example for Schleiermacher's thesis that religion is rooted in a sense of *dependency*" [8].

Psychologically, the sense of dependency is always related to *duality* – there is always a binomen, where either one party is dependent on the other, or between them there is *interdependency* – i.e. they are *interdependent*.

In the interaction between deity and *the* people, there is a relation of submission: *aslama* is *to submit*, and *Islam* is *submission* – therefore, of *dependency*; but in the interaction between people, among themselves, there is a relation of interdependency: Turks owe Arabs the *idée mère*, the fundamental, guiding idea creating the *uni-directionism* in Turks' faith and value system; but the sense of interdependency could not have been complete and completed in the absence of Turks, which makes them *sine qua non* in this equation.

This interaction is the opposite of the haggadic one – it does not describe an *exodus*, but rather an *arrival* – Turks' arriving to faith or "*imana gelmek*".

This entity of faith is unbounded and *immaterial,* therefore can be shared and multiplied to different people and shall always remain one. On the contrary, the more it is distributed, the greater it becomes.

Arabs were the essential entity in Turks' religious identity construction process – and if we consider the very *moment* of their interaction, Arabs could be seen in a superiority rapport, in terms of belief system, due to the fact that Turks were primarily not a monotheistic people.

Nevertheless, we can describe the interaction between Arabs and Turks not as Arabs being superior to Turks, but rather as Arabs being the *godparents* of Turks, having facilitated Turks' means to *come to faith*[1], to an unbounded, immaterial entity.

In order to provide a more applied analysis, we shall follow the four principles stated above. The context of their interaction was immaterial, ideological, therefore having a profound meaning for both peoples.

If we consider the *significance* or interpretation of their interaction, then both of them may be placed on the same scale as a bilateral, circular *giving-receiving* binomen and thence, dual sense of perception.

3.2 Linguistic interactions

After converting to Islam, Turks began to adopt the Arabic alphabet as well, but trying to make it fit the specific sounds and letters of Turks' language [9], therefore the later Ottoman Turkish from the Ottoman Empire period took the form of Turkish language written with the Arab alphabet, but also encompassing a number of words borrowed from Arabic.

The writing system was the *Abjad*. Etymologically, the term *abjad* comes from Arabic and it explains how the words are written, only using the *long* sounds – especially consonants.

"the first words that gathered in them the basis words in the Arabic language".

This interaction being rooted in a religious one, Turks also borrowed religious terms and expressions, such as: "*Maşallah*", "*İnşallah*", "*Bismillah*", "*Estağfurullah*" – originally coming from the Arabic words "*Ma sha'a Allah*", "*In sha'a Allah*", "*B-Ism-Allah*", "*Astaghfr-Allah*" etc. In English, there is no dirrect correspondent for these phrases, but rather some contextual ones.

To be more specific, "Ma sha'a Allah" can be said as an admiring term in order to compliment someone and wish them protection against the *evil eye*.

"In sha'a Allah" could stand for "*God willing*", "*B-Ism-Allah*" means "*in the name of God*" and "*Astaghfr-Allah*" meaning "*God forbid*".

One of the most significant *cultural proofs* is the *tuğra*. Etymologically, "the word comes from the Oghuz Turks, standing for *seal*" [10]; it is known as the "signature of the Ottoman sultans, containing the sultan's name, the sultan's father's name along with a *dua* (*prayer*): "*el-muzaffer daima"* ("*the ever victorious"*)" [11].

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[1] *imana gelmek* – is a Turkish idiom which means "to become Muslim", literally being translated as "*coming to faith*"

The legend behind the origins of *tuğras* states that the first tuğra was made by an illiterate sultan using his fingers dipped in ink [10]. The writing of a tuğra became then the duty of a specialised person, called *nişancı* or *tughrai*, meaning "*calligrapher*" [11].

The religious phrases, like "*Bismillah Al-Rahman Al-Raheem*" ("In the name of God, the most gracious, the most merciful") from mosques are written in the original Arabic form, and one of the most known Islamic calligraphers from the Ottoman Empire is Mustafa Râkım Efendi, who practised two of the Arabic calligraphy forms in the *medrese* (religious school), *thuluth* and *naskh* – and was given the nickname "*Râkım*" ("*superior*") for the remarcable works [12].

It is to be noted that nowadays, the Directorate for Religious Affairs, *Diyanet İşleri Başkanlığı*, organises courses for Turkish people who want to be able to read the Quran in Arabic, but one of the most important aspects is that in very many cases, Turks can only read the Arabic language without being able to completely understand it – due to the fact that they did not adopt Arabic as a cult language.

This time, the context of their interaction is linguistic, language being a very important binding agent between the two communities. The meanings of the interaction are rather symbolic, Turks appropriating terms of Arabic origins through Islam. In terms of interpretation, the perception of Arabic language is related to Islam, becoming highly symbolic.

3.3 Value system. Customs

It is to be mentioned that there are similarities in terms of cultural identities between Turks and Arabs. The first one to be noted is that both of them are very cohesive and welded communities: like Turks, "Arabs gather in collective communities, generally share the same Arabic Islamic culture and speak the same language" [13].

Therefore, the structures of the society are quite similar in their essence, and being collectivist cultures, "their identity and decisions are influenced by social systems" [13].

In fact, the Turkish term used to describe customs is *adet*, coming from the Arabic *adaat*, which originally translates as "*common*" or "*ordinarily*".

Therefore, in both cultures, customs refer to those acts, practices that are not out of the ordinary, that do not exceed the social system.

These similarities have appeared due to geographic proximity, but intensified after the Turks' conversion to Islam, due to their having the own religion and adopting the Islamic cult teachings – here, the *cult*(ural) identity becomes a *civic* identity.

The structure of the society and relations between individuals share, therefore, similar elements. To exemplify, there is an Arabic proverb that says "*Between coffee and tea, stories are told*", following the same idea as in the Turkish saying "*The heart does not want coffee, the heart wants conversation, but coffee is a pretext*".

Even if at a micro level these sayings might appear superficial, they actually underline a very important cultural trait – sharing and coming together in a close environment. Here, the context of the interaction is material, geographical, but also immaterial, spiritual – the material environment leads to the immaterial elements – the values and beliefs, extendedly – the way of life of both communities.

Another significant trait is that for Arabs, family represents the nucleus of the society as well. The idea of family is recurrent in the daily life, under different forms and symbols. For instance, when welcoming someone, the phrase "*Ahlan wa sahlan*" is used, where "*ahlan*" comes from "*ahl*", meaning "*family*" and "*sahlan*" comes from "*sahl*" and it means "*easy*". The interpretation can be "*welcome to the family*" or "*we welcome you as your own family*", wishing "*easiness*" to you, i.e. *no difficulty* or *a pleasant time*.

Another such example is the wish “*tusbih aala khayer*”, with the answer “*wa ant men ahluhu*”, i.e. “*may you become good*” and the answer “*may you be from the same family of goodness*”. We can tell that family is associated with goodness in both cultures, being given a positive meaning, the symbol of prosperity and development.

The meanings and interpretation of these interactions underline the similarities between the two communities, emphasising the fact that cultural identity is constructed also as a consequence of combining geographical elements with *ideological* ones.

3.4 Komşuluk and asabiyyah

One of the most important similarities between the two cultures is their belonging to the collectivistic cultural environment.

One piece of evidence in this case is the way in which the people of both communities place themselves in rapport with *the community per se* and what value is added to the community. As we described the implications of *komşuluk* and its important role in strengthening the group feeling and sense of belonging, we shall also analyse the concept of *asabiyyah* and its implications.

To begin with, etymologically, the term *asabiyyah* comes from the verb *asab*, which means “*to bind*”; therefore asabiyyah is the noun standing for “*tie*”, “*connection*”, or in social terms: “*solidarity*”.

This concept originates from the Arab philosophy, more specifically from *Ibn Khaldun*, an Arab philosopher from the XIVth century, describing the group feeling, collective sentiment, or in other words, the sense of belonging to a group or community, underlying the importance of cohesion and unity [14].

We can therefore understand the psychological emphasis of groups, not due to its material attributes, but rather due to its *immaterial attributes*: it is not the form of organisation, but rather the *feeling* and *lifestyle* attached to it that matter the most.

From a gathering of people, the group becomes *one essential entity* for these two peoples and living in tight connection with the group gives its members a sense of security, belonging, but also some *rules* to follow in order to move in the same direction as the entire group does.

In reductionist terms, the group is the mirror of the family, it reflects it, but its construction is in the opposite way: while a family is the sum of its members (one member, plus one member, plus one member – equals family), the group *mathematics* goes like this: the group determines each of its members, not the members determine the group.

This equation shows that in these societies, the group is placed on a superior hierarchical position towards the family, for family is only *a group* of the *bigger group* – only *a constituent part* of the *entirety* which *constitutes its parts*.

Therefore, Arabs might perceive Turks as being ethnically compatible with themselves – as an interpretation of their similar community constructions.

4. GREEKS AND THE TURKS

Greeks shall be discussed separately, even though they form a part of Europe, because of the problem of Constantinople and inheritance of the Byzantine Empire, but also because of the fact that “Greeks think and talk a lot about Turks”, therefore Turks being “the most significant *other* of the Greeks” [15] – so in terms of *alterity*, Turks represent a *focus* for Greeks. For them, Turkish people are talked about as “*the Turk*”, therefore perceived as a generalised category or group [15].

Despite the fact that Turks represent an important exogenous category for Greeks, they seem to be rather *perceived* than *objectively defined*, becoming a "*hollow category*" [15] – therefore "*constructed from without*", according to Edwin Ardener [16]. In other words, a "hollow category" is a "definitonally and discursively <<empty>> idea that takes on *meaning* through *context*" [17]. We can understand the importance of *context* in shaping perceptions and constructing identities. In the case of Greek-Turkish interactions, Greeks construct an "image" from the position of *neighbours* – the *context* – becoming from an empty concept, a rather "ample one in terms of taxonomic space" [16].

In other words, *Turkishness* is cleared of the meanings Turks themselves impose on it, in order for it to be filled with the meanings Greeks impose on Turks.

Nevertheless, the space of perception is rather unlimited – so that there is always some space left "that can be loaded with additional properties" [16], according to the historical *context* and *interactions* – but also and more importantly, to the symbols those interactions are given.

In terms of cultural identity, the cultural attributes defined as "*stuff* within boundaries" by Fredrik Barth [16] are very prone to interpretation, an important contributing factor being the conflictual clashes the two people have had. The main paradox that appears in this case is the fact that *the origin of conflict is similarity* (of beliefs), and not difference. When two similar mind sets meet, as a consequence of them being both strong and profoundly settled in the collective mind, they produce a clash. Greeks' perspective is included in the concept of "justificatory rhetoric" – "a rationalisation of difference which can deny the <<most self-evident similarities>>" [16].

One of the most significant meeting points in the history of the two entities' relation is the *fall* of Constantinople for Greeks and the *conquest* of Constantinople for Ottomans – one moment, two different understandings, same ideological motivation.

One of the most known phrases related to the fall of Constantinople is "*Ya ben İstanbul'u fethederim ya da İstanbul beni*" of Fatih Sultan Mehmet, meaning: "*Either I conquer Istanbul, or Istanbul will conquer me*" – in ideological terms, this approach can be translated as "*all or nothing*" – for Turks, they fought for the expansion of the Ottoman state, religion being the ideological motivation in the background and thence the conquest representing the symbol of an ideologically infused military victory. In the case of Greeks, they fought for the preservation of their territories, as well ideologically motivated to protect and perpetuate their faith. The conquest of an Orthodox centre by a Muslim expansionist power culminated with the reconfiguration of Hagia Sophia from a cathedral to a mosque – symbolising a *pantheist interaction* between the two cultures.

Moreover, Constantinople was of great geopolitical importance as well – Greeks' cultural identity being forcedly reshaped by Turks taking *the bridge* between the East and the West for themselves. Constantinople was, thence, not the *centrum mundi*, but the point that connected the *worlds* so that the *centrum* could exist – in other words, its condition of existence.

As much as this cultivated *rejection* on both sides, it emphasised similarity of values and for both Greeks and Turks, the importance of acting in the name of faith in order to protect it.

The constructing role of coercive interaction underlined the existence of a sort of *religious nationalism* – protecting the state for its religious foundations.

In other words, *polar opposites* meet at *one single point* which is mutual, shared between them – which makes the *lines* form a *circle*.

In constructivist terms, the memory of *the City* (of Constantine) is perceived by some Greeks as a missing piece of the *complete puzzle*, highly symbolically charged and turned into *enosis* (literally "*union*"), specifically present in the case of Cyprus – advocating for the union with Greece.

Why is it the case of Cyprus that has adopted this doctrine? The answer stands in the meanings attached to the above mentioned events – i.e. a *trauma* – more than it is political, it is rather an ideological trauma, triggered in the mind of Cypriots due to their situation of division between Greek Cypriots and Turk Cypriots.

Enosis is a self-protection and self-preservation psychological mechanism turned into political terms which support the *Megali Idea* (the *idée mère*) of reviving the Byzantine Empire, similar to the Neo-Ottomanist doctrine of protecting and promoting the Ottoman inheritance.

5. EUROPEANS AND THE TURKS

One of the first apects to be mentioned is the geographical difference or more precisely *distance* between the two entities.

It is important due to the fact that it is accompanied by different ways of life and thence different cultures and identities.

In this case, the emphasis is on the differences rather than similarities – Turks are perceived as "*exotic*" by Europeans and the reverse is also valid.

From the very beginning, Turks were perceived as a *threat* by Europeans. The Seljuk Empire and the Christian world encountered in the eleventh century [18]. What we can understand from this is that their very first encounter was filtered through *religion.*

Throughout history, both had been perceived by the others also as a "*threat*", under different aspects and circumstances.

This was very profound in the Ottoman expansionist period, when Europeans developed the "*missa contra turcas*" sentiment, or "*masses against the Turks*", stating that only with the help of God could they defeat the Turks [19]

This means that not only territorially, but also ideologically, Turks were perceived as a threat, portrayed in some cases as being "bloodthirsty" or "God's punishment" as they were the "enemy of Christianity" [19].

Moreover, different *pejorative terms* were used to describe the Turks as an entirety, i.e. the Turkish people, constructing the image of a people *without moral values* [19] due to the fact that they triggered fright in the collective mind of Europeans.

Therefore, we can tell that in the early times, the first interactions between Turks and Europeans were based on conflicts, due to which the perception of Europeans towards Turks was limited to aspects they (had) witnessed – religious ideology, military force etc.

Nevertheless, some aspects took a different turn along with the more various cultural interactions.

For example, the Turkish Janissary music represented a source of inspiration for European composers such as Mozart, leading to what was later called as "*alla turca*" music [19].

Extendedly, this was part of "*Turquerie*" (or *Turkery*), a Turkish trend in Europe, where the source of inspiration was the Ottoman Empire as being of significant importance for the Oriental world, described as having "*tolerance*", "*strength of faith*" and "*goodness*" [20] and being seen as a model due to its development.

We can, therefore, trace a connecting line between interactions and symbols – according to the type of interactions they had with the Turks, European labelled Turks.

When they were perceived as a threat to their territories, ideology etc., Turks were seen as barbarian, bloodthirsty, a series of bad habits being associated with them.

When the dynamics of the interactions changed, Turks became a source of inspiration and even a model for the Europeans, in terms of music, clothing and arts in general.

This explains the "*good-bad*" framework in which identity is framed – if the *context* of the interaction is of good consequences for the Europeans (in this case), then the identity of those whom they interact with is labelled positively and vice versa. The elements of interaction which determined identity construction in this case were mainly military (territorial expansionism) and ideological (religious-based).

One of the stalemates in the interactions between these two entities can be traced in the immediate period after the First World War, when Ottomans were not victorious and they were facing the threat of their territories being shared by the victorious powers [21].

The Ottoman Empire had already been through a series of reforms – *Tanzmiat* – meant to strengthen the weakened Ottoman State, but the supreme reform was its complete replacement.

The paradox is that even if Europeans then represented a threat for the Ottomans, they later constructed or re-constructed their identity by imitating the European model – that is due to the fact that in Turks' *perception*, Europeans symbolised *modernity* – that is development and progress in their understanding. Therefore, if modernity was labelled positively, then so were their representatives.

From these, we can understand again the importance of the *circle* – a constant in Turks' cultural identity – if the flourishing Ottomans were taken as a *model* in the period of *Turquerie*, the Europeans were also taken as a *model* starting from the 1923 moment – involving elements of progress, development and modernity. Nevertheless, when the context of the interaction was territorial, both of them perceived the others as *threats*.

We can therefore trace the symbols according to which these happened: whenever one of the two entities was in a position of superiority related to intangible matters such as way of life, music, arts, reforms etc. it was appropriated, but when the matter was related to tangible aspects, such as the above mentioned lands, the symbols of perception turned negative.

The only *exception* in this case is *faith* – due to its dual character – it is an intangible aspect, but also tangible by means of the places of worship (mosques and churches).

6. TURKIC PEOPLES. SYMBOLIC INTERACTION OF TURKS WITH THEIR TURKIC ALTERITY

As we described the importance of *family* for the Turkish cultural identity, we can understand the Turkic people as members of *the Turkic family* – in this understanding, Turks' *relatives* are the peoples that originate from the same roots, bear similar values and speak languages from the same family.

The vehicular term is "*Türk Dünyası*", meaning "*The Turkish World*", defined as "an entirety made up from Turkic people, who are spread to a large geographical area, tied by means of speaking a mutual language, having a mutual history and having cultural bonds" [22].

Turks do no face *an alterity*, but *their own alterity* – the interaction of Turks with themselves, but as an alteriry – as a memoir and reinterpretation of the *millet* in the Ottoman Empire, that was the gathering of the different peoples under the roof of the Ottoman Empire [23].

This reminds Turks the ideas of *unity* and *plenitude* – the symbol of *force* – together and united, they are stronger. As Turkish language is one of the most important supporting pillars of Turkish nationalism, Turkic languages etxendedly take the same role as a *family* and within this family.

As a political and diplomatic representation of this, the slogan of the Turkish Cultural Institute “Yunus Emre” is “*Türkçe Dünyanın Her Yerinde*”, meaning “*Turkish can be found in every part of the world*”.

These attributes might be framed into a form of sacralising the ethnicity or *ethnic or ethno-cultural nationalism*, placing ethnicity, therefore, in the *centrum* of cultural identity – in other words, cultural identity is what results from the mass-shared ethnicity.

The elements of *ethnic nationalism* or *ethno-cultural nationalism* (or *multi-nationalism*) can be exemplified by the case of the relations between Türkiye and Azerbaijan, often referred to as “*one nation, two states*” [24].

This case helps us return to the idea of proximity, which determined the construction of a shared identity between the two entities. Even at the linguistic level, Azerbaijani is sometimes called “*Azerbaycan Türkçesi*”, i.e. “*the Turkish from Azerbaijan*”.

Even if geographically far, the Northern part of Cyprus is also culturally and ideologically included in the Turkish world denomination, being of great importance for Türkiye, the only state which recognises the “Turkish Republic of Northern Cyprus”.

Therefore, in terms of the context of the interaction, this case bears a special character – Turkic people mirror Turks, but the reflection is not completely accurate; it is rather similar to the branches of a tree – despite their slight difference in aspect, all of them come from the same root and are related in a way that makes their tie strengthened, but also strengthens the *root*.

Here, the root can be understood both *materially* and *spiritually* – materially as lands or language; spiritually as cultural identity per se – beliefs, values, customs, traditions and the feeling of belonging to a widespread Turkish identity or mass identity.

We can state that every different people analysed above has had different types of interactions with the Turks, when in the case of symbolic interactionism even the *constant* is *alterable*: Turks are the constant in each binomen, but nevertheless different for Arabs, Greeks, Europeans in general and Turkic people.

7. CONCLUSIONS

The etic perspective refers to the alterity’s response to the question “*Who are the Turks?*”.

In the case of Arabs, the ideological dimension (religion) is what brought them close, culminating with Turks’ conversion to Islam, the *idée mère* which Turks owe Arabs.

For Greeks, Turks are their most significant other (alterity), representing a *hollow category*: that is a category *constructed from without*. In other words, Turks are perceived by Greeks contextually. In the context of neighbours, the paradox resulting from their interactions is that the origin of conflict between the two is the similarity (of beliefs), but different meanings assigned to same events.

When it comes to the interactions with the Europeans in general, both categories perceive the others as “exotic” and the context and type of interaction is decisive for the perception of the alterity.

The case of Turkic people is the mirroring of Turks as *an other* – Turks take the place of themselves, becoming their own alterity, leading to the increased sense of unity and plenitude in the case of the widespread Turkish identity: cross-border Turkish values leading to coinciding emic and etic perspectives.

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FEAR OF DEATH AMONG MILITARY PERSONNEL

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Abstract: *Fear of death is a complex and subjective concept, with specific manifestations that vary from one individual to another. It naturally emerges as a survival instinct at the level of living beings. In the case of human beings, however, things are far more complex, one reason being the development of consciousness and rationality specific to humans. Various studies show that several variables can influence the intensity of fear of death. These may include gender differences, age, health status, and others. Probably because this fear can sometimes reach very high levels of intensity, human beings have developed certain coping mechanisms, which at times help restore inner balance, especially after a life experience that has activated the fear of death. Another frequently debated factor regarding fear of death is religion. Over time, researchers have attempted to determine whether there are differences in fear of death between religious and non-religious individuals, yet the results do not seem to be very conclusive. Although many of us confront fear of death, it is experienced more frequently and recurrently among military personnel, particularly those who have participated in missions in combat operations.*

Keywords: *fear of death, coping mechanism, religious beliefs, combat operations.*

1. INTRODUCTION

Fear of death is one of the deepest and most universal human fears. It may arise as a fear of the unknown, of losing control, or of being separated from loved ones. For some, it manifests through persistent thoughts, anxiety, or the avoidance of situations associated with danger, illness, or aging. For others, it remains a subtle concern that nevertheless influences life choices. Psychologically, fear of death can be linked to the need for meaning, security, and continuity. When it becomes intense, it may affect quality of life, however, when explored in therapy, it can lead to a clarification of personal values and to a more conscious experience of the present moment.

An important aspect of this article is that the voluntary participants who responded to the questionnaires are active military personnel employed on a contractual basis. Some of these service members have personally participated in missions, or belong to subunits that have carried out operations in theaters outside the territory of Romania, performing combat missions or supporting combat units in which they were confronted with the death or injury of fellow soldiers.

Furthermore, during the mandatory testing required for entry into the military system, candidates are not assessed through eliminatory psychological tests designed to identify levels of anxiety or aggression that may influence fear in the face of death and that, in conflict situations, could incapacitate a soldier. Although anxiety and aggression are states that military personnel may experience in peacetime, fear of death most frequently arises when they operate in conflict zones.

In such circumstances, it is extremely important—sometimes even vital—how they react and how they manage and control their emotions.

2. FEAR OF DEATH – PSYCHOLOGICAL ASPECTS

One of the main sources of stress and anxiety for humans is considered to be the fear of death [1]. This can be seen as the price human beings pay for the development of the brain throughout the evolutionary process, alongside the emergence of human reason and the capacity for self-awareness. All these advantages have enabled humans to become aware of their own end and of life's transience. From the moment this awareness emerged, people began to seek various alternative solutions that would allow for a continuation of life and a more comfortable existence. From a psychological perspective, these aspects suggest that human beings have developed various coping mechanisms in relation to the fear of death.

Fear of death manifests in various ways and with different intensities depending on the context. Thus, females report higher levels of fear of death than males; higher levels of education and socio-economic status are moderately associated with lower fear of death; older individuals do not report greater fear of death compared to younger individuals; religious individuals are not necessarily associated with lower fear of death; good physical health is associated with lower fear of death; and a greater number of psychological problems are associated with higher levels of fear of death [2].

Psychoanalysis postulates that a death instinct generates an unconscious desire to die, while a life instinct is related to survival; when internalized, the death instinct may produce aggression directed toward the self and self-destructive behaviors [3]. Becker suggests that death is one of the main sources of concern for human beings and that this concern may be reduced through proper education, which would lead to a positive attitude toward death. From this perspective, a positive attitude toward death is imperative for the development of a healthy psychological balance in the individual [4].

The existential perspective provides a comprehensive overview, suggesting that death should be confronted rather than avoided, and by doing so, the individual becomes capable of constructing an authentic and meaningful life [5]. Wong's meaning-making theory states that understanding and accepting death as inevitable leads to an increase in the significance of the individual's life [6]. Therefore, it can be argued that psychological balance is necessary, and this can be achieved by bringing attention to the concept of death, which is usually avoided because it produces anxiety. By bringing this concept into the open, a better sense and meaning of life can be attained.

3. COPING MECHANISMS

While some individuals manage the fear of death in an adaptive and positive way (e.g., by living in the present and pursuing a meaningful existence), others may show an actual inability to relate to the imminence of their own death, which can lead to an intense, almost paralyzing fear and the use of unhealthy coping mechanisms.

The reactions manifested in response to the fear of death are characterized by two different mechanisms. One mechanism refers to the fact that the inevitability and awareness of one's own mortality are placed under denial, even by individuals who normally use other coping mechanisms to deal with sources of stress and anxiety in everyday life [7].

Another mechanism of reacting to this fear involves individuals choosing to manage their fear of death by intensifying whatever defense mechanism and coping strategy they typically use when dealing with less extreme forms of stress and anxiety.

Regarding these two mechanisms, the dominant theme in theories and research on this topic appears to be the denial of one’s own mortality. However, denial does not seem to represent a solution because, aside from a few studies, most empirical investigations have shown that there are more extreme reactions to death at lower levels of awareness than at higher levels [1].

4. RELIGIOUS VERSUS NON-RELIGIOUS

In addition to representing the prevalent characterization of the defensive nature of attitudes/responses in the face of death at low levels of awareness, denial has also been used to explain the function of religious beliefs. Schulz uses the construct of death denial to explain the differences in how religious and non-religious individuals relate to the fear of death [1].

In line with Freud’s psychodynamic view of religious belief [8], Schulz argues that religious individuals often report a lower fear of their own death than non-religious individuals because their belief in immortality encourages them to deny their fear of death. However, Schulz’s investigations have been questioned, as Feifel and Branscomb [9] failed to find clear evidence of differences between religious and non-religious individuals regarding fear of death at low levels of awareness. In fact, Pollack (1979–1980) maintains that research findings concerning the relationship between religious beliefs and fear of death are too inconsistent to allow for a rational analysis [10].

Similarly, Kastenbaum and Costa (1977) attribute the inconsistency in this line of research to a lack of conceptual clarity regarding the expected relationship between religious belief and fear of death [11]. They note, “it is unclear whether religious individuals have a greater fear of death (which may have intensified their belief) or a lower fear (as a result of their belief)” (p. 234).

After examining several defense mechanisms and coping strategies, Kellerman (1980) suggests that these can be categorized from relatively simple mechanisms such as denial or repression to relatively sophisticated ones such as rationalization [12]. This suggestion may form the basis of the following implications: if denial and repression represent the response to awareness of one’s own mortality [7], then religious individuals should display a lower fear of death at high levels of awareness. Conversely, at low levels of awareness, they should react with greater fear.

5. FEAR OF DEATH AMONG MILITARY PERSONNEL

By the nature of their profession, military personnel represent a distinct category of individuals who must confront the fear that arises in the face of death. Sigmund Freud argued in his theories that people do not truly experience the fear of death, given that it is not part of their lived experience. In the case of military personnel, this theory may be contradicted, as by operating in theaters of operations they are automatically and abruptly confronted with the imminence of death and its explicit manifestations.

What may previously have been denied or avoided suddenly becomes a real and constant threat that can materialize at any moment [13].

The complexity of military actions and the various uncertainties of external threats can lead soldiers to experience an imminent death that ultimately does not occur.

This type of experience may generate fear of death in military personnel, but in a somewhat delayed manner.

This delay usually appears at certain intervals after the threat has passed, when soldiers exit "combat mode" (in the heat of the moment) and enter the post-incident reflection phase (after the fact). It is at this point that they become aware of the high level of danger they went through and the real possibility of losing their lives.

This delayed fear may arise both in situations where the soldier has control (e.g., a parachutist who releases the main parachute and deploys the reserve) and in situations where control is absent, such as when a military vehicle runs over a hidden improvised explosive device without the soldier being aware of the danger.

Control within the situation is extremely important because it determines whether fear sets in or not. Thus, in situations where the soldier maintains control, fear does not usually arise—this being facilitated by the fact that they are trained to act in extreme circumstances. However, in the absence of control, fear does emerge and may be intensified by the feeling of helplessness when facing a life-threatening situation [13].

The fear of death experienced by military personnel operating in conflict zones is only one facet of the broader construct of death; another is the fear of killing. This aspect has been taken very seriously by those responsible for combat training, who have developed programs designed to reduce the soldier's focus on the fear associated with killing the enemy.

In this regard, training programs tend to concentrate primarily on mission accomplishment, placing less emphasis on the moral dimensions of the act, and instead targeting the soldier's prompt response during action by fostering automatic reactions. For example, they may use human silhouette targets or even photographic targets that fall when hit by a bullet, rather than traditional circular scoring targets.

The feeling of not belonging is defined as an unmet need to belong, which involves a lack of positive and frequent social interactions and the sense that one does not matter to others [15]. Although some individuals may attempt to meet the conditions necessary for belonging, certain barriers prevent them from doing so successfully. The feeling of not belonging typically manifests in individuals who lack social support networks or who, despite having social ties with family and friends, do not perceive these relationships as authentic. Research data indicate that the feeling of not belonging is strongly correlated with suicidal ideation, suicide attempts, and completed suicide, while a higher number of connections with others correlates with decreases in suicidal behavior.

The second construct underlying the desire to die is the feeling of being a burden. This refers to the individual's perception that they are a burden to those around them and, moreover, that they fail to contribute to society while negatively affecting the lives of others. Because of these feelings, the individual may come to believe that their death would be worth more to others than their life. It is important to note that what matters most is how the individual perceives themselves as a burden, even if reality indicates otherwise. The feeling of being a burden has been correlated with suicidal ideation, suicide attempts, and completed suicide.

CONCLUSIONS

The fear of death has a strong potential to profoundly influence the human psyche. Research conducted on both clinical and non-clinical populations has provided solid evidence that fear of death represents a significant issue at the human level.

In support of Yalom’s (1980) existential perspective, fear of death appears to be a fundamental fear from which a range of mental disorders may arise, such as hypochondria, panic attacks, separation anxiety, depression, and eating disorders. Fear of death remains a unique human dilemma that, even at an unconscious level, can have a significant impact on daily functioning and life.

The fear of death is and will remain one of the deepest and most universal human fears. It arises from the awareness of the limits of one’s own existence and from the uncertainty surrounding what follows the end of life. For some people, this fear manifests through anxiety, hypervigilance, or avoidance of situations perceived as risky; for others, it becomes a driver of meaning, motivating them to live more intensely and authentically. At its core, the fear of death reflects attachment to life, relationships, and identity.

For military personnel who have participated in missions in theaters of operations, the fear of death acquires concrete and repeated dimensions. Exposure to real danger, the loss of comrades, and direct confrontation with violence can intensify existential anxiety. Sometimes, this fear is managed through discipline, group cohesion, and rigorous training. At other times, it may persist in the form of post-traumatic stress, insomnia, or hypervigilant reactions, requiring specialized psychological support.

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STRATEGIC LEADERSHIP IN BUILDING NATIONAL CONSENSUS TO SUPPORT SUSTAINABLE DEFENSE INDUSTRIAL DEVELOPMENT

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***Abstract**: Sustainability in the defense industry is an increasingly important concept with growing awareness of the environmental impacts of military activities and weapons production. Various studies of sustainable defense industry development have highlighted the importance of strategic policies, technological innovation, and economic frameworks to foster national defense independence. This study aims to discuss the role of strategic leadership in building national consensus to support Sustainable Defense Industrial Development. This research is supported by a strategic leadership theory approach, change management from the perspective of Kotter's eight-step model based on qualitative methods. The qualitative content analysis technique used a three-step method. By systematically following Kotter's eight steps, Indonesia has significant potential to build a national consensus on developing a sustainable defense industry. In this context, the government, private sector, and civil society must collaborate in formulating policies that not only focus on increasing defense capacity but also address the environmental impacts of these industrial activities. By integrating sustainability principles into its defense industry development strategy, Indonesia can ensure that national security needs are met without compromising ecosystem health.*

Keywords: Defense Industry, Sustainability, qualitative methods, National Consensus, Kotter's eight steps.

1. INTRODUCTION

Sustainability in the defense industry is an increasingly important concept with growing awareness of the environmental impacts of military activities and weapons production [1]. The defense industry is often considered a major contributor to pollution and unsustainable resource use. Many defense companies also invest in research and development to create cleaner and safer weapons systems [2]. Thus, the industry focuses on national security and social and environmental responsibility [3].

The defense industry in Indonesia has experienced significant development in recent decades, particularly after the 1998 reforms. The Indonesian government recognizes the importance of self-reliance in the defense sector to maintain national security and reduce dependence on imported main weapons systems (alutsista) [4]. Several state-owned enterprises (SOEs), such as PT Pindad, PT Dirgantara Indonesia, and PT PAL Indonesia, have played an active role in producing defense systems to meet the needs of the Indonesian National Armed Forces (TNI) and to enhance export capabilities.

Indonesia's defense industry's sustainability is related to economic, environmental, and social aspects [5].

The national consensus on the defense industry in Indonesia involves various stakeholders, including the government, military, academia, and civil society [6]. Defense policy discussions often involve assessing the country's threats and the need to strengthen military capacity independently. This consensus is crucial for all parties to share a vision for building an effective and efficient defense force [7].

Various studies of sustainable defense industry development have highlighted the importance of strategic policies, technological innovation, and economic frameworks to foster national defense independence. However, little has been explored about the role of strategic Leadership in building national consensus as a key element in supporting sustainable defense industry development.

This study aims to discuss the role of strategic leadership in building national consensus to support Sustainable Defense Industrial Development. This research is supported by a strategic leadership theory approach, change management from the perspective of Kotter's eight-step model based on qualitative methods. The qualitative content analysis technique used a three-step method: identifying symbols, filtering and classifying data based on symbols, and synthesizing findings from various sources to determine key themes, patterns, and insights. This research utilizes primary data sources, including interviews, observations, peer-reviewed academic journals, theological texts, and secondary sources such as books and research reports on sustainable defense industry development in Indonesia.

This research makes several contributions. First, it strengthens strategic leadership theory by emphasizing the role of leaders in building national consensus as a prerequisite for sustainable defense industry development. In a national context, strategic Leadership serves not only to formulate a long-term vision but also as a catalyst in aligning the interests of various actors, including government, industry, academia, and civil society. Second, this research enriches theory by demonstrating that in national-scale strategic change, change management emphasizes not only internal organizational factors but also involves external dynamics in the form of interactions between national actors. This broadens the scope of theory by emphasizing that the success of systemic change in the defense sector depends heavily on the ability to create a space for dialogue, trust, and understanding at the national level. Third, this research demonstrates that strategic Leadership plays a role in directing (sense-giving) and connecting between actors. At the same time, change management theory provides a framework for understanding the necessary adaptation and transformation processes.

2. LITERATURE REVIEW

2.1. Strategic Leadership.

Strategic Leadership Theory focuses on leaders' ability to influence and guide their organization toward long-term goals while navigating a complex and dynamic environment [8]. This theory emphasizes the importance of a leader's vision, strategic thinking, and decision-making skills in fostering an organizational culture that promotes innovation, adaptability, and competitive advantage [9]. Strategic leaders must understand their organization's internal dynamics and external market conditions, enabling them to anticipate change and respond effectively. Strategic Leadership Theory states that effective leaders must possess unique skills, including emotional intelligence, strong communication skills, and open-mindedness [10].

These qualities enable leaders to engage with diverse perspectives within their teams, fostering collaboration and creativity [11].

Strategic leadership is a person's ability to anticipate, envision, maintain flexibility, think strategically, and work with others to initiate change that will create a good future for the organization [12]. Sharing knowledge or intellectual capital that is unique to a particular organization will significantly influence the choices made by strategic leaders. Effective strategic leadership in the 21st century is strategic leadership that is able to find ways for knowledge to grow into more knowledge [13].

Strategic leadership refers to the process of directing, directing, and influencing an individual or organization on others to achieve set goals or tasks [14]. Strategic leadership is about overseeing the strategy-making process to boost the company's performance, which in turn boosts the value of the company's owners and shareholders. Nonprofit organizations, including government agencies and universities, are not supposed to make money. However, they are expected to utilize their authority wisely and run their businesses well, and their supervisors set goals to see how well they are doing. The business school rankings may help its programs become some of the top in the world by setting performance goals [15].

Strategic leaders are tasked with aligning their mission with actionable strategies that drive performance while ensuring employees feel valued and motivated [16]. Strategic leadership is the process of shaping a vision for the future, communicating that vision to subordinates, stimulating and motivating followers, and engaging in strategy-supportive exchanges with peers and subordinates. Strategic leadership is a series of processes that determine the extent to which an organization is effective in creating strong connections among people, technology, work processes, and business opportunities, aiming to increase economic, social, and intellectual capital for shareholders, communities, and employees [13].

2.2. Change management

As changes are difficult to predict, and tend to occur with growing frequency, change management is becoming an increasingly significant subject. Regardless of how a new information system is designed and how its implementation is planned, human potential represents a factor shat should play the key role in dealing with changes [17]. Change management theory encompasses a structured approach to managing the transition of individuals, teams, and organizations from their current state to a desired future state [18]. This theory emphasizes the importance of understanding the human side of change, recognizing that successful organizational transformation depends heavily on how well individuals adapt to new processes, technologies, or cultural shifts (Devi & Varghese Thekkekara, 2023).

Documented and functional change management is a decisive factor of project success, as changes are inevitable, especially in a complex, formative and evolving information system development project [17]. Another critical aspect of change management theory is the recognition of different types of organizational change—developmental, transitional, and transformational [20]. Each type requires tailored strategies to effectively manage the associated challenges [21]. Applying various models and frameworks within change management theory enables leaders to systematically address both the technical and emotional components of change, ultimately increasing the likelihood of successful outcomes [22].

As developmental changes are mostly known in advance, it is necessary to find a way to monitor, i.e. control the change implementation itself.

Lesley Partridge [23], includes the following into the process of managing, i.e. controlling change implementation (FIG. **1**):

-Setting and managing objectives so that they are linked to the vision and purpose of change;

-Planning the details and required resources;

-Implementing the plan, with continuous monitoring;

-Possible adjustments of the plan or modification of actions based on information acquired by supervising change implementation, in order to ensure achievement of objectives or continue on the road towards them.

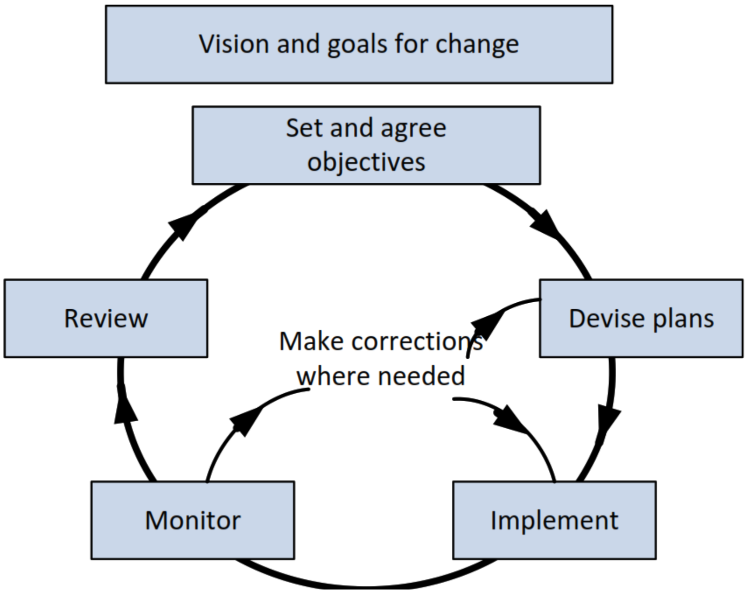

FIG. 1 Monitoring change implementation

2.1. Kotter 8 Steps.

Kotter introduced a theory of change with eight stages known as "Kotter's Eighth Stage of Change Process" [24], ncluding: first, building a sense of urgency, namely the stage to build motivation, by observing market realities and competition, identifying and discussing crises, potential crises or significant opportunities so that a strong reason to do something different emerges. Second, creating a guiding coalition is the stage that forms a coalition to initiate change as a team consisting of people with enough power to lead change. Third, developing a vision and strategy, namely the stage where it is necessary to create a vision to help direct change efforts and formulate strategies to achieve that vision. Fourth, communicating the vision of change, namely the stage to continuously communicate the vision and strategy of change to all elements of the organization by taking advantage of every available opportunity, and making the guiding coalition a model of behavior expected of employees [25].

The fifth, empowering comprehensive action, is a stage for carrying out activities involving all elements of the organization to remove obstacles, change systems or structures that weaken the vision of change, and encourage the courage to take risks and non-traditional ideas, activities, and actions.

Sixth is generating short-term wins, which is a stage for planning performance improvements due to visible changes/wins, and also providing visible recognition and rewards for those who make these wins possible.

Seventh, consolidating gains and producing more change, which is a stage for carrying out activities so that the change process becomes bigger by using increasing credibility to change all systems, structures, and policies that are not appropriate and incompatible with the transformation vision, recruiting, promoting, and developing people who can implement the change vision and rejuvenating the change process with new projects, themes, and change agents. Eighth, anchoring the new approach in culture, which in this final stage, all the changes that have been made are made into a new work culture by creating better performance through customer-oriented behavior and productivity, better Leadership, and more effective management, articulating the relationship between new behavior and organizational success and developing ways to ensure leadership development and success [26], [27].

FIG. 2. Kotter's eight-step model

3. METHODOLOGY

This research adopts a qualitative approach, employing critical literature review and observation [28], to explore the synergy between strategic Leadership and national consensus in supporting sustainable defense industry development. This research utilizes primary data sources, including interviews, observations, peer-reviewed academic journals, theological texts, and secondary sources such as books and research reports on sustainable defense industry development in Indonesia. This article provides a theoretical foundation for future research on strategic Leadership and national consensus in supporting sustainable defense industry development.

Data sources for academic journals will be selected through academic databases such as Google Scholar, Garuda, Sinta, and other databases, using keywords including "strategic leadership," "national consensus," and "defense industry." This research is limited to literature published within the last decade to ensure the material's relevance to current conditions. The qualitative content analysis technique used a three-step method: identifying symbols, filtering and classifying data based on symbols, and synthesizing findings from various sources to determine key themes, patterns, and insights [29]. Data sources were purposively selected to support the significance of the role of strategic Leadership in building national consensus in defense industry development.

Data triangulation will be conducted based on credibility, relevance, and contribution to understanding the research topic, ensuring the integrity and depth of the analysis.

4. RESULTS AND DISCUSSION

4.1 Strategic Leadership builds national consensus to support Sustainable Defense Industrial Development.

To build a national consensus for developing a sustainable defense industry in Indonesia, stakeholders can utilize John Kotter's eight-step process for leading change.

This framework is beneficial in navigating the complexities of stakeholder engagement, policy formulation, and resource allocation necessary to build a robust defense sector aligned with sustainability goals.

a. Step 1: Create a Sense of Urgency.

The first step involves raising awareness among stakeholders about the need to develop a sustainable defense industry. This can be achieved in Indonesia by highlighting the geopolitical landscape, regional security challenges, and the economic benefits of a self-sufficient defense sector. Engaging the media and holding public forums can help disseminate information about how a sustainable defense industry can enhance national security while driving economic growth.

b. Step 2: Creating the Guiding Coalition.

A coalition should be formed to lead this initiative. This group should consist of key stakeholders, including government officials, military leaders, business executives from the defense sector, environmental experts, and civil society representatives. The coalition should work together to ensure that diverse perspectives are included in the decision-making process and to foster trust among the various sectors.

c. Step 3: Formulating a Vision and Strategy

Developing a clear vision of what a sustainable defense industry in Indonesia looks like is crucial. This vision encompasses not only military capabilities but also environmental management and social responsibility considerations. The strategy may include specific goals such as reducing the carbon footprint in manufacturing processes or investing in renewable energy technologies within the defense sector.

d. Step 4: Communicating the Vision for Change

Effective communication ensures that all stakeholders understand and agree with the vision. Utilizing various platforms—such as workshops, seminars, social media campaigns, and official government communications—can help articulate the benefits of transitioning to a sustainable defense industry. Transparency about the goals and expected outcomes will encourage broader support.

e. Step 5: Empowering Employees for Broad-Based Action

Barriers to change must be identified and removed to empower stakeholders at all levels to take action to achieve the vision. This may involve revising regulatory frameworks that hinder innovation or incentivizing companies that adopt sustainable practices in their operations.

f. Step 6: Generate Short-Term Wins

Achieving short-term wins and demonstrating progress toward building a sustainable defense industry are crucial to maintaining momentum. This could include pilot projects showcasing green technology in military applications or partnerships with local businesses focused on sustainability initiatives.

g. Step 7: Consolidate Profits and Generate More Change

Once initial successes are achieved, they should be leveraged to drive change. This involves scaling up successful initiatives across various defense industry sectors while continuing to seek feedback from stakeholders to refine the strategy.

h. Step 8: Anchoring New Approaches in the Culture

Finally, embedding sustainability into the culture of the Indonesian defense industry requires a sustained commitment from leaders at all levels. Training programs focused on sustainability practices must be implemented within military institutions and related industries to ensure these values are ingrained in future generations of leaders.

4.2 Current policies in building a National Consensus to support the Development of a Sustainable Defense Industry in Indonesia.

Strategic Leadership in building national consensus to support the development of a sustainable defense industry in Indonesia involves a multifaceted approach that combines policy formulation, stakeholder engagement, and sustainable practices. The Indonesian government has recognized the importance of a robust defense industry for national security, economic growth, and technological advancement. The following are some of the key policies and strategies currently in place:

a. Defense Industrial Policy Committee (KKIP).

Indonesia's Defense Industry Policy Committee (KKIP) is established to formulate and implement strategic policies for developing the national defense industry. As a strategic step, the KKIP is crucial in creating a sustainable defense industry ecosystem by facilitating collaboration between the government, the private sector, and research institutions [30]. Through integrated policies, the KKIP aims to increase domestic production capacity and encourage technological innovation to meet national defense needs. Furthermore, the committee strives to strengthen the independence of the Indonesian defense industry by reducing dependence on imported primary weapons systems (alutsista). Thus, the KKIP contributes not only to national security but also to economic development through job creation and increased competitiveness of local industries. In an increasingly complex global context, the KKIP's existence is highly relevant as an effort to ensure that Indonesia has strong and independent defense capabilities [31].

b. National Defense Policy (2020-2024).

Indonesia's National Defense Policy (2020-2024) is a strategic measure designed to strengthen national resilience through the development of a sustainable defense industry [32]. In this context, the policy emphasizes the importance of self-reliance in the production of primary weapons systems (alutsista) and strengthening the capacity of the domestic defense industry. By prioritizing technology development and innovation, the government aims to reduce dependence on imports and increase the competitiveness of local industries in the global market. This policy also includes collaboration between the government, the private sector, and research institutions to create an ecosystem that supports research and development (R&D) in the defense sector [30]. Furthermore, the National Defense Policy focuses on improving the quality of human resources in the defense sector, enabling them to produce products that not only meet national needs but also have the potential to be exported to other countries. Therefore, the 2020-2024 National Defense Policy is a crucial pillar in realizing Indonesia's vision of becoming an independent and sustainable defense force.

This stage is the second stage of the Grand Design for Defense Industry Independence related to the Fulfillment of Defense and Security Facilities (Alpalhankam) 2015-2039, where collectivity is the core of the development of the national defense industry.

The national defense industry is gradually focusing on consolidation between entities to achieve the main target of fulfilling the domestic market, as well as international competition, and supporting national economic growth.

This condition makes the consolidation process intense, marked by competition between entities within it to support production needs and ensure the sustainability of each entity's business.

Moreover, this plan is supported by efforts to strengthen defense capabilities contained in the National Medium-Term Development Plan (RPJMN) 2020-2024, namely supporting 100% Essential Force with operational strength ready by 2024, improving the readiness of the main Alpalhankam, and increasing the capabilities of state-owned defense industry companies to support Alpalhankam independence [33].

c. Minimum Essential Force (MEF) Phase III.

Initiated in 2019, this policy focuses on modernizing Indonesia's military capabilities, including the development of maritime defense equipment, to achieve a minimum fundamental strength by 2024. Minimum Basic Strength Development (MEF) Phase III is a strategic step taken by the Indonesian government to strengthen the national defense industry and ensure sustainability in defense system development [34]. MEF Phase III aims to enhance Indonesia's defense capabilities through the modernization of primary weapons systems (alutsista), the development of defense technology, and the enhancement of local industrial capacity. By focusing on self-sufficiency in defense equipment production, this program not only contributes to national security but also encourages economic growth through job creation and skills development in the defense industry sector [35]. Furthermore, MEF Phase III also includes collaboration with various parties, including research institutions and universities, to create innovations relevant to defense needs. Through this approach, Indonesia strives to achieve its strategic goal of creating a resilient and sustainable defense force.

The development of the minimum essential force (MEF) is currently in phase III, which is the final stage of fulfilling MEF needs. This stage is projected in the government's medium-term development plan for the 2020-2024 period. The achievement of MEF phase 2 shows that the Indonesian Army has reached 75%, the Indonesian Navy 62%, and the Indonesian Air Force 44%. The defense budget for 2024 is allocated at IDR 43 trillion, but this is down around 16% from 2023 and is still far from the ambitious target of IDR 1,760 trillion by 2024. Defense modernization is crucial because 70% of the TNI's defense equipment is outdated. To achieve the MEF target, Indonesia needs to accelerate modernization with assistance from countries such as France and increase the budget and fulfillment of MEF, especially for the Indonesian Air Force [36].

The MEF achievement that must be achieved in phase III in 2024 requires an achievement of around 47%, but the current phenomenon is that this achievement is difficult to achieve. This is due to various aspects that hinder the development of the MEF, in addition to the factor of the less than optimal supply from the domestic defense industry for the needs of the TNI's defense equipment, geopolitical aspects also contribute to major obstacles in the realization of the MEF, one of which is the storm of the Covid-19 pandemic in 2019-2022 which forced the government to refocus the budget to save the community. The slowing world economy also contributed to the slowdown in the Indonesian economy [37].

CONCLUSION

By systematically following Kotter's eight steps, Indonesia has significant potential to build a national consensus on developing a sustainable defense industry.

In this context, the government, private sector, and civil society must collaborate in formulating policies that not only focus on increasing defense capacity but also address the environmental impacts of these industrial activities.

By integrating sustainability principles into its defense industry development strategy, Indonesia can ensure that national security needs are met without compromising ecosystem health.

For example, the use of environmentally friendly technologies in the production of weapons and military equipment can reduce the carbon footprint and minimize pollution. Furthermore, involving local communities in decision-making processes will help foster a sense of ownership and shared responsibility for environmental sustainability.

Furthermore, the development of a sustainable defense industry can also positively contribute to Indonesia's economic resilience. By focusing investment on green technology and sustainable innovation, the country can create new jobs and increase competitiveness in the global market. Furthermore, diversifying environmentally friendly defense industry products can open new export opportunities and attract foreign investment. Through this approach, Indonesia will not only be able to meet security demands but also strengthen its economic position on the international stage. A strong national consensus on this matter will be the foundation for inclusive and sustainable development in the future..

Strategic Leadership in building national consensus to support the development of a sustainable defense industry in Indonesia is a complex and multidimensional issue. In this context, several recommendations can be identified based on an analysis of the existing literature. These recommendations include:

a. Strategic Leadership must encourage collaboration between the government, the defense industry, and the private sector. This is crucial for creating an ecosystem that supports innovation and investment in defense technology. Through this partnership, resources can be maximized to achieve shared goals.

b. Enhancing human resource capacity through investment in education and training for the defense sector workforce is crucial. Strategic Leadership needs to ensure that training programs are designed to meet industry needs and the latest technological developments.

c. Policies supporting defense industry development must involve various stakeholders, including civil society, academia, and non-governmental organizations. This will help build a strong national consensus and reduce potential conflicts of interest.

d. Strategic Leadership should encourage research and development (R&D) in defense technology with a focus on sustainability.

e. Strategic Leadership needs to emphasize the importance of transparency in decision-making and accountability in the use of state funds related to the defense sector.

f. Holding dialogue forums between the government, industry, and the public will help build a shared understanding of the importance of defense industry development and its challenges.

g. Strategic Leadership must have a long-term vision for the development of the defense industry in Indonesia, including long-term infrastructure and investment planning to ensure sustainability

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A MULTI-CRITERIA DECISION MODEL FOR STRATEGIC ANTI-AIRCRAFT DEFENSE PLANNING AGAINST EMERGING HYBRID THREATS ON NATO'S EASTERN FLANK

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Abstract: *The strategic security environment on NATO's Eastern Flank has undergone fundamental transformation since 2022, marked by the operational integration of unmanned aerial systems (UAS), cruise missiles, ballistic projectiles, and electronic warfare assets within unified hybrid threat architectures. Conventional air defense planning frameworks, predominantly derived from Cold War deterrence paradigms, demonstrate significant analytical deficiencies when confronted with multi-vector, multi-domain aerial threats that simultaneously exploit kinetic, electromagnetic, and cyber vulnerabilities. This study proposes an integrated Multi-Criteria Decision Analysis (MCDA) framework combining the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to support strategic anti-aircraft defense architecture selection under hybrid threat conditions specific to the Eastern European theater. The model operationalizes seven evaluation criteria derived from structured expert elicitation involving fifteen defense planners, military analysts, and systems engineers following a two-round modified Delphi protocol [ICC(2,1) = 0.83, 95% CI: 0.76, 0.89]. AHP-derived criterion weights identify threat coverage (w = 0.260) and electronic countermeasure resistance (w = 0.232) as co-dominant decision parameters, with force multiplier effect (w = 0.160) emerging as a substantively important third factor. TOPSIS ranking yields the layered multi-tier defense architecture as the optimal configuration (C* = 0.875), consistently outperforming single-layer alternatives across all three scenario profiles. Sensitivity analysis across fourteen criterion-weight perturbation configurations confirms ranking robustness. Findings substantiate the strategic imperative of integrated layered defense while revealing that investment in electronic countermeasure resilience and network-centric integration may generate higher marginal capability returns than additional platform acquisition.*

Keywords: *Multi-Criteria Decision Making; Anti-Aircraft Defense; Hybrid Warfare; NATO Eastern Flank; Analytic Hierarchy Process; TOPSIS; Integrated Air and Missile Defense; Strategic Planning*

1. INTRODUCTION

The concept of hybrid warfare — operationally defined as the deliberate, synchronized employment of conventional military force, irregular tactics, information operations, cyber capabilities, and economic coercion to achieve strategic objectives — has shifted from theoretical construct to observable operational reality across the Euro-Atlantic security space [7, 13, 5]. The military conflict initiated by the Russian Federation against Ukraine in February 2022 provided the international defense community with an unprecedented empirical case study in large-scale hybrid air operations, wherein adversarial forces demonstrated the capacity to integrate Shahed-series one-way attack munitions, Kalibr cruise missiles, Iskander ballistic systems, and electronic warfare platforms into coherent offensive campaigns targeting critical infrastructure, military command nodes, and population centers [9, 2].

This operational reality presents a fundamental challenge to air defense planners on NATO's Eastern Flank — comprising Romania, Poland, the Baltic states, Slovakia, Hungary, and Bulgaria — whose force structures and planning assumptions continue to reflect procurement cycles and doctrinal frameworks developed for a qualitatively different threat environment. The NATO Integrated Air and Missile Defense (IAMD) architecture faces significant implementation gaps across Eastern Flank member states, including insufficient SHORAD coverage, limited counter-UAS (C-UAS) capabilities, electromagnetic spectrum management deficiencies, and procurement cycles that fail to align with the tempo of adversarial technological adaptation [15, 4].

The strategic planning challenge is compounded by the multi-dimensional nature of hybrid aerial threats, which do not conform to the scalar parameters — altitude band, speed, radar cross-section — that traditionally define air defense threat taxonomies. UAS swarm attacks exploit detection thresholds; electronic warfare disrupts fire control; cyber intrusions degrade command-and-control; simultaneous employment of high-value ballistic missiles alongside low-cost munitions forces defenders into economically unsustainable exchange-rate dynamics [6]. No single-platform or single-layer air defense architecture provides adequate coverage across this threat spectrum.

Against this backdrop, optimizing strategic anti-aircraft defense architecture — balancing capability requirements, interoperability constraints, resource limitations, and operational sustainability — constitutes a complex multi-criteria decision problem. Multi-Criteria Decision Analysis (MCDA) methodologies, particularly the Analytic Hierarchy Process (AHP) introduced by Saaty [22] and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang and Yoon [8], have demonstrated utility in defense acquisition and strategic resource allocation [24, 3]. Their structured application to strategic air defense architecture selection in the hybrid threat context specific to NATO's Eastern Flank remains analytically underdeveloped.

This paper addresses that gap through the development, operationalization, and validation of an integrated AHP-TOPSIS decision framework calibrated to the hybrid threat environment of Eastern Europe. The model is designed not as a replacement for human strategic judgment but as a structured, evidence-based analytical instrument that enhances decision quality and provides a replicable framework for recurring defense planning cycles.

2. LITERATURE REVIEW

2.1 Hybrid Warfare and the Aerial Threat Dimension

The academic discourse on hybrid warfare has evolved considerably since Hoffman's [7] conceptualization of 'hybrid threats' as blended combinations of regular forces, irregular forces, and criminal entities operating simultaneously across the full spectrum of conflict. Subsequent scholars have criticized the 'hybrid' designation for conflating operationally meaningful distinctions between threat vectors [14, 21]. This critique carries particular weight in the air defense domain, where threat taxonomy — altitude, velocity, radar cross-section, flight trajectory — remains operationally foundational even as adversarial integration of diverse aerial platforms creates novel combined-arms problems.

Galeotti [5] provides the most operationally current analysis of Russian hybrid warfare doctrine, demonstrating that Russian planners deliberately calibrated their aerial campaign to exploit the seams between SHORAD, medium-range, and theater-level air defense systems.

This exploitation-of-seams doctrine directly challenges air defense architectures designed around discrete engagement envelopes rather than integrated, overlapping coverage zones. Bronk et al. [2] and IISS [9] provide data-rich documentation of hybrid aerial threat capabilities as demonstrated in the Ukrainian theater, revealing that adversarial hybrid air campaigns are characterized by volume, persistence, and coordination rather than technological superiority — a finding with profound implications for architecture optimization.

2.2 Air Defense Systems Analysis and NATO IAMD

The academic literature on air defense systems analysis reflects a persistent divide between technically-oriented studies focused on engagement geometry and sensor-to-shooter timelines, and strategic-level analyses concerned with force structure, deterrence credibility, and alliance burden-sharing. Karako and Dahlgren [10] provide a rigorous assessment of the NATO IAMD architecture, identifying critical capability shortfalls in short-range defense, C-UAS integration, and cross-national command connectivity. Harrison et al. [6] demonstrate mathematically that under certain salvo-rate conditions, even technically superior air defense systems can be defeated through exchange-rate exhaustion — establishing that economic sustainability is an operational variable, not merely a procurement consideration. The European Defence Agency [4] documents significant heterogeneity in capability, doctrine, and interoperability standards among EU member states, constituting a structural constraint on Eastern Flank defense planning.

2.3 Multi-Criteria Decision Making in Defense Applications

Saaty's AHP [22] and Hwang and Yoon's TOPSIS [8] remain the most widely employed MCDM methods in defense contexts. Their integration — using AHP for criterion weighting and TOPSIS for alternative ranking — has established a methodological precedent in defense procurement and systems analysis [24, 3]. Şimşek et al. [24] demonstrate AHP-TOPSIS applicability for military system alternatives evaluation under intuitionistic fuzzy conditions. Wang and Elhag [26] advance fuzzy AHP foundations for decision environments with inherent epistemic uncertainty. Özdağoğlu and Özdağoğlu [19] confirm AHP-TOPSIS robustness in multi-stakeholder, high-consequence settings. Kılıç and Çağlayan [11] apply AHP to air defense positioning decisions, while Yıldız et al. [28] employ integrated MCDM approaches for C-UAS evaluation — both confirming methodological applicability but remaining limited to tactical-operational scopes.

The TOPSIS method's selection over alternatives such as VIKOR or ELECTRE is grounded in its axiomatic properties: it assumes a linear utility function and Euclidean distance from ideal solutions, appropriate for defense architecture decisions where performance improvements on each criterion are uniformly valued and where the distance from an aspirational ideal is a meaningful operational concept.

2.4 Critical Synthesis

The reviewed literature reveals productive but fragmented analytical progress. Hybrid warfare scholars provide operationally rich threat characterizations but limited planning frameworks. Air defense analysts offer technically rigorous system assessments but insufficient strategic integration. MCDM researchers demonstrate methodological sophistication but apply it predominantly to tactical procurement rather than strategic architecture decisions. No existing study integrates hybrid threat characterization, NATO IAMD requirements, and scenario-sensitive multi-criteria strategic decision modeling within a unified, empirically grounded framework for the Eastern Flank context. This integration constitutes the specific contribution of the present research.

3. RESEARCH GAP AND RESEARCH QUESTIONS

No existing study provides a structured, empirically calibrated multi-criteria decision framework for strategic air defense architecture selection that simultaneously: (a) operationalizes hybrid threat characteristics as quantifiable decision criteria; (b) accommodates NATO interoperability requirements as a structural constraint; (c) integrates scenario-based threat variability through differentiated criterion weighting; and (d) addresses the specific geopolitical and operational context of NATO's Eastern Flank. Prior work by Kılıç and Çağlayan [11] and Yıldız et al. [28] demonstrates MCDM applicability in adjacent areas, but neither addresses strategic architecture selection at the campaign level, nor incorporates scenario-dependent criterion weight variability.

Furthermore, existing MCDM applications do not confront the specific challenge posed by hybrid threats: that the relative importance of decision criteria is itself scenario-dependent. A robust model must accommodate this criterion-weight variability through scenario-based sensitivity analysis. This study is guided by four primary research questions:

RQ1: Which evaluation criteria most significantly determine the strategic effectiveness of anti-aircraft defense architectures under hybrid threat conditions on NATO's Eastern Flank?

RQ2: How do criterion weights vary across qualitatively distinct hybrid threat scenarios, and what are the implications for strategic defense planning?

RQ3: Which strategic air defense architecture alternative achieves the highest composite performance score under aggregated hybrid threat conditions, and how sensitive is this ranking to scenario-specific criterion weighting?

RQ4: What decision-support framework can inform NATO IAMD architecture development and national defense procurement planning on the Eastern Flank?

4. METHODOLOGY

4.1 Research Design

This study employs a quantitative, model-based research design integrating structured expert elicitation with AHP for criterion weighting and TOPSIS for alternative ranking [22, 8]. The methodological integration is appropriate for defense planning contexts characterized by incommensurable criteria, multiple stakeholder perspectives, and high-consequence outcomes [24, 3]. The design incorporates three distinct hybrid threat scenarios to address criterion-weight scenario-dependency identified in the research gap analysis.

4.2 Expert Panel and Elicitation Protocol

Criterion weight elicitation was conducted through a structured expert panel comprising fifteen subject matter experts drawn from three professional categories (Table 1). Pairwise comparison judgments were elicited using Saaty's [22] nine-point scale through a structured questionnaire administered in two rounds following a modified Delphi protocol. Inter-round feedback was provided as a summary of mean group judgments and individual consistency ratios, enabling expert reflection without social conformity pressure.

Convergence results: Round 1 mean CR = 0.074 (range: 0.039–0.118); three experts exceeded the CR = 0.10 threshold. Round 2 mean CR = 0.041 (range: 0.021–0.087); zero experts exceeded the threshold. Mean proportion of pairwise comparisons changed by one or more scale points between rounds: 8.3%. Inter-rater reliability: ICC(2,1) = 0.83 [95% CI: 0.76, 0.89], indicating good-to-excellent agreement [12]. Mean pairwise comparison values were aggregated using the geometric mean method [1].

Table 1. Expert Panel Composition

Category	n	Professional Profile	Experience	Geographic Representation
A: Military	7	Active/recently retired air defense officers	15–32 years	4 NATO Eastern Flank states; 2 other NATO; 1 EAPC partner
B: Analytical	5	Defense analysts and researchers	8–22 years	3 NATO-affiliated research institutions; 2 academic centers
C: Technical	3	Systems engineers, procurement specialists	12–25 years	2 government defense agencies; 1 defense industry (conflict-of-interest screened)

4.3 Criteria Definition and Behavioral Anchoring

Seven evaluation criteria were identified through systematic literature review, expert elicitation, and validation against NATO IAMD planning documents:

- **C1 — Threat Coverage Envelope (TC):** Breadth of threat categories effectively countered, spanning from low-altitude UAS to high-altitude ballistic missiles. [1–2: single threat; 5–6: multi-threat with gaps; 9–10: comprehensive coverage].
- **C2 — System Response Time (RT):** Elapsed time from threat detection through engagement authorization to intercept. [1–2: >180 s; 5–6: 45–90 s; 9–10: <15 s with automated authority].
- **C3 — NATO Interoperability (IO):** Technical and procedural compatibility with Allied systems, including Link 16 connectivity, ACCS integration, and IFF standardization. [1–2: no NATO datalink; 5–6: Link 16 with manual interface; 9–10: full ACCS integration].
- **C4 — Cost-Effectiveness (CE):** Ratio of operational capability to total lifecycle cost. [1–2: very high cost relative to capability; 5–6: within NATO median; 9–10: highly favorable ratio].
- **C5 — Electronic Countermeasure Resistance (ER):** System resilience to EW, including radar jamming, GPS denial, and communications disruption. [1–2: highly vulnerable; 5–6: functional in typical jamming; 9–10: fully spectrum-resilient].
- **C6 — Operational Sustainability (OS):** Capacity to maintain effectiveness over extended engagements. [1–2: <24-hour sustained operations; 5–6: 3–7-day; 9–10: continuous with distributed logistics].
- **C7 — Force Multiplier Effect (FM):** Enhancement of adjacent defense elements through shared situational awareness and networked engagement authority. [1–2: no data-sharing; 5–6: moderate sensor fusion; 9–10: full network-centric operations].

4.4 Alternative Architectures

Four strategic air defense architecture alternatives were defined at campaign-level planning scale:

- **A1 — Enhanced SHORAD Layer (ESL):** High-density short-range coverage integrating MANPAD systems, light autocannon, and dedicated C-UAS effectors. Optimized for UAS and low-altitude cruise missile threats.
- **A2 — Medium-Range Integrated Defense System (MRIDS):** Medium-altitude missile systems with integrated radar and command capability, supplemented by electronic countermeasures.
- **A3 — Long-Range Theater Defense (LRTD):** Extended-range interceptor systems targeting ballistic missiles and high-altitude threats within a theater ballistic missile defense framework.
- **A4 — Layered Multi-Tier Architecture (LMTA):** Integrated deployment of complementary short-, medium-, and long-range systems sharing a common recognized air picture, unified command-and-control, and electronic warfare management. Designed for simultaneous multi-vector engagement.

4.5 AHP Methodology

Following Saaty [22], the AHP weight derivation proceeds through construction of the pairwise comparison matrix A = [aij], where aij represents the relative importance of criterion Ci over Cj.

The Consistency Ratio CR = CI/RI, where CI = (λ max - n)/(n - 1) and RI is the Random Index for matrix order n [22]. CR <= 0.10 is required for acceptable consistency. Table 2 presents the aggregated pairwise comparison matrix and derived weights.

Table 2. AHP Pairwise Comparison Matrix (aggregated expert judgments, geometric mean)

	TC	**RT**	**IO**	**CE**	**ER**	**OS**	**FM**
TC	1	2	3	5	1	3	2
RT	1/2	1	1	3	1/2	2	1/2
IO	1/3	1	1	2	1/2	1	1/2
CE	1/5	1/3	1/2	1	1/5	1/2	1/3
ER	1	2	2	5	1	2	2
OS	1/3	1/2	1	2	1/2	1	1/2
FM	1/2	2	2	3	1/2	2	1

Table 3. AHP-Derived Criterion Weights

Criterion	**Row Product**	**Geometric Mean**	**Weight (w_i)**	**Rank**
C1 — Threat Coverage Envelope (TC)	180.000	2.0998	0.260	1
C5 — ECM Resistance (ER)	80.000	1.8701	0.232	2
C7 — Force Multiplier Effect (FM)	6.000	1.2917	0.160	3
C2 — Response Time (RT)	0.750	0.9597	0.119	4
C3 — NATO Interoperability (IO)	0.167	0.7742	0.096	5
C6 — Operational Sustainability (OS)	0.083	0.7012	0.087	6
C4 — Cost-Effectiveness (CE)	0.001	0.3784	0.047	7

4.6 TOPSIS Methodology

The TOPSIS procedure follows Hwang and Yoon [8]. Let J+ denote the index set of benefit criteria (higher score preferred). In this application all seven criteria are benefit criteria (J+ = {TC, RT, IO, CE, ER, OS, FM}). Steps: (1) construct decision matrix X = [xij]; (2) normalize rij = xij; (3) weight vij = wj* *rij; (4) determine positive ideal A+ and negative ideal A- ; (5) compute Euclidean separations Si+ and Si-; (6) compute relative closeness Ci* = Si- , where 0 <= Ci* <= 1.

4.7 Scenario Definition and Weight Adjustment

Three hybrid threat scenarios were defined from documented operational patterns. Scenario-differentiated weight vectors were derived by applying theoretically justified scaling factors to the baseline vector, then renormalizing to unit sum. **S1 — Ballistic-Dominant:** TC and ER receive increased weight (x 1.12 each); RT and FM reduced (x 0.80). **S2 — UAS-Dominant:** RT and ER increased (x 1.40 and x 1.15 respectively); TC reduced (x 0.80). **S3 — Multi-Domain Saturation:** FM increased (x 1.25); IO and OS moderately increased (x 1.15 and x 1.10). Table 4 presents all four weight vectors.

Table 4. Scenario-Differentiated AHP Weight Vectors

Criterion	**Baseline**	**S1 — Ballistic**	**S2 — UAS**	**S3 — Multi-Domain**
TC	0.260	0.290	0.203	0.244
RT	0.119	0.095	0.163	0.112
IO	0.096	0.096	0.094	0.103
CE	0.047	0.047	0.037	0.044
ER	0.232	0.259	0.261	0.218
OS	0.087	0.087	0.085	0.090
FM	0.160	0.127	0.156	0.188
Sum	1.001	1.001	0.999	0.999

5. RESULTS

5.1 Decision Matrix

Expert panel assessments of each alternative against each criterion were aggregated on a 1–10 performance scale. Each panelist scored all alternatives against all criteria independently in Round 2 of the Delphi process, using the behavioral anchoring descriptors from Section 4.3. Table 5 presents the mean scores across panelists.

Table 5. Raw Decision Matrix (expert-elicited, 1–10 scale, post-Delphi Round 2 means)

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	6	8	5	8	4	7	5
A2 (MRIDS)	7	7	7	6	6	7	6
A3 (LRTD)	8	5	6	4	8	6	8
A4 (LMTA)	9	7	9	5	8	8	9

5.2 TOPSIS Step-by-Step Computation (Baseline Weights)

Table 6. Normalized Decision Matrix (r_ij)

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	0.3956	0.5851	0.3618	0.6737	0.2981	0.4975	0.3484
A2 (MRIDS)	0.4616	0.5119	0.5065	0.5053	0.4472	0.4975	0.4181
A3 (LRTD)	0.5275	0.3657	0.4342	0.3368	0.5963	0.4264	0.5574
A4 (LMTA)	0.5934	0.5119	0.6512	0.4211	0.5963	0.5686	0.6271

Table 7. Weighted Normalized Matrix (vij), Positive Ideal (A+) and Negative Ideal (A-)

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	0.1029	0.0696	0.0347	0.0316	0.0690	0.0432	0.0557
A2 (MRIDS)	0.1200	0.0609	0.0486	0.0237	0.1036	0.0432	0.0669
A3 (LRTD)	0.1372	0.0435	0.0416	0.0158	0.1381	0.0370	0.0892
A4 (LMTA)	0.1543	0.0609	0.0625	0.0198	0.1381	0.0494	0.1003
A+ (PIS)	0.1543	0.0696	0.0625	0.0316	0.1381	0.0494	0.1003
A- (NIS)	0.1029	0.0435	0.0347	0.0158	0.0690	0.0370	0.0557

Note: A4 attains PIS on TC, IO, OS, and FM; A3 ties A4 at PIS on ER; A1 attains PIS on RT and CE.

Table 8. Separation Measures and TOPSIS Closeness Coefficients (Baseline)

Alternative	S+	S-	C*	Rank
A1 (ESL)	0.1011	0.0312	0.236	4
A2 (MRIDS)	0.0621	0.0470	0.431	3
A3 (LRTD)	0.0440	0.0844	0.657	2
A4 (LMTA)	0.0147	0.1032	0.875	1

Final baseline ranking: A4 (LMTA) > A3 (LRTD) > A2 (MRIDS) > A1 (ESL).

5.3 Scenario-Specific Results

Table 9 presents TOPSIS closeness coefficients across the three hybrid threat scenarios.

Table 9. Scenario-Differentiated TOPSIS Closeness Coefficients

Alternative	Baseline	S1 — Ballistic	S2 — UAS	S3 — Multi-Domain	Rank (all scenarios)
A4 (LMTA)	0.875	0.889	0.876	0.882	1
A3 (LRTD)	0.657	0.693	0.657	0.653	2
A2 (MRIDS)	0.431	0.439	0.459	0.418	3
A1 (ESL)	0.236	0.194	0.269	0.225	4

Key observations: (i) A4 maintains first rank across all scenarios (C = *0.875–0.889), demonstrating exceptional robustness. (ii) The margin between A3 and A2 contracts by 22% when shifting from ballistic-dominant (gap = 0.254) to UAS-dominant conditions (gap = 0.198), driven by A3's low RT score (5/10) becoming more penalizing as RT weight rises from 0.119 to 0.163. (iii) A1 performs relatively better under S2 (C* = 0.269 vs. 0.194 under S1), reflecting that SHORAD-optimized architectures derive proportional benefit from UAS-dominant threat environments.

5.4 Sensitivity Analysis

A one-at-a-time criterion weight perturbation of +/-20% was applied to each of the seven baseline weights, generating 14 test configurations (7 criteria x 2 directions). In all 14 configurations, A4 maintained the top-ranked position. The smallest observed margin between A4 and A3 occurred when TC weight was reduced by 20% combined with CE weight increased by 20% — under this configuration, A4 C = *0.849 versus A3 C* = 0.678 (gap: 0.171). The ranking A4 > A3 > A2 > A1 was maintained in all 14 configurations, confirming the recommendation's robustness.

6. DISCUSSION

6.1 Interpretation of the Co-Dominant Weight Structure

The AHP-derived weight vector yields a finding of theoretical and practical significance: electronic countermeasure resistance (w = 0.232) is effectively co-dominant with threat coverage (w = 0.260), together accounting for 49.2% of total decision weight. Force multiplier effect (w = 0.160) ranks third — substantially above response time (w = 0.119) and far above cost-effectiveness (w = 0.047). This weight structure challenges prevailing procurement frameworks that tend to emphasize kinetic engagement capability and unit cost as primary evaluation parameters [6, 10].

The expert panel's elevation of ER to near-parity with TC reflects a doctrinal recognition — accelerated by post-2022 operational evidence — that air defense systems unable to survive in a contested electromagnetic environment deliver no operational value regardless of their kinetic intercept capability [2, 9]. The high weight on FM (0.160) reflects a complementary recognition: that networked, sensor-sharing architectures generate emergent capability exceeding the sum of their component contributions. The relatively lower weight on RT (0.119) reflects that modern fire control automation increasingly compresses the human-in-the-loop delay, partially decoupling architecture response time from platform response time.

6.2 Implications of the Layered Architecture Finding

The consistent top-ranked performance of A4 (LMTA) across all scenarios — C* ranging from 0.875 to 0.889 — provides quantitative substantiation for the strategic logic underlying NATO's IAMD conceptual framework [15, 17].

The model reveals that A4's performance advantage is attributable primarily to its systemic properties: the force multiplier effect generated by shared situational awareness and networked engagement authority, and the ER benefits derived from architectural redundancy. This finding aligns with Harrison et al. [6]: modern air defense effectiveness is increasingly determined by integration quality rather than platform-level kinetic performance.

For Eastern Flank member states approaching layered coverage thresholds, the findings suggest that investment in C2 network modernization and interoperability infrastructure may yield higher marginal capability returns per defense euro than additional platform acquisition.

This differentiates states with no layered coverage (platform acquisition priority) from states with partial coverage (integration investment priority).

6.3 The Scenario-Margin Finding

The meaningful variation in the A3-A2 performance margin across scenarios — from 0.254 under ballistic-dominant to 0.198 under UAS-dominant — carries practical planning implications. A defense planner in a predominantly UAS-threat environment faces a 22% smaller performance differential between long-range theater defense and medium-range integrated systems. For NATO burden-sharing arrangements, Eastern Flank states should differentiate their architecture investments based on their specific threat exposure profile. States facing primarily ballistic threats realize greater relative benefit from A3-type capabilities than states primarily exposed to UAS saturation campaigns. The present framework can be adapted to individual national contexts by adjusting the scenario weight vectors to reflect country-specific intelligence assessments.

6.4 Limitations of the Expert Elicitation Approach

The AHP weight elicitation is subject to limitations that appropriately bound results. Geometric mean aggregation assumes independence between expert assessments, which may not fully hold where panelists share institutional formation. The modified Delphi protocol partially mitigates anchoring effects through structured inter-round feedback, but residual conformity effects cannot be fully excluded. The dual role of experts — providing both criterion weights and alternative performance scores — introduces potential for self-consistent but collectively biased results. Future research should separate the weighting panel from the scoring panel, or replace expert-scored alternative assessments with empirical performance data from documented procurement specifications.

7. CONCLUSIONS

This study developed, operationalized, and validated an integrated AHP-TOPSIS multi-criteria decision model for strategic anti-aircraft defense architecture selection under hybrid threat conditions on NATO's Eastern Flank. Four primary conclusions emerge.

First, criterion weighting through structured expert elicitation identifies electronic countermeasure resistance (w = 0.232) as co-dominant with threat coverage (w = 0.260) in hybrid threat environments, collectively accounting for 49.2% of total decision weight. Force multiplier effect (w = 0.160) ranks third. This finding challenges conventional procurement frameworks that prioritize kinetic performance metrics.

Second, the Layered Multi-Tier Architecture achieves consistent first-ranked performance across all three hybrid threat scenarios and all fourteen sensitivity configurations (C* = 0.875–0.889), significantly outperforming single-layer alternatives.

Third, the performance margin between long-range theater defense (A3) and medium-range integrated systems (A2) contracts by 22% when the threat environment shifts from ballistic-dominant to UAS-dominant conditions. Architecture decisions optimized exclusively for ballistic threats accept reduced efficiency against UAS-dominated campaigns.

Fourth, the force multiplier criterion's high weight (0.160) and A4's PIS-attaining FM score indicate that investment in interoperability infrastructure and networked C2 may generate higher marginal capability returns than additional platform procurement for states that have already achieved partial layered coverage. The proposed framework provides a replicable, transparent decision-support instrument that can be institutionalized within national defense planning cycles and NATO force planning processes.

8. POLICY IMPLICATIONS AND DECISION-SUPPORT PATHWAY

The analytical outputs translate into a structured decision-support pathway comprising three stages:

Stage 1 — Threat Profile Assessment: Using national intelligence assessments and NATO threat analyses, defense planners establish the relative frequency and severity of each scenario profile for their specific geographic exposure, generating a scenario-weighted composite weight vector.

Stage 2 — Architecture Evaluation: The national-context weight vector is applied to expert-elicited or specification-derived performance scores for candidate architectures, generating TOPSIS closeness coefficients specific to the national planning context.

Stage 3 — Procurement Prioritization: For states whose composite ranking identifies LMTA as optimal but whose current force structure corresponds to A1 or A2: states with only SHORAD should prioritize medium-range integration before theater defense; states with medium-range systems should prioritize C2 network investment and ER enhancement before additional platform acquisition. This pathway acknowledges that the model's absolute recommendation (LMTA is optimal) does not prescribe the same procurement sequence for all Eastern Flank states.

9. LIMITATIONS

Several limitations merit acknowledgment. The expert panel does not constitute a probabilistic sample of the full population of air defense planning expertise. The four strategic architecture alternatives are conceptual archetypes rather than specific fielded systems, limiting direct applicability to specific procurement decisions involving systems such as PATRIOT, NASAMS, IRIS-T SLM, or current SHORAD variants. The three hybrid threat scenarios cannot exhaustively represent the full spectrum of adversarial options available to sophisticated state actors. The TOPSIS method's assumption of linear utility may not capture threshold effects in air defense performance — for example, the non-linear degradation of system effectiveness under simultaneous ECM and kinetic attack. Finally, the dual-expert design introduces potential circularity that future research should address through panel separation or empirical data substitution.

10. FUTURE RESEARCH DIRECTIONS

Several directions emerge directly from the study's findings and limitations. First, extension to fuzzy AHP-TOPSIS would enable more realistic representation of expert judgment uncertainty, producing confidence-bounded rankings rather than point estimates. Second, application of System Dynamics modeling would simulate the temporal evolution of architecture effectiveness under sustained hybrid campaigns, complementing the static evaluation framework. Third, extension to the Alliance-level burden-sharing optimization problem — analyzing how Eastern Flank states can collectively achieve optimal scenario robustness through differentiated architecture specialization — represents a high-value research direction with direct policy applicability. Fourth, replacement of expert-scored alternative performance values with empirical data from documented system specifications would substantially increase reproducibility. Fifth, validation through structured war-gaming exercises with operational air defense units would provide empirical testing of the model's decision-support value under conditions of operational stress and information uncertainty.

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