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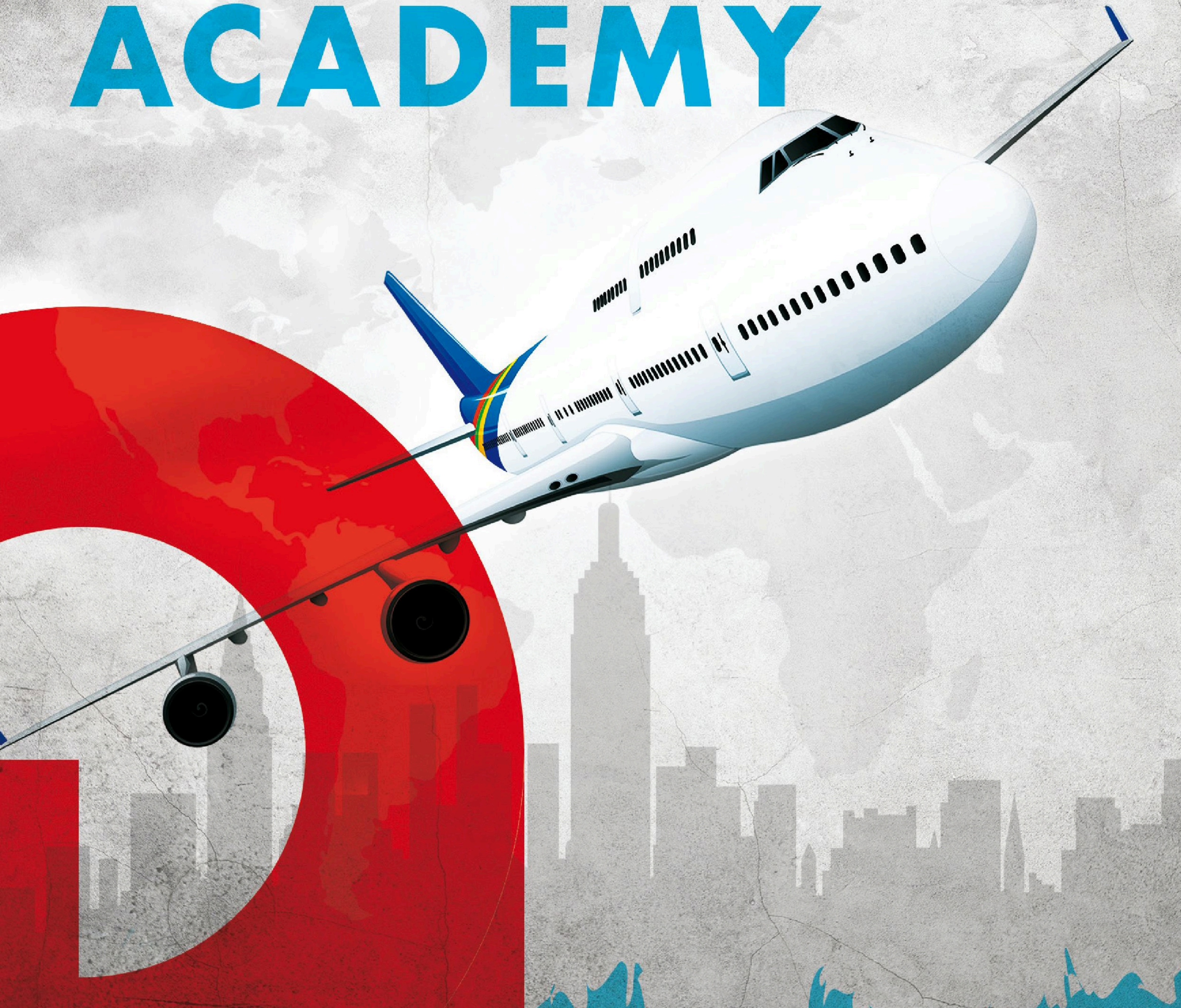

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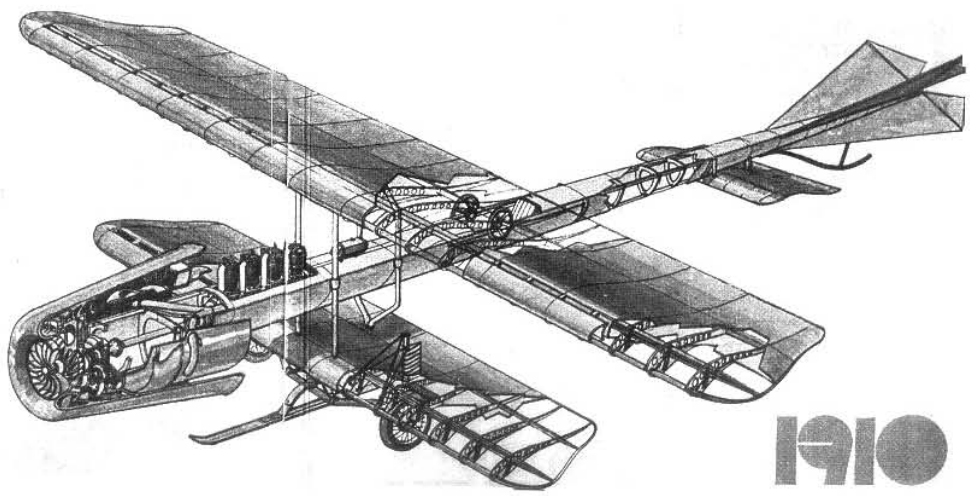

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C O N T E N T S

USE AND ADAPTATION OF CLASSIC ANTI-AIRCRAFT MISSILE SYSTEMS AGAINST DRONES

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Abstract: *The significant increase in the use of drones for military and civilian purposes has required the development of advanced solutions to counter them. Anti-aircraft missiles have become an essential defense tool due to their ability to detect, track and neutralize small and highly maneuverable aerial vehicles. However, their use presents limitations, such as high costs compared to the price of drones, low effectiveness against swarms and difficulties in detecting small or fast drones. In this context, the adaptation of classic anti-aircraft missile systems includes the modernization of short-range missiles, integration with advanced radars and sensors, the use of multi-layer systems and the development of more economical solutions. These measures contribute to optimizing the cost-effectiveness ratio and increasing the defense capacity against asymmetric aerial threats posed by drones.*

Keywords: *UAV, anti-aircraft missiles, drone swarms, hypervelocity missiles …*

1. INTRODUCTION

The rapid growth of drone use, both for military and civilian purposes, has created an urgent need for advanced solutions capable of effectively countering these versatile devices, which are becoming increasingly accessible and sophisticated. In the military, drones are used for reconnaissance, surveillance, intelligence gathering and even precision attacks on strategic targets, reducing the risk to operators and allowing long-range strikes. On the other hand, in the civilian environment, they are used for monitoring critical infrastructure, delivering goods, mapping, but also in illicit activities, such as smuggling or industrial espionage. This rapid expansion of drone use turns them into a complex and difficult-to-manage threat, as they can be launched in large numbers, can be extremely small in size and can operate at variable altitudes, which makes them difficult to detect and neutralize.

In this context, anti-aircraft missiles have emerged as one of the most effective defense options, due to their superior ability to detect, track and neutralize small and highly maneuverable aerial vehicles. These defense systems play an essential role in ensuring the security of critical infrastructure, such as power plants, airports or communication networks, which can be vulnerable to drone attacks. They also contribute to the protection of strategic areas and armed forces, providing a high level of security against increasingly diverse and sophisticated threats. The integration of modern technologies, such as advanced radars and high-precision guidance systems, has considerably increased the efficiency of anti-aircraft missiles, making them capable of responding in real time to critical situations.

2. LIMITS OF THE USE OF ANTI-AIRCRAFT MISSILES AGAINST DRONES

With the increasing use of drones in modern conflicts, anti-aircraft missiles have become a crucial solution for protecting strategic infrastructure, military forces and the civilian population. However, despite their effectiveness, the use of anti-aircraft missiles against drones presents a number of technical, operational and economic limitations that need to be analyzed to improve defense strategies.

1. The high cost of missiles compared to drones

The high cost of missiles compared to drones poses a major challenge in managing military resources, especially in scenarios where drones are used in swarm attacks or as multiple targets. Modern missiles, such as those in the Patriot, S-400 or THAAD systems, which can cost hundreds of thousands or even millions of dollars per unit, are designed to take down complex threats, such as fighter jets or ballistic missiles, and include advanced guidance, propulsion and detection technologies, which justify their high price. On the other hand, drones used in recent conflicts are often simple, mass-produced models with a minimal cost per unit (a few hundred or thousand dollars). This cost-effectiveness asymmetry creates a situation in which adversaries can exploit the drone economy, causing defensive forces to spend disproportionate resources to counter relatively cheap threats. This disproportion makes the use of missiles economically unsustainable in the case of massive attacks.

In the context of modern tactics, a reassessment of the balance between efficiency, costs and strategies is necessary, such as the development of more economical defense systems against drones [1, 2].

2. Low effectiveness against drone swarms

Drone swarms represent a significant innovation in the military field, with the potential to fundamentally change the way air operations are conducted. Consisting of dozens or hundreds of coordinated vehicles, they pose a serious challenge to traditional air defense systems, which are designed to counter individual threats, not mass attacks launched simultaneously. These drones are equipped with advanced sensors and miniaturized warheads, which allows them, at least theoretically, to strike high-value strategic targets, such as radars and surface-to-air missile (SAM) launchers. This capability makes them ideal candidates for suppression of enemy air defenses (SEAD) missions, where they could quickly and effectively neutralize adversary defenses.

A key factor in the operation of these drone swarms is the Global Positioning System (GPS), which provides autonomous navigation and precise position reporting for Mini/Micro-Aerial Vehicles (MAVs). These technologies allow for precise coordination between drones, increasing their operational efficiency and reducing the need for direct human intervention [3].

Figure 1 graphically presents some possibilities for using drone swarms in SEAD (Suppression of Enemy Air Defences) missions.

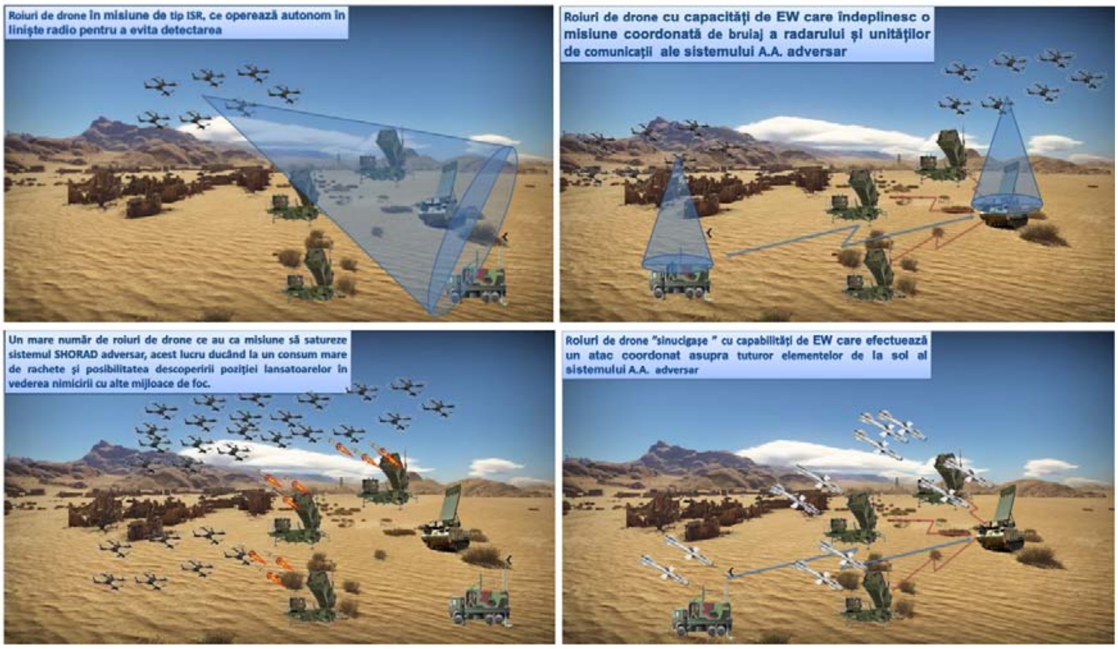

FIG. 1 Possibilities of using drone swarms in SEAD missions

Although some systems can intercept multiple targets simultaneously, the density of swarm attacks can overwhelm defenses. This is compounded by the fact that some drones in the swarm can act as decoys, distracting defenses from more dangerous targets.

3. Difficulties in detecting small, fast drones

Small drones, operating at low altitudes and with low radar signatures, are difficult to detect with conventional radar systems. Small, fast drones pose a major challenge to air defense systems due to the following characteristics that allow them to evade detection and interception:

- Low altitude and small size: Small drones frequently operate at very low altitudes, which allows them to slip through natural or urban obstacles, thus reducing the effectiveness of traditional radar systems. Their small size also contributes to minimal radar reflection, making them difficult to identify in a timely manner.

- Advanced Stealth Technologies: Modern drones are often equipped with stealth technologies that reduce their thermal and acoustic signature. These measures counteract traditional sensors, such as radar or infrared systems, which rely on detecting the heat emitted or the sound produced by engines.

- Confusion with other small objects in the air: Conventional radars can confuse small drones with other objects, such as birds, making it difficult to clearly identify real threats. This confusion can lead to operational errors and inefficient use of defensive resources.

- The constant evolution of drones: As technology advances, drones are becoming increasingly sophisticated, integrating new methods of avoiding detection, such as radar-absorbing materials or flying in formations that disrupt radar operation. [4].

4. Constraints related to range and reaction speed

Anti-aircraft missiles are primarily designed to intercept targets at medium to long altitudes and distances. Drones, on the other hand, can operate very close to the ground, in tight spaces, or near urban areas, which limits the effectiveness of missiles. Also, fast and maneuverable drones can sometimes exceed the reaction time of air defense systems.

At the same time, this characteristic significantly complicates the process of tracking and interception, since many defense systems are optimized for targets with more predictable trajectories [5].

5. Vulnerability to electronic and cyber attacks

Sophisticated drones can use electronic countermeasures to jam radar systems or missile guidance. Furthermore, cyberattacks on air defense systems can compromise their effectiveness, allowing drones to evade interception.

6. Logistics and recharging issues

In the event of sustained attacks with a large number of UAVs, anti-aircraft missile stocks can be quickly depleted, creating a significant vulnerability in air defense. Reloading missile launchers is not an instantaneous process, requiring time, logistical resources, and effective coordination to transport and distribute new ammunition to combat units.

In addition, the infrastructure required to store and transport anti-aircraft missiles can become a strategic target for adversaries, increasing logistical difficulties. If supply routes are compromised or if there are limitations in the production and delivery of these weapons, defense capabilities can be severely affected.

This logistical vulnerability can be exploited by adversaries by launching successive and prolonged attacks, designed to force the rapid consumption of anti-aircraft ammunition. In addition, enemy tactics may include the use of cheaper and more numerous UAVs to exhaust defense resources, followed by attacks with more advanced drones or other means of striking, taking advantage of any gaps created [6, 7].

3. USE AND ADAPTATION OF CLASSIC ANTI-AIRCRAFT MISSILE SYSTEMS AGAINST DRONES

Although designed to counter large and complex aerial threats, classic anti-aircraft missile systems have undergone modifications and improvements to deal with the threat posed by drones. Here are some ways in which these systems have been adapted:

1. Use of specialized ammunition (particularly hypervelocity missiles): Hypervelocity weapons, such as projectiles or missiles, are similar to conventional weapons, but they fly at a higher speed, leading to increased effectiveness in two ways:

1) A less sophisticated fire control system is required, as the time between launch and impact is less than half the flight time of a conventional missile, eliminating the need for numerous in-flight corrections (the probability that the target will change its elevation, azimuth, and range is reduced). The shorter flight time reduces the probability that the target will successfully evade the projectile by maneuvering. Hypervelocity projectiles also offer significantly greater maximum engagement ranges.

2) Hypervelocity projectiles cause more damage than conventional projectiles of equal size due to their higher penetrating kinetic energy resulting from higher velocities. The kinetic energy of this type of ammunition is approximately four times that of conventional missiles [8].

2. Integration with specialized radars

Traditional radar systems have been upgraded or integrated with high-frequency radars capable of detecting small, fast-moving objects at low altitudes. These radars have specialized algorithms to differentiate between drones and other airborne objects, such as birds.

3. Integration of optical and infrared systems

Drones can have low radar signatures, making them difficult to detect solely by radar.

For this reason, many conventional missile systems have been integrated with optical and infrared systems to detect drones visually or by their heat signatures. These systems work well even in low visibility conditions, such as at night or in adverse weather conditions.

4. Multi-layered defense systems

Conventional missile systems are increasingly integrated into a multi-layered defense that combines missiles with other technologies to provide effective protection against drones. This approach involves the use of multiple types of weapons and sensors, such as automated anti-aircraft guns, jamming systems, and even lasers.

FIG. 2 Graphic representation of a multilayer anti-aircraft missile system with capabilities to combat multiple aerial targets including small drones [9]

5. Modernizing short-range missiles for more cost-effective interception

One of the main challenges in using missile systems against drones is the cost disparity between the anti-aircraft missiles and the intended targets. Currently, many air defense systems use sophisticated missiles, equipped with advanced guidance technologies, high-precision sensors, and complex detection and tracking systems. These missiles, originally intended to intercept fighter jets, ballistic missiles, or other major aerial threats, have high costs, reaching hundreds of thousands or even millions of dollars per launch. In contrast, small drones, increasingly used in modern conflicts, are often much cheaper to manufacture and operate. Some modified commercial drones or small military attack drones can cost several hundred or thousands of dollars, making them an "asymmetric" threat from a financial point of view.

This significant discrepancy between interception costs and target value poses serious problems for traditional air defenses. The repeated use of expensive missiles to shoot down relatively inexpensive drones is not economically sustainable, especially in situations where drones are used in "swarm" tactics to overwhelm air defenses. This attack strategy can lead to rapid depletion of expensive missile stocks and significantly increase operational costs.

To address this problem, militaries are focusing on developing more affordable and cost-effective solutions.

One example is smaller missiles specifically designed to intercept drones. These missiles are simpler, lighter, and use less expensive technology, but are still capable of neutralizing small drones. By reducing the size and complexity of these missiles, their cost of production and operation is greatly reduced, making them a more economically viable solution, saving expensive missiles for major threats such as aircraft or operationally tactical missiles. [11, 12].

FIG. 3 Reprezentarea grafica a unui sistem de lansare multiplu de rachete antiaeriene de mici dimensiuni ce prezinta un cost redus

CONCLUSIONS

Anti-aircraft missiles have proven effective in protecting critical infrastructure and armed forces against drones, significantly contributing to the security of strategic areas. The integration of advanced technologies, such as modern radars and high-precision guidance systems, has considerably increased the ability of these systems to respond to the complex and diversified threats posed by drones.

The use of anti-aircraft missiles against drones presents challenges such as high costs in relation to the value of the targets, the difficulty of countering drone swarms, and logistical problems related to reloading. Also, modern drones with reduced radar signatures and stealth capabilities challenge the detection and interception capacity of these systems.

To deal with new threats, classic anti-aircraft missile systems have been modernized. Smaller and more affordable missiles, high-performance radars, and optical and infrared systems have been implemented. Also, multi-layered defense, which combines missiles with other technologies, such as electronic jamming and laser weapons, offers a more robust solution against drones.

General conclusion: Continuous development and adaptation of anti-aircraft missile systems are essential in the face of the increasing use of drones. A strategic approach that combines economic efficiency, technological modernization and defense diversification can help maintain a balance between security and costs in this dynamic field.

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AERODYNAMIC ANALYSIS ON MANEUVER CONTROL FOR THE MORPHING WING

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Abstract: *The morphing concept has generated emerging technologies in the last decades, from aerodynamic and actuation approaches to advanced materials and artificial intelligence-based control methods that can be used in unmanned aircraft. These approaches can be seen to be focused both on the aerodynamic efficiency and the response speeds of the solutions of the adopted systems. The comparative numerical analyses in the paper consider a series of aspects regarding the translation of the center of pressure and the continuity of the surface, numerical aspects managed by the computational methods of the XFLR5 software tool.*

The article aims to quantify the aerodynamic performance values in the cases of 3D maneuver control of a morphing rectangular wing using the VLM method and the XFLR5 software tool.

Keywords: *morphing wing, aileron, VLM, XFLR5, aerodynamic analysis, NACA 2405*

Acronyms and symbols

c_L ,c_D	*lift and drag coefficient*	c_{mx},c_{my},c_{mz}	*moment coefficients*
c_a, b_a	*Chord and lenght aileron*	δ_A	*Aileron turning angle*
AoA	*Angle of attack*	*BM*	*Bending moment*
CP	*Pressure coefficient*	L_A	*Roll moment*
LLT	*Lifting Line theory*	*S*	*Wing surface*
VLM	*Vortex Lattice Method*	*b*	*Span wing*
V	*Speed*		

1. INTRODUCTION

1.1. General consideration

The morphing concept has generated emerging technologies in recent decades, from aerodynamic and actuation approaches to advanced materials and artificial intelligence-based control methods. These approaches are noted to be focused on both aerodynamic efficiency and response speeds of the adopted system solutions.

According to the literature in the field, aerodynamic analyses regarding maneuver control for biologically inspired morphing wings (variable shape/geometry) are focused on numerical and experimental evaluations regarding the influence of geometry modification on aerodynamic performance and 3D trajectory control capability.

The main objective of the work is to establish the causal link between the 3D deformations of the 3D surface of a rectangular wing and the aerodynamic response (forces and moments) regarding the maneuver control on the 3 axes (roll, pitch, yaw). Objective achieved using the XFLR5 software tool through a series of comparative numerical analyses applied to relatively thin airfoil geometries (NACA 2405 profile).

1.2. Morphing concept

The morphing concept applied to aircraft is treated multidisciplinary in a vast series of authors in recent works, including: *Najmul Mowla et all* in 2025 [1], *Srivastava et all* in 2025 [2], *Majid et all* in 2021 [3], *Pecora et all* in 2021 [4], *Zhu* in 2025 [5], *Chu et all* in 2022 [6], *Dong et all* in 2025 [7], *Budholiya et all* in 2021 [8], *Kabir et all* in 2023 [9] and *Tavarez et all* in 2025 [20].

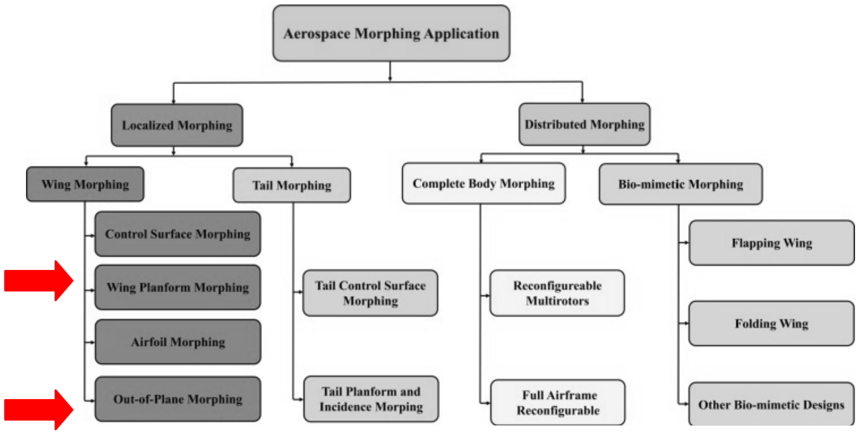


FIG. 1 Morphing classification and application, [1]

A number of recent references outline diverse approaches to evaluating the performance of morphing wings, such as: aerodynamic analyses *Hui et all* in 2020 [10], *Bardera et all* in 2020 [11], *Arai et all* in 2024 [12], *Jini Raj, Bruce* in 2023 [13], *Bardera et all* in 2021 [14], *Abdessemed et all* in 2022 [15], *Negahban et all* in 2024 [16]; experimental analyses *Pan et all* in 2024 [17], *Pecora et all* in 2021 [18], *Zhou et all* in 2022 [19]; use of artificial intelligence *Najmul Mowla et all* in 2025 [1]; actuation methods *Majid et all* in 2021 [3] or aeroelastic *Yuzhu et all* in 2022 [21], *Guo et all* in 2021 [22].

2. THEORETICAL REFERENCES REGARDING AILERON AERODYNAMICS

According to Sadraey 2012 [23], the main function of the ailerons is lateral (roll) control with moment and directional control effects as the ailerons are used symmetrically with different levers, so any change in aileron position/geometry will change the roll rate. The lever deformation of the control surfaces also implies the occurrence of an aerodynamic hinge moment that must be overcome to deform the control surface (the aileron), so a dimensional optimization process is applied to the ailerons to minimize the control forces.

In the process of designing an aileron, a series of parameters are considered (see figure 2), the most relevant being: the aileron area (S_a), the ratio between the chord and the span (length) of the aileron (c_a/b_a), the maximum values of the steering angles (δ_{Amax}) and the aileron position on the span (b_{ai}).

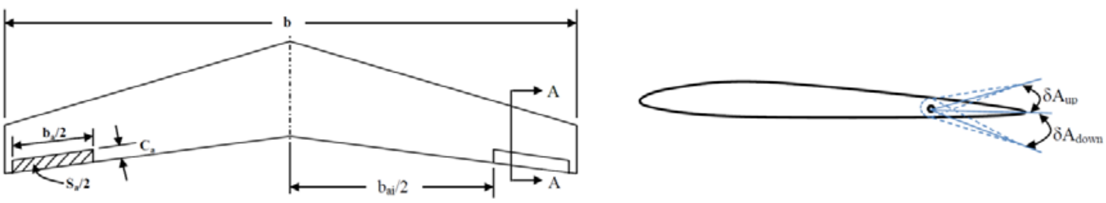


FIG. 2 Aileron geometry, [23]

The maneuverability of an aircraft is a sum of factors considered in the design of the ailerons, such as: the required articulation moment, the effectiveness of the aileron, aerodynamic balancing, the shape (geometry of the ailerons), the type of aircraft structure and the cost of making the ailerons.

As a basic characteristic, the aileron rolling moment (LA) has the equation 1:

$$L_A = 2 \cdot \Delta L \cdot y_A \tag{1}$$

where y_A- the force arm (from the longitudinal axis to the point of application of the force)
ΔL- the variation of the rolling moment

The overall moment on the wing (L_A) is expressed by equation 2:

$$L_A = \frac{1}{2} \cdot \rho \cdot V^2 \cdot S \cdot C_l \cdot b \tag{2}$$

where ρ-air density
V-speed
S- wing surface
C_l- rolling moment coefficient (depending on aircraft configuration)
b- anvewing span

An estimate of the rolling moment (due to lift distribution) for an aileron based on *the strip integration method* has equation 3:

$$\Delta C_l = \frac{C_{LA} \cdot C_a \cdot y_A \cdot dy}{S \cdot b} \tag{3}$$

wheree C_{LA}- the lift coefficient of the section containing the aileron
C_a-aileron chord
y_A- the force arm (from the longitudinal axis to the point of application of the force)
S- wing surface
b- wing span

and the lift coefficient of the section containing the aileron C_{LA} has equation 4:

$$C_{LA} = C_{L\alpha} \cdot \tau_a \cdot \delta_A \tag{4}$$

where $C_{L\alpha}$ – the lift coefficient of the section with the aileron turned
τ_a – aileron effectiveness parameter
δ_A-aileron rotation angle

Figure 3 highlights the dependence of the variation of aileron effectiveness as a function of the ratio between the aileron area (S_a) and the chord of the wing's airfoil (c).

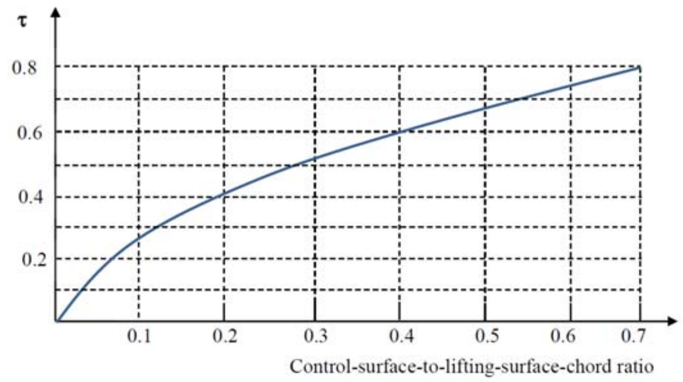


FIG. 3 Aileron efectiveness, [23]

3. LIMITATIONS, METHODS AND SOFTWARE TOOLS

3.1. Limitations of the aerodynamic analyses used

Maneuver control using the morphing concept involves a series of challenges that need to be analyzed, as follows: aerostructural (aeroelastic) coupling regarding aerodynamic deformations coupled with structural deformations, translation of the center of pressure that modifies static stability, 3D surface continuity involving geometric inflections due to the deformation process, response speed that involves dynamic analyses of the actuation systems that determine the 3D deformation of the geometry.

The comparative numerical analyses in the paper consider a series of aspects regarding the translation of the center of pressure and the continuity of the surface, numerical aspects managed by the calculation methods of the XFLR5 software tool. The numerical analyses focus on a series of aerodynamic parameters, such as: the variation of the aerodynamic coefficients of lift Δc_L, and drag Δc_D, the variation of the moment coefficients: pitch Δc_{mx}, roll Δc_{my} and yaw Δc_{mz} and the variation of the aerodynamic smoothness $\Delta c_L/c_D$.

3.2. Vortex Lattice Method

VLM is a numerical method used in fluid mechanics in the pre-design phases of aircraft and in academia. The method models airfoils (wings, empennages) as a thin web of discrete vortices for the calculation of lift and induced drag, the aspects determined by thickness and viscosity being omitted. By simulating the flow field, the pressure and force distribution around the simulated body can be calculated from which the aerodynamic coefficients and their derivatives are extracted for the evaluation of the aircraft's handling qualities in the conceptual design phase.

The VLM method is comprehensively described in a number of aerodynamics works, such as: *Katz & Plotkin* in 2001 [25], *Anderson* in 1991 [26], *Bertin & Smith* in 1998 [27], *Houghton & Carpenter* in 1993 [28], or *Drela* in 2014, [29].

The method is designed on the ideal flow theory (potential flow theory) which neglects the effects of flow viscosity and does not resolve the given aspects of turbulence and boundary layer. It is based on a series of assumptions, the most relevant of which are: the flow field is incompressible, inviscid and irrotational; modeling of compressible subsonic flow with small perturbations with the 3D Prandtl-Glauert transformation; the lifting surfaces are thin, the influence of thickness on aerodynamic forces is neglected; the angle of attack and the glide angle are small.

So the flow field is a conservative vector field, so the local velocity vector (V) is given by equation 5:

$$\boldsymbol{V} = \boldsymbol{V}_\infty + \boldsymbol{\nabla}_{\boldsymbol{\varphi}} \tag{5}$$

where $\boldsymbol{V}_\infty$*- the speed vector of the undisturbed current*

$\boldsymbol{\nabla}_{\boldsymbol{\varphi}}$*- φ satisfies the Laplace equation (2nd order linear equation)*

3.3. XFLR5

It is freeware tool used in the preliminary design phase (based on XFOIL) for 2D and 3D aerodynamic analyses of individual wings and complete aircraft at low Reynolds numbers for gliders, RC models and UAVs. The main modules are:

-2D analysis of wing airfoil through: direct analysis, inverse analysis, aerodynamic airfoil generation and modification, serial analysis;

-3D analysis through geometric modeling of the aircraft, 3D aerodynamic analysis (LLT, VLM, 3D panel method) and aircraft stability analysis;

-visualization and comparison through graphic visualization, flow field visualization.

XFLR5 has a number of limitations, the most relevant being: analyses at low Reynolds numbers and using the incompressible flow assumption (being inaccurate at transonic and supersonic speeds. The XFLR5 instrument user menu includes functions corresponding to the previously described modules, such as: file management commands (new project, open project, insert project save/saveas project), aerodynamic analysis modules (direct/inverse analysis, wing/aircraft design).

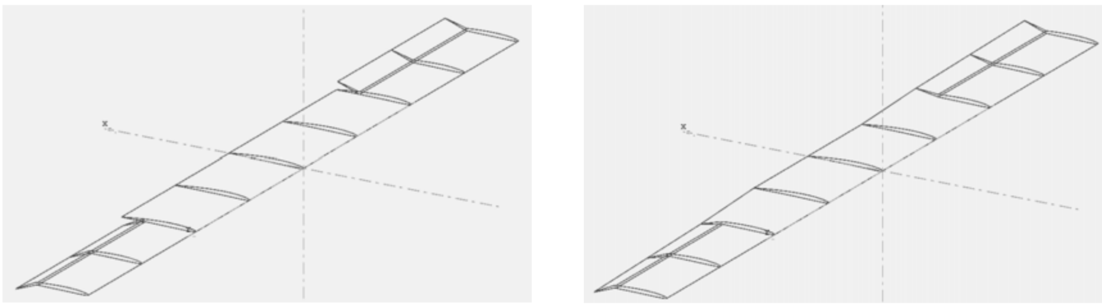
4. 3D COMPARATIVE NUMERICAL ANALYSES

4.1. Methodology and analysis conditions

The objective of the numerical analyses is to highlight the influence of using a morphing lateral maneuver concept (twist wing aileron) for a lifting surface versus the constructive solution with classic ailerons.

Table 1. 3D geometry

Features	Value	Features	Value
Span	2 m	Aspect ratio	10
Chord	0,2 m	Taper ratio	1
Lever Aileron angle	± 20 º	Mesh elements	494 / 416 / 494
Airfoil	NACA 2405		



a b

FIG. 4 Wing geometry for analysis, a. with classic ailerons, b. with morphing ailerons

The analysis objectives are instrumented with XFLR 6.61 applied to a 3D wing geometry in three variants: plank wing, classic ailerons wing and morphing ailerons wing (see table 1 and FIG. 4). The numerical analysis conditions and simulation cases are based on the Vortex Lattice Method (VLM) described in the previous chapter and are indicated in Table 2.

Table 2. Analysis conditions

Condition	Value	Condition	Value
Nr. iteration	100	Analysis method	VLM1
Polar type	Fixed speed	Vortex position VLM	25%
Alpha precision	0,01	Control point position VLM	75%
Speed	10 m/s	AoA	$-15^{o} \div 15^{o}$
Air density	1,225 kg/m^3	Air viscosity	1,5 x 10^{-5} m^2/s

4.2.Results and discussions

The comparative results of the numerical simulations for the 3 geometries are presented in the figures below. All comparative polars indicate the influence of the geometry change on the analyzed angle of attack range.

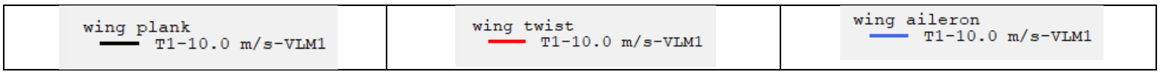
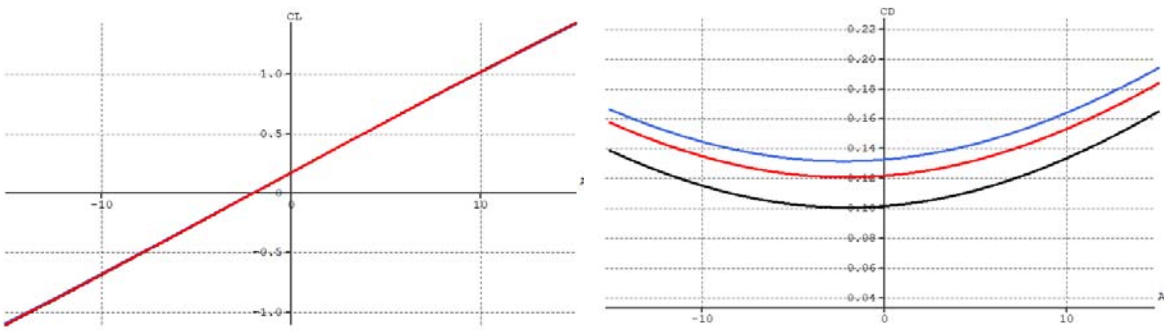


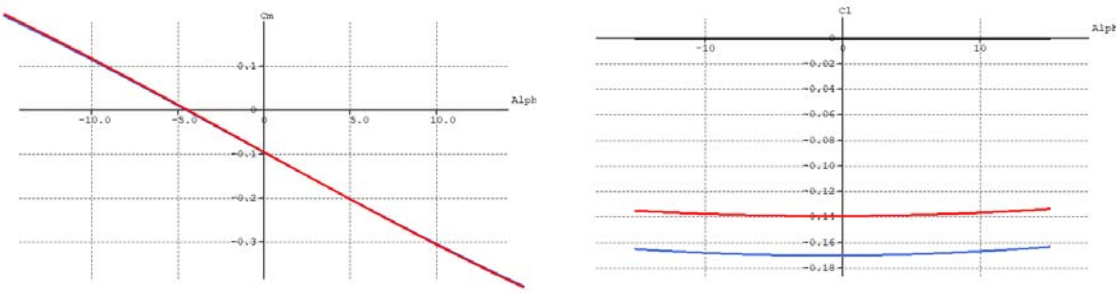
Figure 5a indicates a minimal influence of geometry on the lift coefficient. Figure 5b as expected shows an increase in the drag coefficient C_D for the hinged wing variants.



a b

FIG. 5 Polars C_L și C_D, a. C_L vs AoA, b. C_D vs AoA

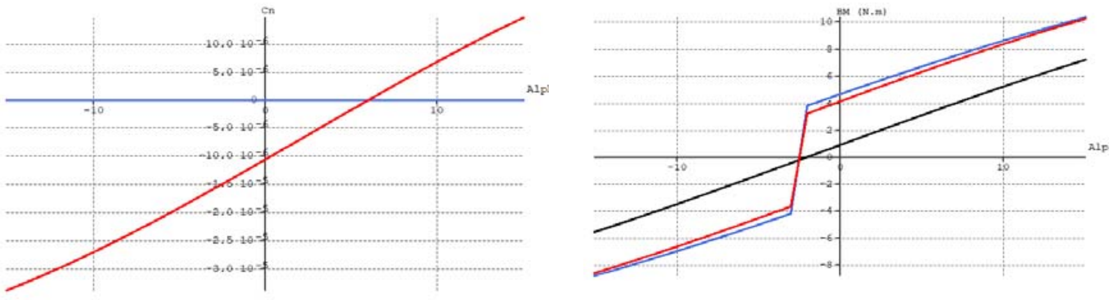
The graph in figure 6a indicates a minimal influence of the geometries with turns on the pitching moment coefficient C_m , while the roll coefficient C_l is higher in the case of classic ailerons (0.17), also noting the efficiency of morphing ailerons at zero angle of attack (0.14).



a b

FIG. 6 Polars C_m și C_l, a. C_m vs AoA, b. C_l vs AoA

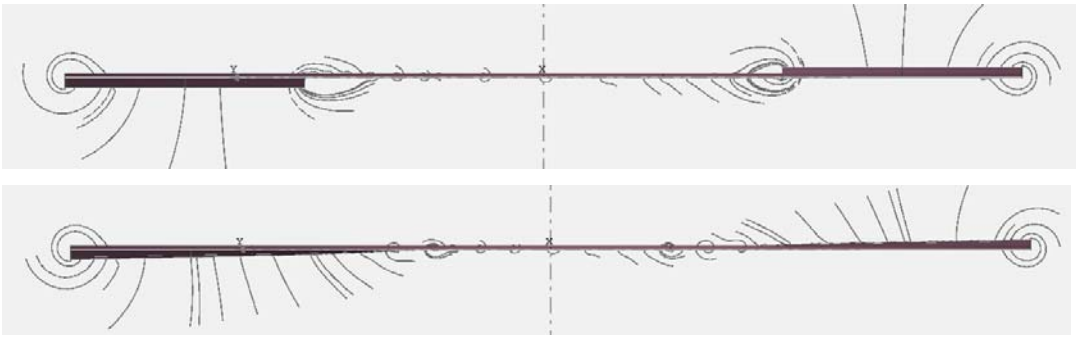
Figure 7a indicates a similar behavior for the roll motion through values of the roll coefficient C_n , and figure 7b shows higher values of the hinge moment (BM) in the case of classical ailerons (over the range AoA =-3°÷3°).



a b

FIG. 7 C_n polar and BM chart, a. C_n vs AoA, b. BM vs AoA

Figure 8 shows the distribution of airfoils for the wing at AoA=0o in the two geometric configurations, we note the reduction of turbulence in the geometric inflection areas of the morphing ailerons (fig. 8b).

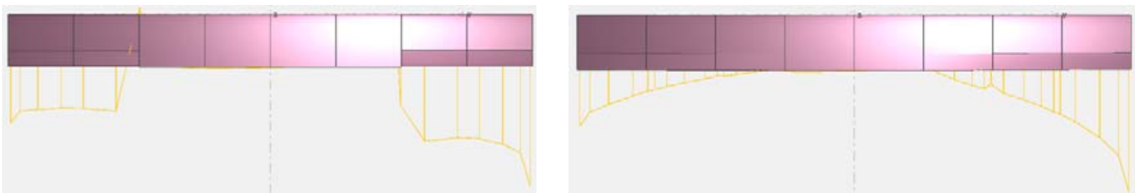


a

b

FIG. 8 Airflow distribution wing, a. classic aileron wing, b. morphing aileron wing

As an additional argument for modifying the drag coefficient (CD) for the two geometries (FIG. 5b) we have differences regarding the induced drag profile for angle of attack AoA= 0o (see FIG. 9).



a b

FIG. 9 Induced drag, a. classic aileron wing, b. morphing aileron wing

The influence on the pressure coefficient (CP) coordinates due to the change in geometry given by the rotations of the classic ailerons vs. morphing is found in the data in table 3, for values at AoA= 0^o, where we have a smaller lateral displacement of the CP for the morphing wing versus the classic aileron wing.

Table 3. CP coordinate

3D geometry	X_{cp} mm	Y_{cp} mm	Z_{cp} mm
Wing plank	112,741	0	3,402
Wing classic aileron	112,064	1986,979	-1,693
Wing morphing aileron	112,185	1641,757	0,146

After the analyses, a lower maneuvering efficiency is observed in the case of the geometry with morphing ailerons, considering the similar extreme rotate angles (±20°). Therefore, a higher steering value of the morphing ailerons or the use of a larger useful area is required, an aspect that is also found in the series of equations exposed in the theoretical chapter. For an evaluation of the aerodynamic qualities of the selected 2D (NACA 2405) and 3D wing geometries, we can also consult the appendix with the numerical simulation values.

CONCLUSION

The paper presented a software analysis case regarding the influence of geometric modifications of the classic/morphing aileron type on the maneuverability of aircraft, a case based on software simulations on a 3D single wing geometry.

The morphing concept used in 3D maneuver cases involves increasing the active area and/or the rotation angle to obtain similar values of the rolling moment as in the case of classic (articulated) ailerons. An advantage of morphing ailerons is the reduction of drag and a minimization of turbulence due to the geometric inflection zones of the ailerons in the near of the unsteering surfaces (see figure 8).

The paperwork can be considered a first step in the study of performance analyses applied to fixed airfoils in the construction of unmanned aircraft with classic or morphing concept maneuvering/control surfaces.

Future analyses can be based on morphing geometries with a higher degree of fidelity and to quantify the effects of using morphing geometries in maneuvering cases, the use of finite element CFD numerical simulations is required for a more accurate visualization of the values of the moment coefficients due to geometric changes.

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APPENDIX

Wing twist

Plane name : wing twist
Polar name : T1-10.0 m/s-VLM1
Freestream speed : 10.000 m/s

alpha	Beta	CL	CDi	CDv	CD	CY	Cl	Cm	Cn	Cni	QInf	XCP
-15.000	0.000	-1.098358	0.057091	0.100091	0.157182	0.000271	-0.135088	0.216685	-0.000034	-0.000034	10.0000	0.0403
-14.000	0.000	-1.016580	0.051857	0.100091	0.151948	0.000263	-0.135654	0.197431	-0.000033	-0.000033	10.0000	0.0394
-13.000	0.000	-0.934220	0.046977	0.100091	0.147068	0.000255	-0.136179	0.177852	-0.000031	-0.000032	10.0000	0.0384
-12.000	0.000	-0.851300	0.042465	0.100091	0.142557	0.000246	-0.136662	0.157973	-0.000030	-0.000030	10.0000	0.0372
-11.000	0.000	-0.767872	0.038338	0.100091	0.138430	0.000238	-0.137104	0.137817	-0.000029	-0.000029	10.0000	0.0358
-10.000	0.000	-0.683984	0.034609	0.100091	0.134700	0.000229	-0.137504	0.117400	-0.000027	-0.000027	10.0000	0.0340
-9.000	0.000	-0.599682	0.031290	0.100091	0.131381	0.000220	-0.137861	0.096770	-0.000026	-0.000026	10.0000	0.0318
-8.000	0.000	-0.515015	0.028393	0.100091	0.128484	0.000210	-0.138177	0.075929	-0.000024	-0.000024	10.0000	0.0288
-7.000	0.000	-0.430031	0.025927	0.100091	0.126018	0.000201	-0.138451	0.054900	-0.000022	-0.000023	10.0000	0.0247
-6.000	0.000	-0.344780	0.023901	0.100091	0.123992	0.000191	-0.138682	0.033736	-0.000021	-0.000021	10.0000	0.0185
-5.000	0.000	-0.259311	0.022321	0.100091	0.122413	0.000182	-0.138871	0.012434	-0.000019	-0.000020	10.0000	0.0082
-4.000	0.000	-0.173674	0.021195	0.100091	0.121286	0.000172	-0.139018	-0.008970	-0.000018	-0.000018	10.0000	-0.0125
-3.000	0.000	-0.087919	0.020526	0.100091	0.120617	0.000162	-0.139122	-0.030451	-0.000016	-0.000016	10.0000	-0.0720
-2.000	0.000	-0.002097	0.020316	0.100091	0.120408	0.000152	-0.139184	-0.051982	-0.000014	-0.000014	10.0000	-5.0398
-1.000	0.000	0.083742	0.020569	0.100091	0.120660	0.000141	-0.139204	-0.073539	-0.000012	-0.000013	10.0000	0.1767
0.000	0.000	0.169547	0.021283	0.100091	0.121374	0.000131	-0.139181	-0.095096	-0.000011	-0.000011	10.0000	0.1122
1.000	0.000	0.255268	0.022458	0.100091	0.122549	0.000121	-0.139115	-0.116626	-0.000009	-0.000009	10.0000	0.0918
2.000	0.000	0.340853	0.024090	0.100091	0.124181	0.000110	-0.139007	-0.138103	-0.000007	-0.000007	10.0000	0.0805
3.000	0.000	0.426253	0.026176	0.100091	0.126267	0.000100	-0.138857	-0.159502	-0.000005	-0.000006	10.0000	0.0743
4.000	0.000	0.511417	0.028710	0.100091	0.128801	0.000089	-0.138664	-0.180798	-0.000004	-0.000004	10.0000	0.0701
5.000	0.000	0.596297	0.031685	0.100091	0.131776	0.000079	-0.138429	-0.201964	-0.000002	-0.000002	10.0000	0.0671
6.000	0.000	0.680842	0.035093	0.100091	0.135184	0.000068	-0.138152	-0.222976	-0.000000	-0.000000	10.0000	0.0649
7.000	0.000	0.765004	0.038925	0.100091	0.139016	0.000058	-0.137832	-0.243807	0.000002	0.000001	10.0000	0.0632
8.000	0.000	0.848735	0.043168	0.100091	0.143259	0.000047	-0.137471	-0.264433	0.000003	0.000003	10.0000	0.0619
9.000	0.000	0.931987	0.047812	0.100091	0.147903	0.000037	-0.137068	-0.284830	0.000005	0.000005	10.0000	0.0608
10.000	0.000	1.014714	0.052842	0.100091	0.152933	0.000027	-0.136622	-0.304973	0.000007	0.000006	10.0000	0.0599
11.000	0.000	1.096870	0.058244	0.100091	0.158335	0.000016	-0.136136	-0.324837	0.000008	0.000008	10.0000	0.0591
12.000	0.000	1.178410	0.064001	0.100091	0.164093	0.000006	-0.135607	-0.344400	0.000010	0.000010	10.0000	0.0585
13.000	0.000	1.259290	0.070098	0.100091	0.170189	-0.000004	-0.135037	-0.363636	0.000012	0.000011	10.0000	0.0579
14.000	0.000	1.339467	0.076516	0.100091	0.176607	-0.000014	-0.134426	-0.382525	0.000013	0.000013	10.0000	0.0575
15.000	0.000	1.418899	0.083235	0.100091	0.183326	-0.000024	-0.133775	-0.401042	0.000015	0.000014	10.0000	0.0571

Wing aileron

Plane name : wing aileron
Polar name : T1-10.0 m/s-VLM1
Freestream speed : 10.000 m/s

alpha	Beta	CL	CDi	CDv	CD	CY	Cl	Cm	Cn	Cni	QInf	XCP
-15.000	0.000	-1.089544	0.065790	0.100098	0.165888	-0.000000	-0.165105	0.212632	-0.000000	-0.000000	10.0000	0.0399
-14.000	0.000	-1.008196	0.060775	0.100098	0.160873	-0.000000	-0.165791	0.193554	-0.000000	-0.000000	10.0000	0.0390
-13.000	0.000	-0.926262	0.056104	0.100098	0.156203	-0.000000	-0.166427	0.174177	-0.000000	0.000000	10.0000	0.0380
-12.000	0.000	-0.843788	0.051794	0.100098	0.151892	-0.000000	-0.167013	0.154502	-0.000000	0.000000	10.0000	0.0368
-11.000	0.000	-0.760818	0.047858	0.100098	0.147957	-0.000000	-0.167547	0.134555	-0.000000	0.000000	10.0000	0.0353
-10.000	0.000	-0.677383	0.044311	0.100098	0.144409	-0.000000	-0.168031	0.114358	-0.000000	-0.000000	10.0000	0.0335
-9.000	0.000	-0.593552	0.041163	0.100098	0.141262	-0.000000	-0.168463	0.093936	-0.000000	-0.000000	10.0000	0.0312
-8.000	0.000	-0.509364	0.038426	0.100098	0.138525	-0.000000	-0.168844	0.073313	-0.000000	-0.000000	10.0000	0.0282
-7.000	0.000	-0.424867	0.036110	0.100098	0.136208	-0.000000	-0.169174	0.052514	-0.000000	0.000000	10.0000	0.0239
-6.000	0.000	-0.340109	0.034221	0.100098	0.134320	-0.000000	-0.169452	0.031564	-0.000000	0.000000	10.0000	0.0175
-5.000	0.000	-0.255139	0.032768	0.100098	0.132867	-0.000000	-0.169678	0.010489	-0.000000	-0.000000	10.0000	0.0070
-4.000	0.000	-0.170007	0.031756	0.100098	0.131854	-0.000000	-0.169853	-0.010687	-0.000000	-0.000000	10.0000	-0.0142
-3.000	0.000	-0.084762	0.031188	0.100098	0.131287	-0.000000	-0.169976	-0.031938	-0.000000	0.000000	10.0000	-0.0780
-2.000	0.000	0.000545	0.031068	0.100098	0.131167	0.000000	-0.170047	-0.053239	-0.000000	-0.000000	10.0000	15.8309
-1.000	0.000	0.085865	0.031397	0.100098	0.131496	0.000000	-0.170066	-0.074564	-0.000000	-0.000000	10.0000	0.1746
0.000	0.000	0.171148	0.032175	0.100098	0.132274	0.000000	-0.170034	-0.095887	-0.000000	-0.000000	10.0000	0.1121
1.000	0.000	0.256344	0.033401	0.100098	0.133499	0.000000	-0.169950	-0.117183	-0.000000	0.000000	10.0000	0.0911
2.000	0.000	0.341403	0.035070	0.100098	0.135169	0.000000	-0.169814	-0.138427	-0.000000	0.000000	10.0000	0.0806
3.000	0.000	0.426276	0.037181	0.100098	0.137279	0.000000	-0.169626	-0.159592	-0.000000	-0.000000	10.0000	0.0743
4.000	0.000	0.510913	0.039726	0.100098	0.139824	0.000000	-0.169387	-0.180654	-0.000000	-0.000000	10.0000	0.0702
5.000	0.000	0.595264	0.042699	0.100098	0.142797	0.000000	-0.169096	-0.201587	-0.000000	-0.000000	10.0000	0.0672
6.000	0.000	0.679283	0.046091	0.100098	0.146190	0.000000	-0.168754	-0.222366	-0.000000	-0.000000	10.0000	0.0649
7.000	0.000	0.762919	0.049894	0.100098	0.149992	0.000000	-0.168360	-0.242967	-0.000000	-0.000000	10.0000	0.0632
8.000	0.000	0.846127	0.054096	0.100098	0.154194	0.000000	-0.167915	-0.263364	-0.000000	-0.000000	10.0000	0.0619
9.000	0.000	0.928860	0.058685	0.100098	0.158783	0.000000	-0.167418	-0.283533	-0.000000	0.000000	10.0000	0.0607
10.000	0.000	1.011070	0.063647	0.100098	0.163745	0.000000	-0.166871	-0.303449	-0.000000	0.000000	10.0000	0.0598
11.000	0.000	1.092718	0.068968	0.100098	0.169067	0.000000	-0.166273	-0.323090	-0.000000	-0.000000	10.0000	0.0591
12.000	0.000	1.173746	0.074633	0.100098	0.174732	0.000000	-0.165624	-0.342431	-0.000000	-0.000000	10.0000	0.0584
13.000	0.000	1.254124	0.080625	0.100098	0.180723	0.000000	-0.164925	-0.361450	-0.000000	0.000000	10.0000	0.0579
14.000	0.000	1.333805	0.086925	0.100098	0.187024	0.000000	-0.164175	-0.380123	-0.000000	0.000000	10.0000	0.0574
15.000	0.000	1.412748	0.093515	0.100098	0.193614	0.000000	-0.163376	-0.398427	-0.000000	-0.000000	10.0000	0.0570

CAPABILITIES TO USE THE UNMANNED WATER VEHICLES IN COMBAT MISSIONS

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Abstract: *Unmanned Water Vehicles represent an essential element in modernizing and increasing the efficiency of naval forces, meeting the requirements imposed by asymmetric threats and the complexity of contemporary operations. In this article, the possible capabilities of using these systems in combat type missions are presented. These autonomous, unmanned systems are categorized by size and type of use and are capable of diverse missions, from surveillance and reconnaissance (ISR) operations to anti-submarine warfare, mine clearance and defense against surface threats. Autonomous systems contribute to precise offensive power design and fleet protection by integrating advanced technologies and state-of-the-art sensors. These systems improve rapid response in critical situations, reduce risks to personnel and enable operations in hostile or inaccessible environments for human crews.*

Keywords: *UWV, USWV, UUWV, naval strike, naval shield, combat missions…*

1. INTRODUCTION

The development of the use of autonomous systems in combat represents a significant transformation in the way military operations are conducted. These systems, powered by advances in artificial intelligence, robotics and advanced sensors, are designed to perform critical missions such as reconnaissance, precision strike, logistics and tactical support. Their use enables the reduction of risks to human troops by providing operational capabilities in dangerous or inaccessible environments. For example, UAVs can perform surveillance or attack missions while autonomous ground vehicles provide equipment transport or logistical support. Autonomous naval systems such as robotic submarines play an important role in maritime defense and monitoring of strategic areas [1].

The development of these technologies has been accelerated by modern military requirements for efficiency, speed of reaction and loss minimization. At the same time, the associated challenges, such as the integration of these systems into existing command structures, the ethics of their use in combat, and protection against cyber-attacks, are essential topics within this technological advance. Thus, autonomous systems are becoming a central pillar of the future of modern warfare, with the potential to fundamentally change the dynamics of military confrontations.

The use of autonomous naval vehicles presents the following advantages:

1. Essential strategic role: Autonomous Water Systems (UWS) are a vital component in the modernization of maritime forces, having the ability to effectively respond to contemporary threats, including asymmetric ones and complex operational environments.

2. Operational Versatility: UWS can perform a wide range of combat-type missions, from ISR and demining, to defense against cyber and physical threats. This adaptability makes them indispensable tools for modern navies.

3. Risk Reduction and Personnel Protection: By eliminating the need for a human crew in hazardous environments, autonomous systems improve personnel safety, reducing the risks associated with operations in hostile areas.

4. Increased efficiency through advanced technology: The use of artificial intelligence, advanced sensors and autonomous capabilities enables rapid detection of threats and accurate reactions, optimizing resources and response time.

5. Littoral operations and defense of strategic resources: Due to increased risks in littoral areas, UWSs play a crucial role in operations such as combating diesel submarines, neutralizing small boat swarms and harbor protection.

6. Complementary offensive and defensive capabilities: Naval autonomous systems can perform both naval strike and naval shield missions, supporting both offensive power projection and defense of fleets and critical assets.

2. UNMANNED WATER VEHICLE IN COMBAT MISSIONS

Broadly speaking, the role of naval forces is to provide credible and sustained sea combat power when and where it is needed. Increased uncertainty about possible threats, the possible locations of attacks, and the means by which they might be carried out have shifted power projection, force protection, and expeditionary operations from global ("blue water") areas to littoral ("brown water" or "green water")[1] [2]. Many future naval combat operations will likely be littoral to project power ashore and provide a defensive umbrella for forces operating ashore. Naval forces are expected to be attacked by diesel submarines, swarms of small boats, and artillery and anti-ship missile batteries, and naval operations are expected to take place in areas planted with surface or depth mines [3].

Thus arose the requirement for new capabilities of the respective naval forces: ISR, bathymetric surveys, battlespace preparation, battlespace awareness, naval surface warfare, ASW (anti-submarine warfare), demining operations, special operations and attack support, A^2/AD (Anti-Access/Area Denial) missions, protection and defense of ports and port facilities against small but fast boats loaded with explosives.

Increasing needs arising from new threats can be mitigated to an increasing extent by exploiting the benefits of unmanned systems [4]**.** In an era where technology is redefining the rules of war, naval drones provide a crucial strategic advantage, supporting naval forces to carry out their missions efficiently and with little impact on human and material resources. The use of naval drones in combat missions has revolutionized the way maritime forces conduct their operations, offering a unique combination of autonomy, versatility and efficiency. These systems, known as Unmanned Water Vehicles (UWS), play a critical role in adapting to the new challenges of modern warfare, characterized by asymmetric threats and complex operational environments. In the context of threats such as diesel submarines, swarms of armed small boats, sea mines and anti-ship missiles, the naval drone becomes an indispensable tool to protect fleets, strategic resources and trade routes.

Naval autonomous systems are used for missions such as mine clearance, anti-submarine warfare, surface target neutralization and defense against cyber and electronic attacks.

[1] Blue water navy - A blue water navy is a maritime force capable of operating globally, essentially over the deep waters of the open oceans, brown - water navy, green - water navy – naval forces on the river and near shore, naval forces close to the shore

By integrating artificial intelligence and advanced sensors, naval drones enable rapid detection and response to threats, reducing risks to human personnel and enabling operations in dangerous or inaccessible environments. This flexibility and adaptability make them key elements for offensive and defensive operations in littoral and offshore regions. Table 1 presents a classification of UWS and their capabilities.

Table 1. Classification of UWS systems [5]

UWS (Unmanned Water Vehicles)	
USWV (Unmanned Surface Water Vehicles)	**UUWV (Unmanned Under Water Vehicles)**
LUWSV (Large UWSV) (Class 4; Length >50m)	XL UWSV(ExtraLarge UWSV) Dia. >84in
MUWSV MediumUWSV (Class 3; 12m ≤ Lungime ≤50m)	LUUWV(Large UUWV) (21in ≤ Dia. ≤84in)
S UWSV (Smal. UWSV) (Class 2; 7m ≤Length>7m and ≤12m)	MUUWV (Medium UUWV) (10≤Dia.≤21in)
VSUWSV (Very Smal. UWSV) (Class 1; Length ≤7m)	SUUWV (Smal UUWV) (3in ≤Dia.≤10in)
They are unmanned surface boats and can be used in a number of missions such as mine clearance missions, ISR, anti-submarine warfare or as fast attack craft.	They are underwater systems used to retrieve objects from the seabed and even to carry out clandestine intelligence missions.

In accordance with the capabilities presented above, the UWS can carry out the following types of combat type missions:

1. Naval strike (offensive operations): is a broad concept for projecting precise and persistent offensive power at sea. Under this concept, networked autonomous naval sensors integrated with national and alliance systems will provide persistent ISR data, enabling the development of a comprehensive understanding of adversary capabilities and vulnerabilities. Tightly integrated with these capabilities, naval forces will be able to strike static or moving targets so as to defeat any plausible enemy force.

2. Naval shield (defensive operations): it is a concept focused on the protection of resources and national interests at sea through defensive operations. Traditionally, navies maintain vital lines of communication at sea, protect their own offensive forces, detect and intercept ships of hostile intent, participate in mine clearance missions, anti-submarine operations, air defense protection missions by providing sensor carrier platforms and even anti-aircraft weaponry [3].

3. NAVAL STRIKE (OFFENSIVE OPERATIONS)

1. C^4ISR missions: cover a wide range of missions related to decision-making, as well as data collection, processing and transmission. Many of these missions must be carried out clandestinely, especially in terms of intelligence gathering. The C4ISR missions, presented in FIG. 1 that can be executed by the UWS include ensuring communications; carrying out the operational order; electronic attack and counter attack; cyber attack; cyber security; developing and maintaining the operational picture; observation and data collection as well as data processing, exploitation and dissemination. Naval drones play a crucial role in achieving these missions, contributing to informed decision-making, reducing risks for personnel and replacing traditional solutions with modern high-precision technologies.

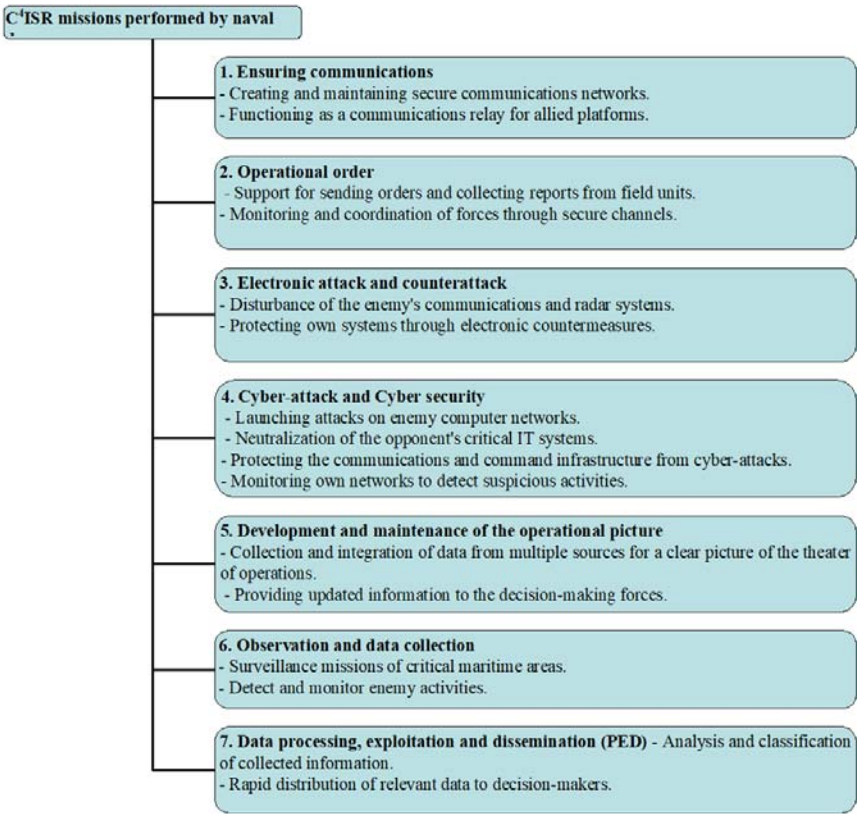

FIG. 1 Possible C4ISR missions that can be performed by naval drones

2. Offensive missions: Naval drones play a crucial role in the execution of offensive missions, being able to use controlled force or support operations involving it. Offensive missions involve the use of controlled force or support for the use of controlled force. These missions, shown in FIG. 2, may include conventional strike, forcible entry into ports and maritime bases, transport of special forces, mine planting and ASW missions. Current systems require a person to be in the decision loop for each of these missions, which requires the provision of communications links. UMSs could be a component in a system dedicated to one of these missions (eg, serving as a platform that houses the sensors for a conventional attack weapon system). One possible mission is to use a UWSV as a "surface torpedo" that hits a target with guidance, or as a blockade that detonates and sinks in a narrow waterway, preventing other ships from passing [6].

4. NAVAL SHIELD (DEFENSE OPERATIONS)

Missions of this type serve to protect the fleet or other key objectives from possible attacks, ASW protection, demining, cloaking and deception measures, defense against terrorist attacks by small boats, anti-submarine missions. In some cases, such as defense against small craft these missions can be performed almost entirely by a UWS. In other cases, such as anti-ship missile defense, a UWV can serve as part of a network, as the platform for detection sensors or an interception system.

It is for this reason that the Navy has begun development of a LCS (Littoral Combat Ship) model, the purpose of which is to secure littoral regions, to protect the Navy from a number of significant asymmetric threats, such as mines, diesel submarines and swarms of small surface ships. LCS is a platform for several types of autonomous systems, namely air, naval, land. This ship type can use different mission-specific modules that can be swapped out as needed [3].

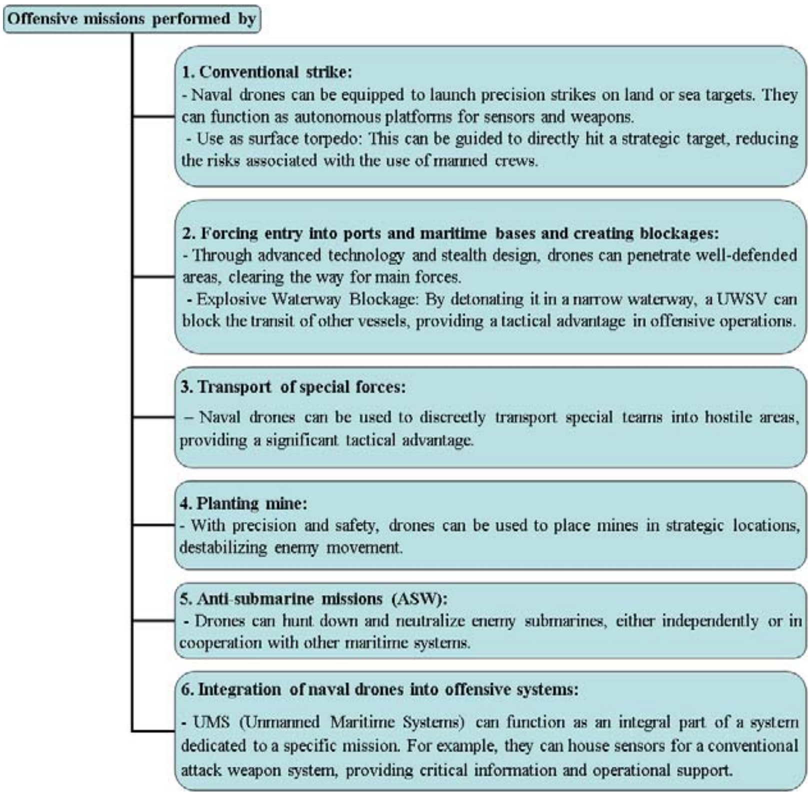

FIG. 2 Possible offensive missions that can be carried out by naval drones

1. Minesweeping: Mines are a major impediment to naval forces, are relatively cheap, can be widely deployed, and are difficult to detect. The methods used today to combat mines are cumbersome, very slow, expensive. One of the modules on the LCS is the UISS (Unmanned Influence Sweep System), and FIG. 3 shows a possibility of its use on an LCS. It consists of an underwater system that uses an acoustic and magnetic signal generator that provides a false signature that triggers the mines. The surface ship during operation will be far enough away not to be damaged by a detonating mine [7].

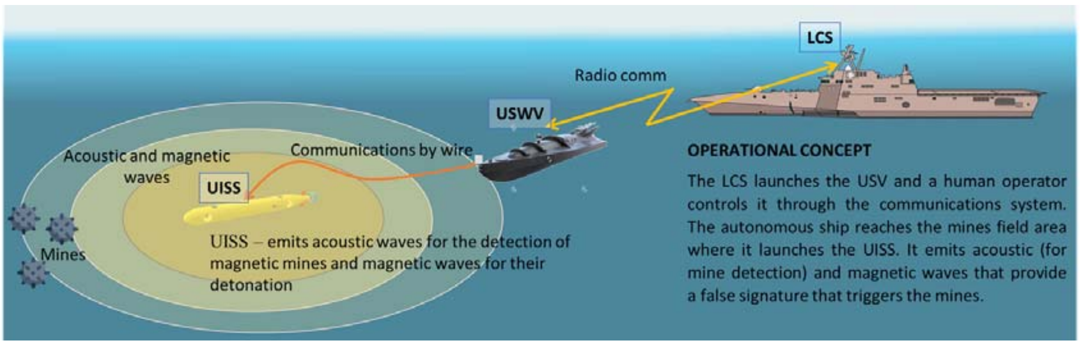

FIG. 3 Using the UISS system in a demining mission [8]

2. Anti-submarine warfare: Modern diesel submarines, while moving slowly near the littoral, are difficult to detect, thus they pose a serious threat to a littoral naval force, requiring increased anti-submarine capabilities. Autonomous systems can play a major role in providing this capability. UUWVs can help detect and combat submarines by deploying and monitoring various sonar sensors, tagging submarines and, if necessary, attacking them, as shown in FIG. 4. USWVs can also play a role platform for sensors such as laser radars, sonar and magnetic anomaly detectors and platforms for anti-submarine grenades.

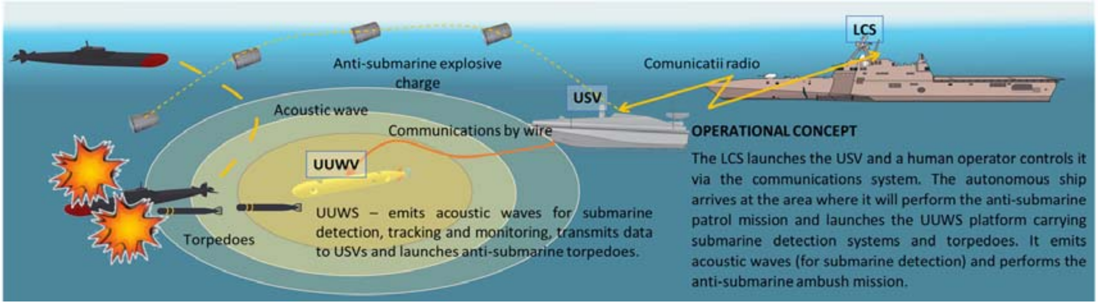

FIG. 4 The use of Naval Autonomous Systems within an anti-submarine mission [8]

3. Countering Surface Threats: A serious threat to surface ships in a littoral region today is swarms of small boats, armed or carrying explosives. The severity of the threat is compounded by the potential for very large numbers of boats in the attack area. Potential countermeasures, presented in FIG. 5, include the following:

- Their early detection with autonomous systems using ISR sensors.

- Attacking them with USVs equipped with targeting sensors, autonomous or controlled by a human operator equipped with a rapid-fire weapon system [3].

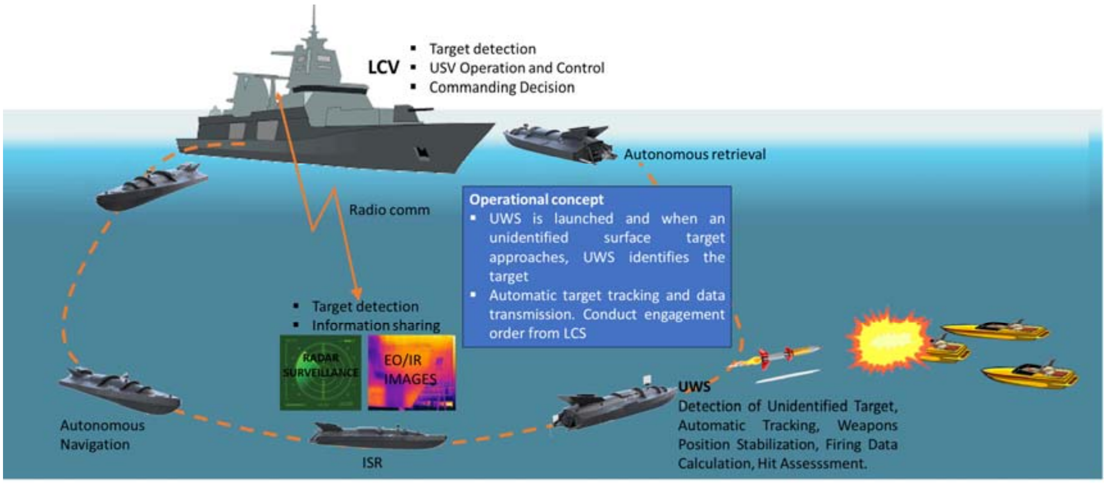

FIG. 5 The use of Naval Autonomous Systems within a mission to combat a swarm of naval drones [9]

At the present time, the possibility of creating a manned ship team - autonomous systems under the MRCV (MultiRole Combat Vessels) concept is being analyzed, presented in FIG. 6. This represents a new generation of military vessels, characterized by versatility, advanced technology and the integration of autonomous systems. These ships are designed to perform a wide variety of missions, from combat operations to humanitarian interventions, and are essential to the modern navy.

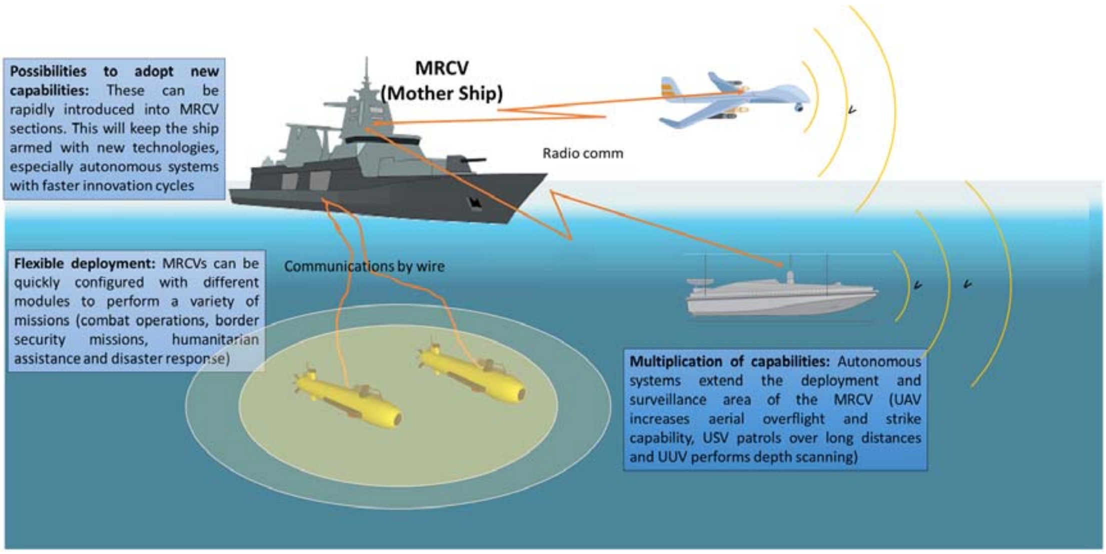

FIG. 6 Possibilities of the MRCV system [10]

CONCLUSIONS

UWSs are an advanced technological solution that redefines naval operations, providing efficiency, safety and flexibility. They are essential for adapting maritime forces to the requirements of modern warfare, contributing decisively to maintaining global maritime security. The use of autonomous naval vehicles presents the following advantages:

Challenges and future directions: Integrating UWSs into existing command structures and addressing cyber security issues are major challenges. The continued development of these systems will fundamentally influence the dynamics of modern warfare.

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MICROSTRUCTURAL AND FUNCTIONAL CHANGES INDUCED BY HEAT AND THERMOCHEMICAL TREATMENTS OF X5CrNi18-10

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Abstract: *This paper analyses the influence of heat and thermochemical treatments on the structure and mechanical properties of X5CrNi18-10 (AISI 304) austenitic stainless steel. In particular, there are assessed the effects of treatment parameters – temperature, time, cooling rate and working atmosphere – on internal structure and hardness. There are compared processes such as annealing, hardening, ageing and plasma nitriding. The results indicate that heat treatments applied in a controlled manner can improve properties, and thermochemical treatments can significantly increase surface hardness without compromising the anti-corrosion integrity if the parameters are well chosen. The paper provides a solid basis for the optimal selection of treatments in demanding industrial applications.*

Keywords: *X5CrNi18-10, heat treatment, nitriding, hardness, structure*

1. INTRODUCTION

In the context of modern industrial development, materials must meet increasingly stringent requirements with respect to mechanical performance, corrosion resistance, and durability in extreme environments. Austenitic stainless steels, especially X5CrNi18-10 (AISI 304), are extensively used in industries such as food, pharmaceutical, chemical and nuclear ones due to their chemical and structural stability [1, 2].

However, X5CrNi18-10 features relatively modest mechanical strength and low hardness in its standard state, while its sensitivity to intergranular corrosion following improper heat treatment constitutes a risk for critical applications [3, 4].

X5CrNi18-10 (AISI 304) is chosen when a combination of aesthetic appearance, corrosion resistance, and ease of processing/welding is required, in environments that are not extremely aggressive.

It is recommended for his properties: good corrosion resistance in atmospheric environments, drinking water, and mildly oxidizing solutions, excellent toughness even at low temperatures, very good weldability without the need for post-weld heat treatments, working temperature range: up to about 300–350 °C in continuous service.

Therefore, research focuses on optimizing heat and thermochemical treatments to improve the performance of this material, without compromising its essential properties.

The purpose of this paper is to identify and analyze the correlations between the specific parameters of the applied treatments and the resulting properties of X5CrNi18-10. Both conventional heat treatments and advanced thermochemical treatments – nitriding – are being investigated, as these can significantly influence the internal structure and functional properties of this material [4, 5].

2. EXPERIMENTAL RESEARCH

The experimental tests were performed on samples of X5CrNi18-10 austenitic stainless steel with the chemical composition presented in Table 1.

Table 1. Chemical composition of X5CrNi18 10 austenitic stainless steel, according to STAS and determined chemical analysis

Steel grade			Chemical composition [%]							
Numerical symbols	Alphanumerical symbols	STAS 3583-87	C	Cr	Mn max	Si max	Ni max	S max	Mo max	Cu max
1.4301	X5CrNi18 10	X5NiCr180	0.03	17-19	2.00	1.00	8.00-10.5	-	-	-
determined chemical analysis			0.02	18.3	1.80	1.00	9.5	-	-	-

After determining the chemical composition, the samples underwent heat and thermochemical treatments, hardness determinations and structural analysis. There should be noted that the hardness values presented below are the average of 5 measurements.

Table 2 shows the secondary heat treatment parameters and the hardness values obtained.

Table 2. Heat treatments of X5CrNi18-10

Item	Heat treatment					
	Homogenisation annealing [°C]	Solution immersion quenching		Artificial ageing		Hardness [HB]
		Temp [°C]	Cooling			
1	1050	-	-	-		282
		1050	water	510	air	235

It follows that, in delivery state, the material is characterized by greater hardness than after preliminary treatments; this implies that it was in a slightly out-of-equilibrium state due to cold drawing, a normalizing treatment, etc.

After the homogenization annealing and approaching the equilibrium state, there were observed slight decreases in hardness, which was to be expected.

The purpose of quenching from 1050°C is to resolve precipitated phases and improve chemical properties.

Heating and cooling were carried out in air. The rapid cooling, necessary to prevent the precipitation process after quenching, was carried out in water and the ageing was carried out in air.

There was selected an artificial ageing temperature of 510°C in order to avoid the 350....450°C range, where intergranular precipitation phenomena and tempering embrittlement may occur.

Figures 1-4 show the structures after primary and secondary heat treatments.

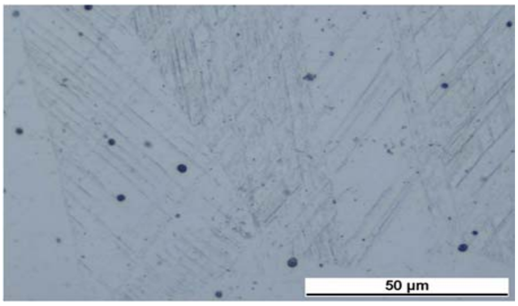

FIG. 1 X5CrNi1810 in delivery state. Aqua regia etching. 200:1

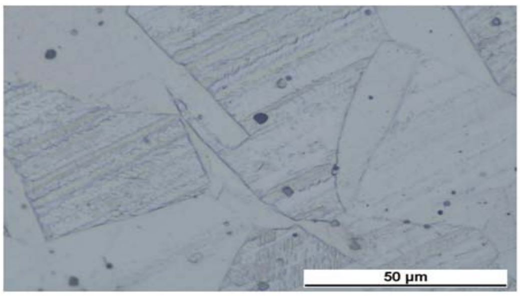

FIG. 2 X5CrNi1810 after homogenisation annealing at 1050 °C. Aqua regia etching. 200:1

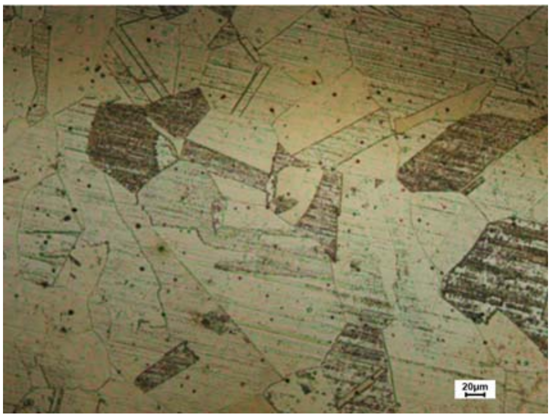

FIG.3 X5CrNi18-10. After quenching from 1050°C Aqua regia etching. 1000:1

FIG.4 X5CrNi18-10. Metallographic structure after solution immersion quenching from 1050°C and artificial ageing at 510°C. Aqua regia etching. 1000:1

In the three states, the X5CrNi18-10 structure consists of polyhedral γ solid solution crystals, with twinning bands. Compared to the delivery state, after the heat treatment, the polyhedral crystals are better outlined. To some extent, an increase in granulation is also observed. The different color shades are due to the different orientation of the crystals in the polycrystalline assembly.

In the next stage of the experimental research, there were monitored the changes in the steel performance as a result of applying a quenching + ageing sequence followed by nitriding. In this context, the aim was to modify the superficial hardness, respectively the generalized corrosion resistance of these steels. Table 3 presents the parameters of the ion nitriding treatment.

Table 3. Ion nitriding treatment parameters

Gas composition	NH_3 - Ammonia cracked at 750 °C
Holding at temperature	~20 h
Pressure	2.5-3.5mbar
Holding temperature	420+/-10°C
Thickness of the deposited layer	30-60 µm

The nitriding process is more efficient in the γ phase and slower in the α phase. Usually, the α phase is stable at lower temperatures, while γ at higher temperatures. For this reason, nitriding is carried out at lower temperatures, when they are generally encountered in BCC matrices.

In this case, the temperature selected was of 420°C, for 20 hours, not the 520°C temperature used for nitriding α structure steels. This is because the 520°C temperature can lead to a continuous desorption process.

From a practical point of view, a higher efficiency was found at 420°C compared to 520°C for γ structure steels; this is because the nitride layer of very small thickness and high hardness deposited on a relatively soft γ phase layer leads to the cracking of this layer and of the transition zone.

The metallographic structures of the thermochemically treated samples were analyzed next.

The structures were studied in parallel with microhardness measurements (Table 4 and FIG. 5).

Table 4. Hardnesses values of X5CrNi18-10 samples

Steel grade	Heat treatment				Plasma nitriding			Hardness	
	Solution immersion quenching			Artificial ageing					
	Temp. [°C]	Holding [h]	Cooling	Temp. [°C]	Temp. [°C]	Time [h]	Layer thickness [µm]	Core HV	Layer $HV_{0.1}$
X5CrNi 1810	1050	2	water	510	420	20	0.3..0.6	60.4-60.9	708-719

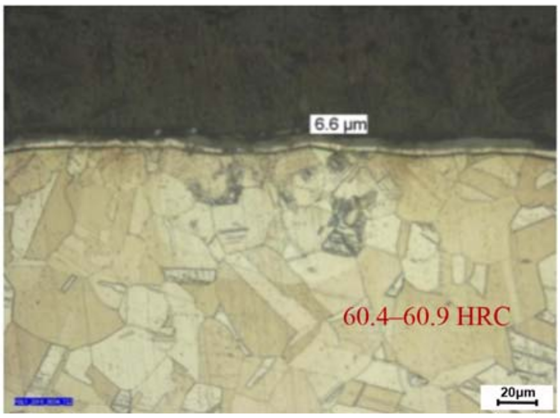

FIG. 5 X5CrNi18-10. Solution immersion quenching at 1050°C, artificial ageing at 510°C, nitriding at 420°C. layer thickness 6.6 µm. Etching reagent: aqua regia. 200:1

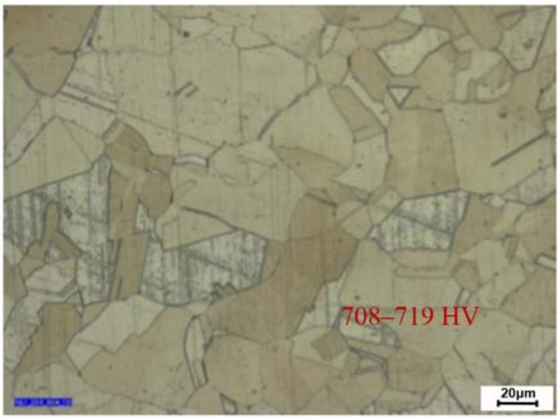

FIG. 6 X5CrNi18 10. Solution immersion quenching at 1050°C, artificial ageing at 510°C, ion nitriding at 420°C. Core – polygonal austenite crystals. Etching reagent: aqua regia. 200:1

No structural transformations can be observed for prolonged holding at 420°C. There may have also occurred, however, minor intercrystalline precipitations.

Nitrogen diffuses with difficulty into the γ crystal lattice of X5CrNi1810. Very thin surface layers are obtained as a result thereof. These layers generally consist of two layers: a white one made up of chemical compounds and a dark one of nitrogen-enriched solid solution underneath. The surface hardness is relatively high, but decreases sharply towards the interior.

No visible transformations occur in the basic mass upon heating to the nitriding temperature of 420°C, as the structure consists of polygonal crystals of γ substance and twinning bands.

CONCLUSIONS

Homogenisation annealing had a significant impact on restoring the structural homogeneity of X5CrNi18-10. As a result of this treatment, chromium carbides were dissolved from the grain boundaries, preventing the occurrence of intergranular corrosion.

Quenching applied conventionally did not lead to X5CrNi18-10 hardening, because it has a stable austenitic structure that does not undergo martensitic transformations.

Ageing applied after quenching had no significant effects, given that the material did not undergo a structural transformation during the quenching phase.

Nitriding determined a significant increase in the hardness of the stable superficial layer without compromising the basic austenitic structure, preserving corrosion resistance, while avoiding excessive oxidation and increasing wear resistance.

Of all the treatments analysed, plasma nitriding proved to be the most effective for increasing hardness without adversely affecting corrosion resistance. In contrast, quenching and ageing, effective for classically quenched steels, offer no significant benefits to X5CrNi18-10 considering the stability of the austenitic structure.

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SIMULATION AND EXPERIMENTAL VERIFICATION OF A PATCH ANTENNA FOR 2.4 GHz BAND APPLICATIONS

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Abstract: *The paper presents the design and development process of a microstrip patch antenna prototype intended for operation in the 2.4 GHz band, with applications in wireless communications for unmanned aerial vehicles (UAVs). The initial design was carried out using* ***MATLAB*** *software, in order to optimize key parameters such as* ***S11****,* ***VSWR****,* ***gain****, and* ***radiation pattern****. A prototype was fabricated using* ***laser engraving*** *and* ***chemical etching*** *techniques based on the obtained results.*

Experimental verification was conducted using specialized measuring equipment, namely a ***spectrum analyzer*** *to assess the real performance of the antenna. The experimental results were compared with the simulations, showing a satisfactory correspondence between the two stages.*

The paper confirms the feasibility of using a ***patch antenna*** *suitable for drone integration, offering a* ***compact*** *and* ***easily integrable*** *solution for UAV communication systems. This process provides a practical foundation for the development of* ***efficient communication solutions*** *for UAVs.*

Keywords: *patch antenna, MATLAB simulation, antenna parameters*

1. INTRODUCTION

Patch antennas are a subcategory of microstrip antennas**.** The patch antenna concept was first introduced in 1972 by Howell, and due to its shape and dimensions, it was quickly integrated into systems where space and weight are particularly important. Their flat structure offers the advantage of being manufactured using printed circuit board (PCB) techniques, which are both cost-effective and efficient.

Patch antennas consist of a metal plate or conductive patch, usually made of copper or gold, placed on a dielectric substrate and a ground plane. The standard shape of such an antenna is shown in FIG. 1.

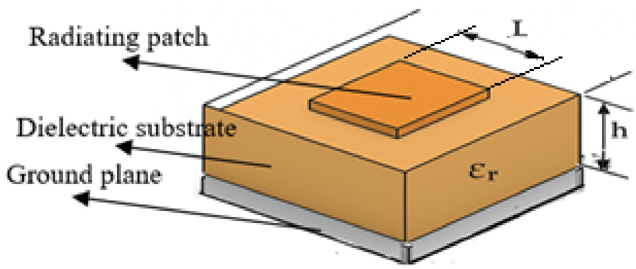


FIG.1 Patch antenna and standard parameters

The three regions of the antenna are:

1. Radiating patch – the part that transmits and receives the electromagnetic signal; it is the active component that radiates, and its shape and dimensions, L and W, determine the resonance frequency.
2. Ground plane – serves as a reference, reflecting the electromagnetic fields to ensure proper radiation and aiding in the impedance matching of the antenna.
3. Dielectric substrate – characterized by its relative permittivity ε_r; it influences the antenna dimensions, resonance frequency, and the losses determined by the loss tangent (tan δ).

In this study, the physical implementation of the antenna was carried out as a rectangular patch, using FR-4 as the dielectric substrate material, commonly used in PCB manufacturing. FR-4 is characterized by a relative permittivity $\varepsilon_r = 4.4$ and a loss tangent $\tan\delta = 0.025$. The radiating patch and the ground plane were made of copper due to its high electrical conductivity, which helps reduce losses and achieve efficient radiation.

This configuration is intended for integration into UAV-type applications, where miniaturization and efficiency requirements are essential. The following sections present the design and simulation stages of the antenna using MATLAB Antenna Toolbox, as well as the experimental verification of its characteristics through measurements performed with RF domain-specific testing equipment.

2. THEORETICAL FOUNDATIONS

The construction of the antenna involves correctly defining its dimensions and performing simulations to evaluate the antenna's behavior. It must be directive, meaning that all the radiated energy should be concentrated in a specific direction [1, 2].

2.1. Antenna design. After defining the format and simulation settings, the next step was the creation of the antenna and the determination of its physical dimensions. The effective wavelength for the 2.4 GHz frequency is 125 mm.

Patch width:

$$W = \frac{c}{2f\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

As a result of electromagnetic field losses, part of the electromagnetic field propagates through the dielectric substrate, while another part "radiates" into the air. The effective permittivity will have a value given by equation (2), where the which is h = 1 mm.

$$\varepsilon_{ef} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} = 4{,}182 \tag{2}$$

At the edges of the patch, the **fringing effect** of the electromagnetic field occurs, through which the field lines partially extend into the air, modifying the field distribution and leading to an effective increase in the electrical length of the antenna. For this reason, the physical length of the patch must be designed shorter than λ/2, with the correction introduced by the term ΔL in the calculation formulas.

$$\Delta L = 0.412h\frac{(\varepsilon_{ef} + 0.3) \times (\frac{W}{h} + 0.264)}{(\varepsilon_{ef} - 0.258) \times (\frac{W}{h} + 0.8)} \tag{3}$$

With the mentioned equation, the dimensions of the radiating patch are obtained.

$$\mathrm{L} = \mathrm{L_{ef}} - 2\Delta\mathrm{L} = \frac{\mathrm{c}}{2\mathrm{f}\cdot\sqrt{\varepsilon_{\mathrm{ef}}}} \qquad (4)$$

1.2.Parameters of the designed antenna

To characterize the performance of the designed antenna, the main specific parameters were analyzed:

1. Return loss (S11) reflects the level of matching between the antenna and the feed line; values lower than –10 dB indicate satisfactory performance.
2. Bandwidth (BW) indicates the frequency range over which the antenna maintains proper impedance matching and operates efficiently.
3. VSWR expresses the degree of the impedance matching between the antenna and the transmission line; values below 2 indicate proper impedance matching.
4. Antenna gain indicates how effectively the antenna directs radiated power in a given direction, considering internal losses.
5. Directivity describes the antenna’s capability to focus radiation on a specific direction, independent of material or matching losses.
6. The radiation pattern illustrates the spatial distribution of the electromagnetic field emitted by the antenna and allows the evaluation of its directionality.

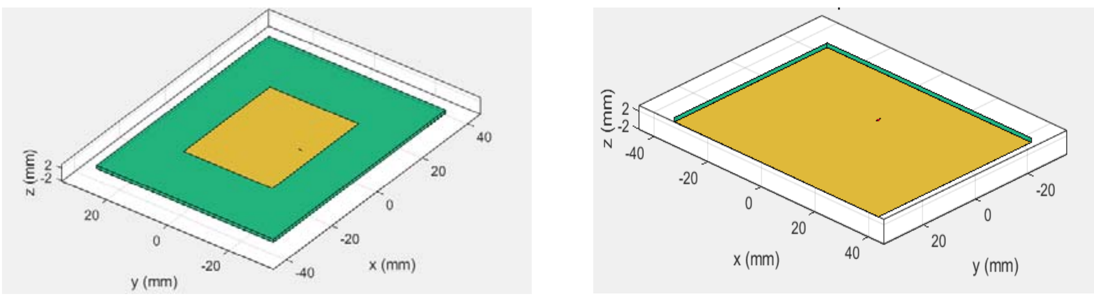
3. MATLAB SIMULATION

For the MATLAB [3] design of the patch antenna, the following conditions were imposed:

- operating frequency of 2.4 GHz, specific to UAV applications;
- use of the FR-4 dielectric substrate, a material commonly used for PCB manufacturing and prototyping;
- initial dimensions determined based on relations (1) – (4).

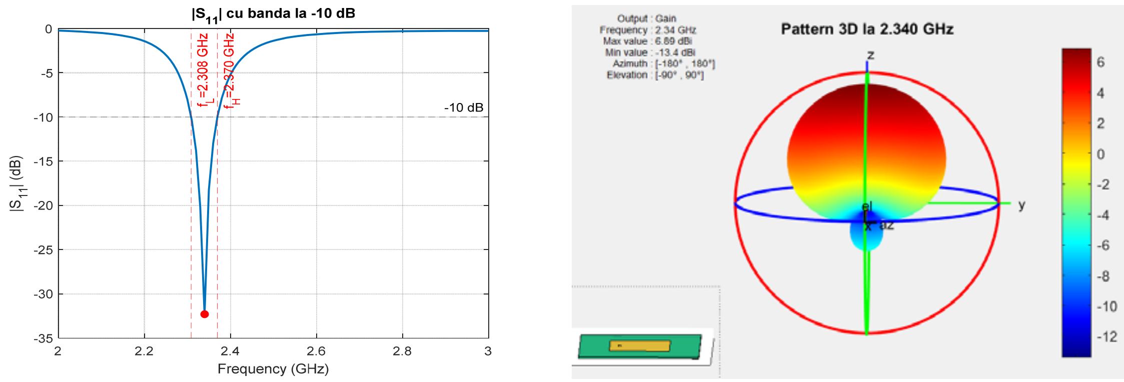
Based on the theoretical design, the resulting patch dimensions are: width W = 38 mm and length L = 29.12 mm. The feed point position, determined for matching to the standard 50 Ω impedance, was calculated at the coordinates 19 mm / 4.81 mm.

This section presents the obtained results, in the form of characteristic parameters and the corresponding graphical representations.



(a) (b)

FIG.2 Patch antenna obtained in MATLAB. (a) radiating patch, (b) ground plane



(a) **(b)**

FIG.3 (a) Return loss. (b) Radiation pattern

S11 expresses how much of the incident power is reflected by the antenna. For a minimum below –30 dB obtained through simulation (FIG. 3), the matching is very good, meaning that practically all the power enters the antenna.

4. PRACTICAL IMPLEMENTATION OF THE ANTENNA

4.1. Physical implementation of the patch antenna. For this purpose, well-established methods for processing conductor-coated boards specific to PCB technology were used. The prototype fabrication process aimed to obtain a precise structure with appropriate electromagnetic performance. The following stages were carried out for prototype realization:

1. Definition of the antenna geometry.

According to the calculations and simulations obtained in MATLAB, the contour of the patch and the ground plane were transferred onto the FR-4 dielectric substrate, characterized by a relative permittivity εr = 4.4 and a thickness of h = 1 mm.

2. Laser engraving.

To define the copper areas, a CNC machine equipped with a laser module was used to remove the protective layer and expose the copper in the regions to be etched away. This method ensures high precision of the patch contour (FIG. 4).

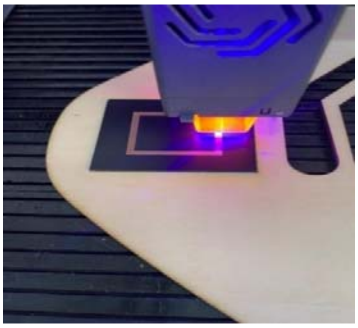


FIG.4 Patch antenna engraving [4]

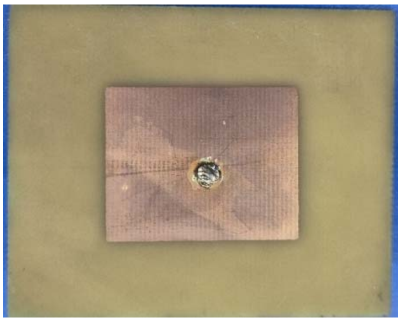


FIG.5 Patch antenna prototype

3. Chemical etching:

The board was immersed in a ferric chloride ($FeCl_3$) solution, a process through which the exposed copper was selectively removed, leaving the radiating patch and the ground plane intact. After etching, the protective layer was removed, obtaining the final geometry of the antenna.

4. Feed point implementation:

In the designated connection area, the substrate was drilled, and a coaxial connector was mounted, ensuring proper soldering with tin to provide high-quality electrical contact and good mechanical stability.

5. Final prototype:

The manufactured antenna is a rectangular patch design on an FR-4 substrate, with copper used for both the patch and the ground plane, prepared for characterization through experimental measurements. (FIG. 5).

4.2. Manufacturing alternatives. In addition to traditional methods for fabricating patch antennas on dielectric substrates (mechanical engraving, laser engraving, and chemical etching), modern rapid prototyping technologies have recently been adopted. 3D printing represents an alternative option with increasing applicability in the field of antennas. This technology allows the creation of complex geometries and three-dimensional structures that are difficult to achieve using conventional methods. Moreover, 3D printing enables the direct integration of antennas into the mechanical structures of UAV platforms, reducing overall weight and increasing the level of functional integration. Although the presented prototype used the conventional FR-4 substrate and chemical processing of the conductive layer, including 3D printing in the prototyping process represents a promising direction for future developments of this study.

4.3. Experimental verification. After fabricating the patch antenna for the 2.4 GHz band, experimental tests were carried out to evaluate its performance. The verification process included several stages and the use of dedicated equipment: a signal generator, a spectrum analyzer, and a vector network analyzer.

In the first stage, emission testing was performed by connecting the patch antenna to a signal generator (Rigol DSG3065B-IQ) and a log-periodic antenna to a real-time spectrum analyzer (SSA 3075X-R). The settings were configured for a central frequency of 2.4 GHz, with a power of 10 dBm, and 2m between the antennas (FIG. 6).

FIG.6 Experimental verification of the patch antenna prototype

For reception testing of the designed patch antenna, the two antennas shown in FIG. 6 were reversed: the patch prototype operated as a receiver, while the log-periodic antenna acted as a transmitter. The results demonstrated proper signal reception at the 2.4 GHz frequency, confirming the dual functionality of the antenna (FIG. 7. (a)).

(a) **(b)**

FIG.7 Resonant frequency obtained on the spectrum analyzer [4]. (a) Signal reception with the patch antenna at 2.4 GHz. (b) Reflection coefficient

The matching performance was analyzed using a vector network analyzer (VNA SNA5012). The monitored parameter was the reflection coefficient S11, measured within the 2.2–2.6 GHz range. The experimental values indicated a minimum of approximately –3 dB and a VSWR ≈ 3, suggesting partial matching to the 50 Ω impedance and moderate efficiency. (FIG. 7. (b)).

ANALYSIS OF RESULTS AND CONCLUSIONS

The comparison between the simulated and experimental data revealed moderate differences, which can be explained by:

- Additional losses in cables and connectors, which led to significant attenuation with a loss of about 23dB.
- Reflections from the testing environment. The measured reflection coefficient of –3.033dB is closer to the desired value.
- Variations in the actual parameters of the FR-4 dielectric substrate compared to nominal values.

Nevertheless, the real antenna's behavior was close to the simulated one, confirming the validity of the design.

Conclusion. The fabricated patch antenna prototype operates in the 2.4 GHz band but exhibits imperfect matching.

The next stage will include:

- adjusting the patch dimensions to recalibrate the resonance frequency,
- optimizing the feed point position,
- using dielectric materials with lower loss tangents.

Although testing in an anechoic chamber or controlled environments could provide more precise characterization and eliminate external influences, considering the intended applications and operating conditions of the antenna, experiments conducted in environments like real operational conditions are preferable for the designed patch antenna.

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ANALYZING THE EFFECTIVENESS OF CONTENT DETECTION PROGRAMS GENERATED USING AI (ARTIFICIAL INTELLIGENCE)

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Abstract:*Taking into account the current context in the technological field, this paper aims to emphasize the way in which, the methods of combating and detecting the use of artificial intelligence in the academic environment are or not effective and whether the old methods of approaching this environment, are still effective today.*

Keywords: *Artificial intelligence, Chatbots, AI Detection, Effectiveness, Digitalization, Technology, Educational*

1. INTRODUCTION

With the growing need for technological development and an increasing level of innovation in the field of digitization, numerous inventions have laid the foundations for a new approach on a global scale. Among these fundamental breakthroughs is the implementation of artificial intelligence in various systems and processes. Throughout this paper, we aim to obtain as objective an analysis as possible on how the presence/use of artificial intelligence in academia can be detected in a way that inspires certainty and efficiency. In more detail,the aim of this research is to analyze how renowned programs for the detection of AI-generated content manage to determine whether or not an article is generated, whether or not these methods are effective, and whether or not the results of our study can have an influence in demonstrating that current methods used in education should be rethought.

This study does not want to shift the focus away from the negative effects that the use of artificial intelligence in the realization of academic work can generate, but it wants to provide a different perspective on the methods by which to combat this topical phenomenon.

The study conducted by Vieriu and Petrea, on the impact of artificial intelligence on students in the academic environment, brings the following statistics to the fore, based on the questioning of 85 students in the fields of medical and aerospace engineering:

- 96% of surveyed students recognized the use of AI in the educational process
- 88.2% use virtual assistants (ChatGPT, Siri, etc.)
- 17.6% recognized using AI to generate content (the actual percentage is possibly much higher)
- 16.5% believe that AI has a negative effect on critical thinking (Vieriu and Petrea, 2025).

Analyzing the aforementioned statistics and quantifying the results of the study to the total number of students in the educational units, we highlight the following, according to the online statistics page, AIPRM:

- 53% of higher education students use artificial intelligence to generate content used in various materials
- 24.11% of students reported that materials made with AI have been detected and treated as fraud (6.44% in private high schools and 15.2% in public high schools)
- 51% of teachers believe that using AI in education will have a positive impact (AIPRM, 2025)

Thus,one fact can be for sure inquired: the use of AI in the accomplishment of tasks outlined in the line of education, especially in the accomplishment of work requiring content production is evident.

Although Romania's objectives in this direction are to promote the use of artificial intelligence in numerous ways that could streamline the educational process, such as: much faster browsing on the Internet, taking suggestions and implementing them in organizational and mechanization functions (making tables, graphs, statistics, etc.), the level of use of AI in content generation is becoming increasingly alarming. A consequence of this is the implementation of programs that can detect AI-generated content and their implementation in educational institutions. Our goal is to demonstrate whether or not this method is workable through the following approaches:

1. We will generate passages with different AI tools such as ChatGPT, Gemini, QuillyBot.
2. We will analyze the results of passing these passages through AI detection programs such as QuillyBot, Undetectable.AI.
3. We will apply minimal modifications to the AI generated texts to make them less detectable.
4. We will design various conclusions based on the obtained results.

2. ARTIFICIAL INTELLIGENCE AND CONTENT GENERATION TOOLS

In order to be able to analyze and discuss the results obtained through this article, it is necessary to know the conceptual elements underlying the concept of artificial intelligence, but also to be able to analyze in detail the context in which this technology has become so useful and used among young people for various purposes, with emphasis on that of generating content for school tasks.

What is artificial intelligence? In the scientific paper done by Rituraj Mahato artificial intelligence is defined as a replica of the way human intelligence works, but does not provide biologically observable methods. (Mahato, 2022). This concept is also defined in the paper titled: „Introduction to Artificial Intelligence" as a branch of computer science that helps computers mimic human behavior in order to generate better performance in science and technology. Replicating human intelligence, solving knowledge-intensive tasks, building machines that can perform tasks that require human intelligence, and creating systems that can learn on their own are some specific goals of AI." (Ghosh et al., 2021).

What are the most widely used and available ways in which mebers of the education system can get in touch with artificial intelligence? According to the Exploding Topics page we have identified the following statistic: Over 987 million people are using an AI content generation program, of which we can identify a number of 500 million people using ChatGPT. (Cardillo, 2025). Therefore, the most widely utilized type of artificial intelligence made available to internet consumers is certainly the use of an AI product designed to generate content, mimicking the classical communication model. This artificial intelligence product will be further referred to as ***Chatbot***.

What is a Chatbot? In his study on the functioning of artificial intelligence, Adamopoulou identifies the following representative definitions for the term Chatbot, namely:

- A program that reacts as an intelligent entity when initiating a text or voice communication and has the ability to understand one or more human languages through natural language processing.
- A program designed to simulate conversations with human users over the Internet
- A chatbot is described as the most advanced and intuitive expression of human-computer interactions (Adamopoulou *et al.* , 2020)

How is a chatbot created and how does it work? In order to build a Chatbot it is necessary to have a broad knowledge of computer science and to apply a variety of specific techniques, among which can be: representing the correct information, creating a strategy for organizing the received responses, making a set of neutral responses that are displayed at the moments when the message was not correctly received. Also, each chatbot will be configured according to its needs and purpose based on an extensive process. The same Adamopoulou identifies a logic chain through which a chatbot analyzes and generates the information requested by the user:

A first step in the development of any information system is to realize a logical schema. The whole response generation process starts with the user's request, usually represented by a question. Once this request has been processed by the artificial intelligence, the linguistic component of this chatbot analyzes it in order to be able to identify the user's intention and associate it with an information. Once the artificial intelligence has correlated the information with the user's intent it, depending on how it has been trained, chooses the most appropriate way to interpret the user's intent and chooses a course of action. It can directly generate the correlated information, it can retain the information and feed it into the training process, and it can also request more information from the user to choose the appropriate response. The information generated by this chatbot comes from a generic database that underpins all the responses generated. The response generation component is responsible for organizing and preparing the response in the form of the natural human language used by the user. Another component that is part of the structure of any chatbot is represented by the dialog management component that has the role of maintaining and updating the context of a conversation, which is the current intent, identified entities or missing entities needed to fulfill the user's requests to the users, also having the ability to request missing information by processing clarifications made by the users. (Adamopoulou *et al.* , 2020)

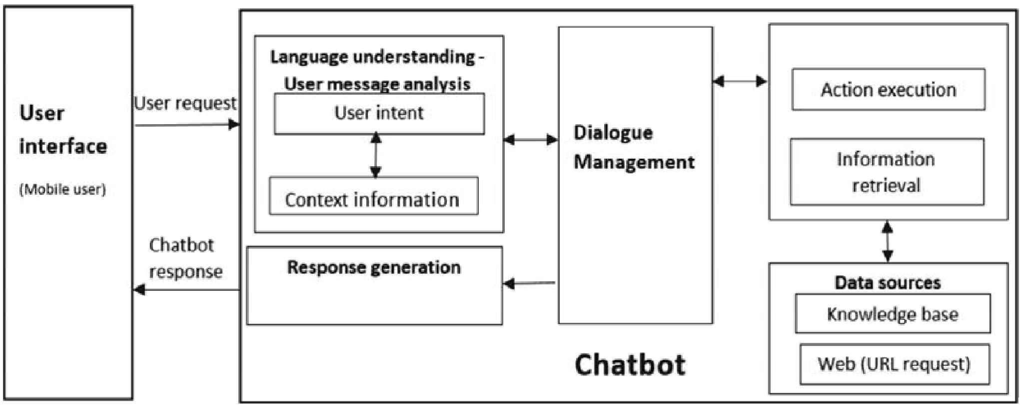


FIG.1 General architecture of a chatbot (Adamopoulou *et al.* , 2020 : 380)

3. STUDY ON THE EFFECTIVENESS OF AI GENERATED CONTENT DETECTION PROGRAMS

In the course of our own analysis of the concept of effectiveness, we were able to conceptually define what this term refers to:

> *"Effectiveness reflects the ability of an action, process or strategy to produce results in line with pre-set objectives. It is often associated with the successful achievement of an explicitly defined goal or mission. Furthermore, effectiveness refers to the ability to produce superior results."* (Mariș, 2024).

Therefore, the effectiveness of a computer program or a software tool (in our case: an AI content detection tool), boils down to the degree of success with which the presence of the use of artificial intelligence can be identified in the process of writing content.

With the accelerating emergence of numerous *Chatbot* tools (defined and explained in the previous chapter), which are increasingly used in the realization of specific papers in today's academic environment, the problem of developing and designing systems that can combat and detect, based on a brief analysis of the content entered, the level of use of AI technologies in content writing has arisen. These detection tools work on the basis of processing the inputted content and checking some parameters that are considered to be defining parameters in delineating the boundary between the activity of artificial intelligence and human (Odri & Yoon, 2023). Specialists have identified as useful parameters in detecting the influence of artificial intelligence, perplexity and writing rate variability. Perplexity is a measure used to evaluate the performance of language production models. Essentially, perplexity determines the ability of a system to choose the most appropriate next word in a sequence.

As mentioned by Xu and Sheng in "*Detecting AI-Generated Code Assignments Using Perplexity of Large Language Models*", perplexity is defined as a:

> *measure of how well a probability model predicts a sample. In the context of code, it's used to evaluate the predictability of the next token or line of code based on a given context.* (Xu & Sheng, 2024: 23156).

A lower perplexity score indicates that the model better predicts the next word in a sequence, while a higher score indicates that the model is less accurate. In other words, the lower the perplexity, the less likely it is that content is generated with AI.

Researches in the techonological fields consider burstiness quality as:

> *The clustering or frequent appearance of certain patterns, identifiers, or constructs in a specific section of the code. For example, in a code module dealing with database operations, there might be a burst of commands and identifiers related to database queries.* (Xu & Sheng, 2024: 23156).

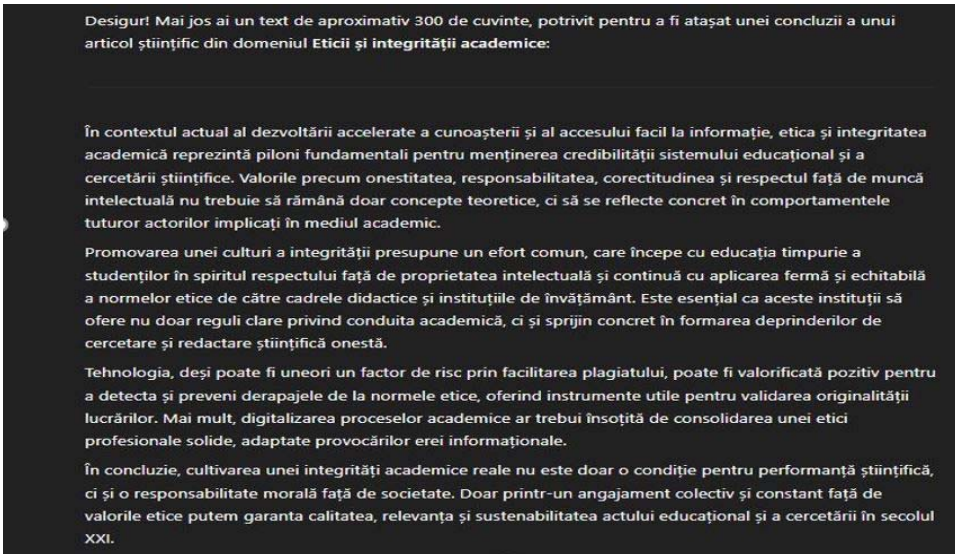
The variability in the rate of writing usually mentioned as burstiness in scintific researches, boils down to the way the structure of a piece of content is written, based on comparing the number of words and phrases used throughout the analyzed text. Therefore, a content generated with AI will be more uniform and easier to detect. (UNIC, 2025).

The steps of conducting this study, regarding the effectiveness of AI-generated text detection system sare presented below:

1. Generating a text consisting of an average of 300 words through the most popular Chatbot on the market, namely ChatGPT.
2. Using 5 AI usage detection software tools for content generation and compare the results: GPTZero, Quillbot, Undetectable.AI, Originality and Writer.

3. Manipulating and editing the text with minimal effort to provide a more natural form of AI generated content
4. Double-checking(re-checking) the results provided by the detection tools.

After using ChatGPT we generated the text sequence shown in Figure 2, in the fictitious context of producing a scientific paper in the field: Ethics and Academic Integrity. The text generated by this Chatbot tool will be analyzed on the 5 platforms mentioned above, able to detect, both the percentage of use of artificial intelligence and the Chatbot model used to generate the content.



Desigur! Mai jos ai un text de aproximativ 300 de cuvinte, potrivit pentru a fi atașat unei concluzii a unui articol științific din domeniul **Eticii și integrității academice**:

În contextul actual al dezvoltării accelerate a cunoașterii și al accesului facil la informație, etica și integritatea academică reprezintă piloni fundamentali pentru menținerea credibilității sistemului educațional și a cercetării științifice. Valorile precum onestitatea, responsabilitatea, corectitudinea și respectul față de muncă intelectuală nu trebuie să rămână doar concepte teoretice, ci să se reflecte concret în comportamentele tuturor actorilor implicați în mediul academic.

Promovarea unei culturi a integrității presupune un efort comun, care începe cu educația timpurie a studenților în spiritul respectului față de proprietatea intelectuală și continuă cu aplicarea fermă și echitabilă a normelor etice de către cadrele didactice și instituțiile de învățământ. Este esențial ca aceste instituții să ofere nu doar reguli clare privind conduita academică, ci și sprijin concret în formarea deprinderilor de cercetare și redactare științifică onestă.

Tehnologia, deși poate fi uneori un factor de risc prin facilitarea plagiatului, poate fi valorificată pozitiv pentru a detecta și preveni derapajele de la normele etice, oferind instrumente utile pentru validarea originalității lucrărilor. Mai mult, digitalizarea proceselor academice ar trebui însoțită de consolidarea unei etici profesionale solide, adaptate provocărilor erei informaționale.

În concluzie, cultivarea unei integrități academice reale nu este doar o condiție pentru performanță științifică, ci și o responsabilitate morală față de societate. Doar printr-un angajament colectiv și constant față de valorile etice putem garanta calitatea, relevanța și sustenabilitatea actului educațional și a cercetării în secolul XXI.

FIG.2 Initial text sequence generated by ChatGPT

Results:

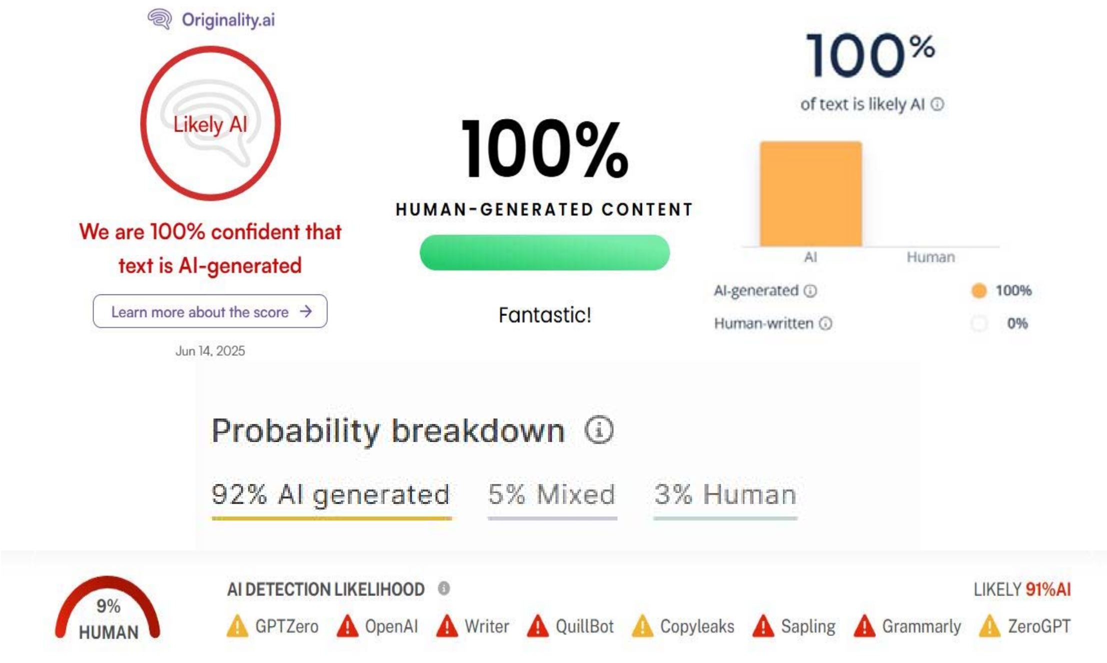


FIG.3 Results obtained on each of the 5 platforms

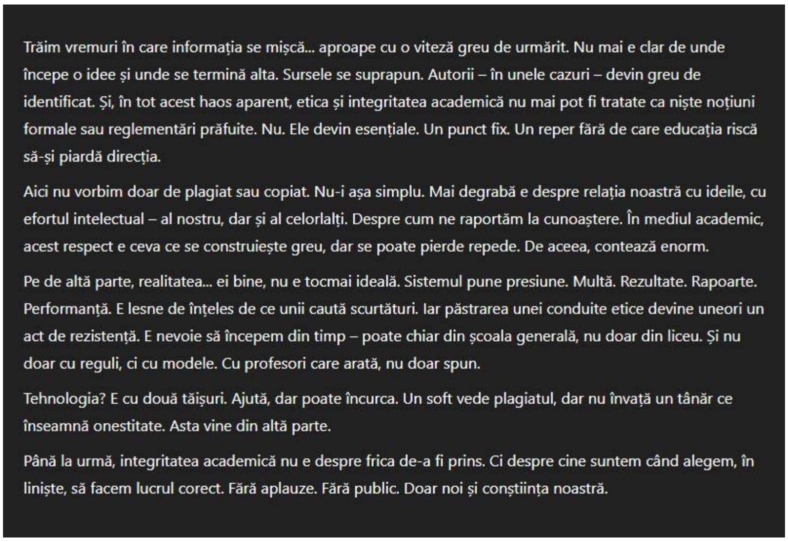
Figure 3 represents a centralization of the results obtained using in order the 5 AI detection platforms mentioned in the course of the paper: Originality, Writer, Quillbot, GPTzero, Undetectable.AI.

As can be seen, 4 out of 5 platforms defined the analyzed content as generated using an AI-based chatbot.

It should also be noted that the vast majority of platforms that can detect the presence of AI tools are not fully compatible with the English language, therefore the results obtained may also be influenced by this factor.

The next step is based on modifying the text initially generated by Chatgpt in order to obtain a lower degree of perplexity and a higher variability in the content structure. We will therefore train the artificial intelligence so that the language used is as natural as possible and the number of words becomes much more variable. By applying these changes we can bring to the forefront a finding related to the ease with which, also through the use of artificial intelligence, we were able to transform the initially generated text into a more natural, human and less predictable structure: in less than a minute, the ChatGpt chatbot was able to generate content with a more authentic flavor.

The new text generated by the artificial intelligence will undergo the same process of detecting the involvement of AI in its creation, and will be successively checked by all the platforms mentioned above: Originality, Writer, Quillbot, GPTzero, Undetectable.AI, in order to compare the initial and the actual results.



Trăim vremuri în care informația se mișcă... aproape cu o viteză greu de urmărit. Nu mai e clar de unde începe o idee și unde se termină alta. Sursele se suprapun. Autorii – în unele cazuri – devin greu de identificat. Și, în tot acest haos aparent, etica și integritatea academică nu mai pot fi tratate ca niște noțiuni formale sau reglementări prăfuite. Nu. Ele devin esențiale. Un punct fix. Un reper fără de care educația riscă să-și piardă direcția.

Aici nu vorbim doar de plagiat sau copiat. Nu-i așa simplu. Mai degrabă e despre relația noastră cu ideile, cu efortul intelectual – al nostru, dar și al celorlalți. Despre cum ne raportăm la cunoaștere. În mediul academic, acest respect e ceva ce se construiește greu, dar se poate pierde repede. De aceea, contează enorm.

Pe de altă parte, realitatea... ei bine, nu e tocmai ideală. Sistemul pune presiune. Multă. Rezultate. Rapoarte. Performanță. E lesne de înțeles de ce unii caută scurtături. Iar păstrarea unei conduite etice devine uneori un act de rezistență. E nevoie să începem din timp – poate chiar din școala generală, nu doar din liceu. Și nu doar cu reguli, ci cu modele. Cu profesori care arată, nu doar spun.

Tehnologia? E cu două tăișuri. Ajută, dar poate încurca. Un soft vede plagiatul, dar nu învață un tânăr ce înseamnă onestitate. Asta vine din altă parte.

Până la urmă, integritatea academică nu e despre frica de-a fi prins. Ci despre cine suntem când alegem, în liniște, să facem lucrul corect. Fără aplauze. Fără public. Doar noi și conștiința noastră.

FIG.4 The new AI generated text following the modifications according to the mentioned strategy

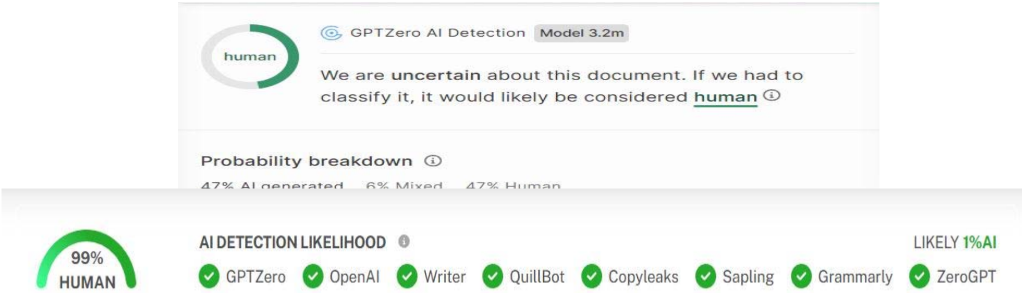


FIG.5 Results obtained after checking the new AI generated content (ChatGPT)

CONCLUSIONS

Table 1. Comparing result before and after text manipulation

AI detection software	Results *before* text manipulation	Results *after* text manipulation
Originality.AI	100% confident that text is AI generated	100% confident that text is original
Writer AI	100% Human Generated content	98% human-generated content
Quillbot	100% of text is likely AI	53% of text is likely AI
GPTzero	92% AI, 5%mixed, 3%human	47%AI - 47% human
Undetectable.AI	9% human	99% human

In the first instance, generating a text passage with the help of artificial intelligence and keeping exactly the raw form of the generated content 4 out of 5 best AI detectors returned results that, taking into account also the partial incompatibility of the software tools with the Romanian language, can be used in arguing that a text, part of a scientific article was written by means of specific Chatbots offered by companies in the field. However, by training artificial intelligence and studying the ways in which these software tools manage to detect the presence of AI, we manage, with great ease, to generate texts that can pass unnoticed by detection tools. As a proof, the example provided above (Fig. 5), where 3 out of 5 software are sure that the text generated by AI is in fact human-made, one out of 5 believes that the text is not AI-made but does not give a clear answer, and the last one believes that the text would be AI-generated but in 53% of the cases.

The study also wants to highlght that these results were obtained without subjecting the AI-generated text to a human thought filter, relying only on the content generated directly by artificial intelligence. Following the analysis obtained and the ease with which the output of artificial intelligence detection tools can be manipulated, it can be considered that by applying a series of minor modifications to a text passage generated by a *Chatbot* such as ChatGPT and adapting terms specific to human colloquial language in the content of the passage, it can be able to obtain an AI-generated text that is capable to return completely negative results in terms of the percentage of AI usage. To cancel any lack of transparency, the whole verification process of the modified AI-generated content is attached in the appendix section.

This study may represent a first step in dismantling a whole strategy to combat the use of artificial intelligence in the realization of academic work and, moreover, it could be used for a much broader research that could highlight the usefulness of using these new emerging technologies. Concerning the concept of effectiveness, the evaluated software tools were found to be vulnerable to changes in the texts generated with artificial intelligence.

In conclusion, the use of dedicated tools for the detection of the use of artificial intelligence in the content of different papers, often required in academia, is an ineffective method to combat the educational system's desire to remove this new technology.

Moreover, these techniques can not be considered effective, as the vast majority of detection tools charge money for analyzing papers with high word counts, and even in these situations, they cannot be manipulated. We propose, in this sense, a rethinking of the approach strategies used to preserve students' creativity and shifting the focus from quantity to quality. Artificial intelligence, in addition to the negative effects that are brought, more and more often, to the attention of society, can have, on the other hand, numerous ways in which it can offer improvements to educational sustems and in which it can train and keep active the attention, involvement and creativity of the educational product, the student.

Considering future research directions in the AI domain, present study will state as a base understanding on the ease of how a detection tool can be manipulated, generating new ideeas regarding the evolution of the AI usage in the academic field. In the future, the need to find new methodology and teaching practices is an imperative way to start studying how to implement Artificial Intelligence in a healthier and more ethical way.

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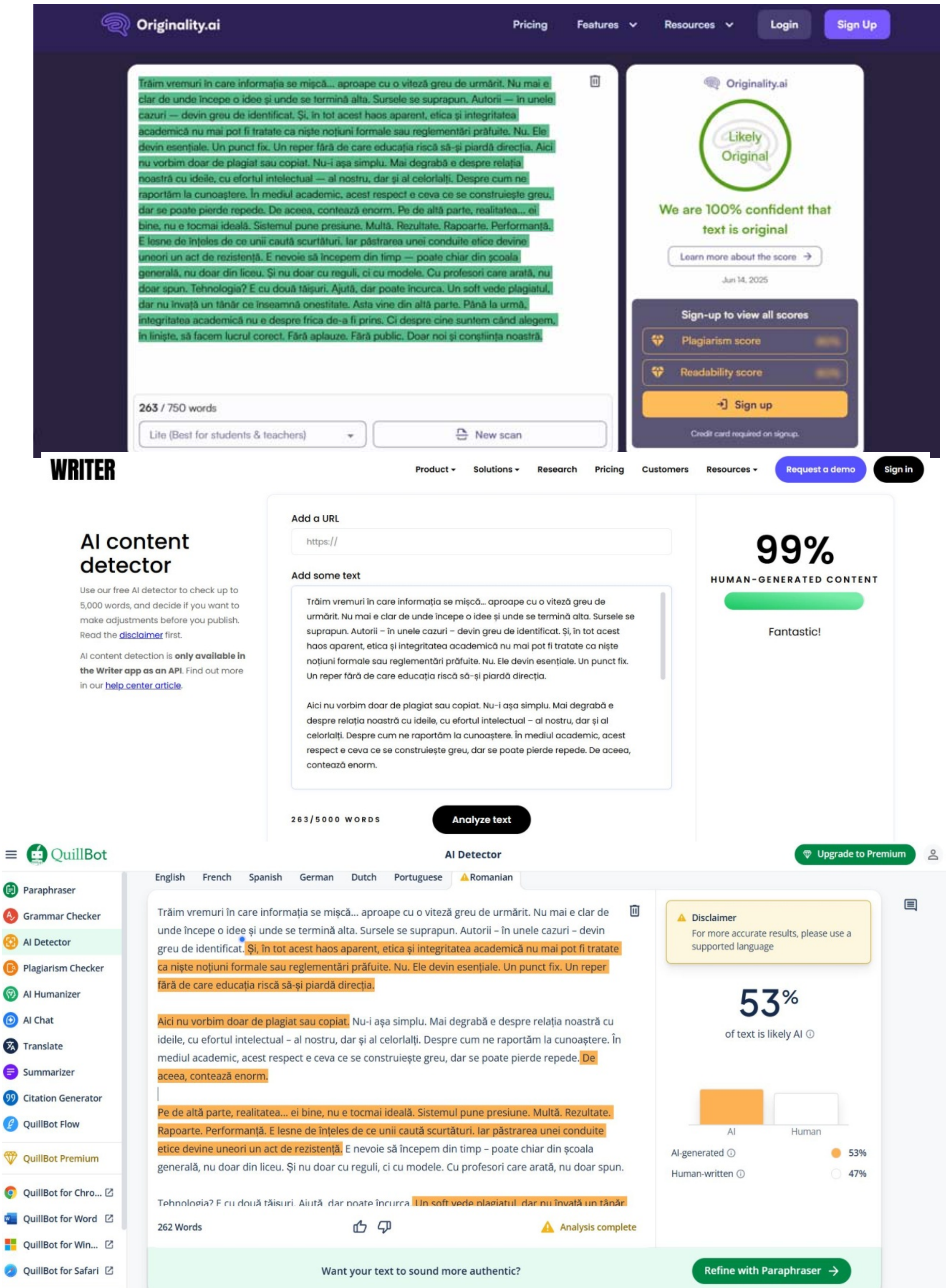
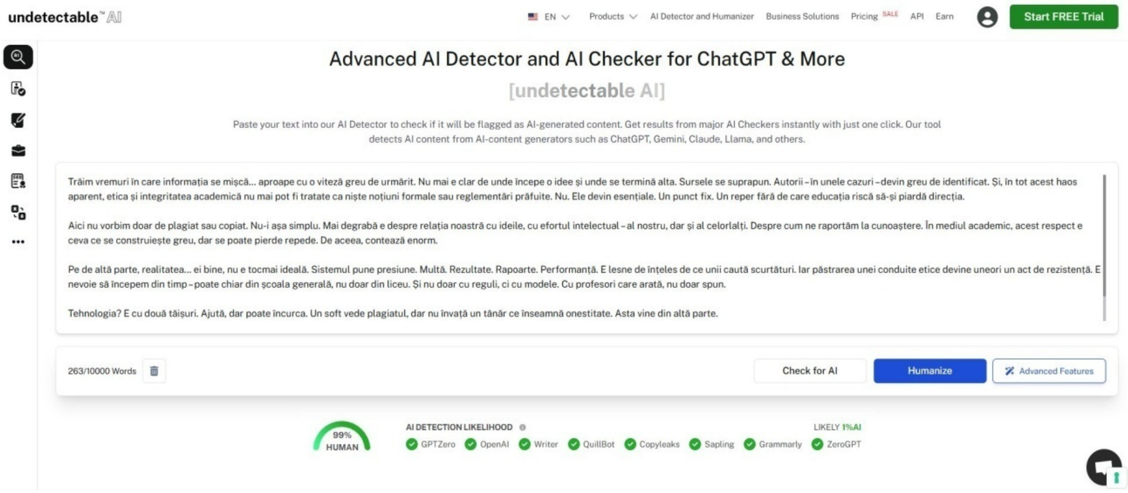
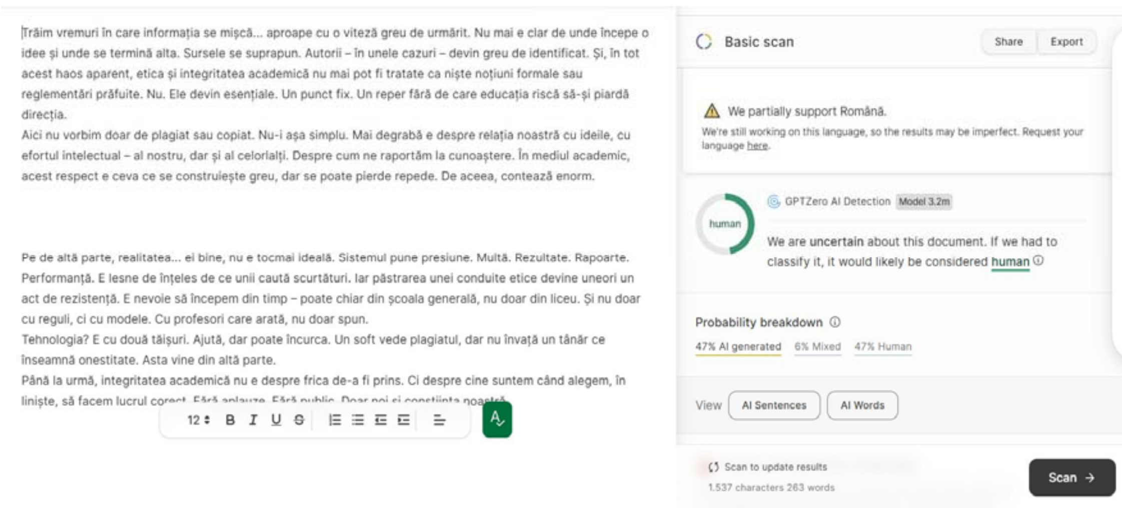
Appendix.1. Verification of AI-generated text in the OriginalityAI, Writer, QuillBot detection tool OriginalityAI.



Checking AI-generated text in the GPTzero and Undetectable.AI detection tool





EMERGING AND DISRUPTIVE TECHNOLOGIES INTEGRATION AND NATO'S OPERATIONAL AND STRATEGIC POSTURE

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Abstract: *This article explores the strategic implications of integrating Emerging and Disruptive Technologies (EDTs), including AI, autonomy, quantum, and hypersonic systems, into NATO's operational doctrine and warfighting capabilities. By analysing doctrinal shifts, lessons from the Ukrainian conflict, and the evolving role of unmanned aerial systems (UAS), the study reveals how NATO's Allied Command Transformation (ACT) and strategic foresight tools enable proactive adaptation to future threats. The article employs comparative-descriptive methodology and doctrinal content analysis to assess NATO's transformation frameworks and their operationalization through ACT initiatives. It concludes that anticipatory innovation and inter-domain convergence are crucial to NATO's deterrence posture in a contested security environment shaped by peer adversaries, hybrid warfare, and technological proliferation.*

Keywords: *drones, hybrid warfare, multi-domain operations*

1. INTRODUCTION

Are any geo-political side effects when utilizing drones on a large scale?

Over the course of history, the evolution of military systems has changed the physiognomy of warfare, doctrinal orientations, tactics and procedures. In recent decades, such a major shift in the way modern conflicts will be fought, whether unconventional or conventional, is foreshadowed.[16]

The integration of Emerging and Disruptive Technologies (EDTs) into NATO's operational and strategic posture is reshaping the Alliance's force structure, capability development, and doctrinal alignment. EDTs, including artificial intelligence (AI), autonomy, quantum technologies, hypersonic, and biotechnologies, present both opportunities and threats. [1]

The Alliance's embrace of these technologies is not merely additive but transformational, requiring multi-domain interoperability, agile experimentation, and digitally enabled decision-making frameworks. Through Allied Command Transformation (ACT), NATO has launched the *Emerging and Disruptive Technologies Implementation Roadmap***,** designed to accelerate technology adoption and guide member states in synchronizing innovation with interoperability. The result is a shift toward more flexible, responsive, and anticipatory warfighting concepts**,** laying the groundwork for a Multi-Domain Operations-enabled Alliance. The development of Unmanned Aerial Systems (UAS) has introduced profound geopolitical consequences by expanding the strategic military toolkit available to state actors. These systems enable states to project power and enforce regional interests with reduced political risk and deniability.

As noted by Supreme Allied Commander Europe, General Christopher Cavoli, "*adaptation in contact is no longer enough. We need to adapt in anticipation*." [14]This call for anticipatory adaptation underscores NATO's need to evolve beyond reactive force design and instead institutionalize foresight, resilience, and innovation at the doctrinal level.

I was a direct witness to such radical doctrinal and conceptual transformation, participating to all NATO Military Committee meetings between 2023-2025. To meet this challenge, NATO must synchronize its conceptual frameworks with rapid technological experimentation, particularly in the realm of autonomous and semi-autonomous systems. Such systems are not simply tools, they are enablers of new forms of command and control, distributed lethality, and precision engagement.

In the context of the ongoing war in Ukraine, Russian forces have systematically employed drones to achieve two interlinked objectives: precision deep-strike targeting of infrastructure and population, and the psychological erosion of Ukrainian civilian morale

Russian forces employ a wide array of unmanned aerial vehicles (UAVs) to strike not only military targets but also critical infrastructure and densely populated civilian areas. These operations extend beyond tactical utility; they serve a deliberate psychological objective.

This strategy blurs the line between conventional and irregular warfare, weaponizing fear and destabilizing public morale.

The lessons emerging from the Ukrainian conflict reveal profound shifts in both technological adaptation and doctrinal transformation. This war has accelerated the fusion of conventional, hybrid, and cyber capabilities into a multifaceted approach to warfare, wherein state and non-state actors employ "*all instruments of national and multinational power to pursue political objective*s."[25]

The integration of drone swarms, loitering munitions, electronic warfare, and information operations underscores the "*evolving character of conflict*" [2] and the urgent need for flexible, resilient, and technologically, enabled force structures.

The accelerated development of unmanned aerial systems (UAS) has necessitated their integration not only into traditional military operations and force structures but also into planning cycles and unconventional operational domains. UAS now influence decision-making at every level of command, requiring adaptive doctrines, revised operational concepts, and technology-informed leadership. [3]

Allied Command Transformation (ACT), headquartered in Norfolk, Virginia, is the NATO body responsible for capability development and technology integration. "*Emerging technologies, however, function as a double-edged sword. While they offer unprecedented advantages in surveillance, strike capability, and autonomy, they also introduce new vulnerabilities, such as electronic warfare, spoofing, and rapid obsolescence*."[5] Under the leadership of General Philippe Lavine and Admiral Pierre Vandier, ACT leads efforts to experiment with and implement UAS, AI, and multidomain connectivity across the Alliance. In my role as SACT Representative to Europe (since July 2023), I have observed the direct application of these strategies in high-level transformation policy and joint capability development. Secretary General Mark Reutte asserts the continuous support for Ukraine in next years.

2. METHODOLOGY

This article employs a comparative-descriptive research method, reinforced by strategic foresight and predictive modelling techniques.

The analytical framework incorporates doctrinal content analysis, contrasting NATO conceptual documents, such as the *NATO Warfighting Capstone Concept* (NWCC), the *Strategic Concept 2022*, and the *NATO Command Structure (NCS) Adaptation* initiative, with operational data from recent NATO and Ukrainian applications of Unmanned Aerial Systems.

The study further integrates empirical evidence from NATO Allied Command Transformation (ACT) outputs, "Romanian Military Strategy guidelines (2021), and open-source operational assessments."[25]

This multifaceted approach enables the identification of technological convergence points, doctrinal asymmetries, and resilience gaps, providing a grounded yet forward-looking evaluation of NATO's evolving counter-terrorism and UAS integration frameworks.

3. NATO TRANSFORMATION PROCESS

Peer competitors to NATO can be expected to employ UAS at the same level of technology, and under comparable operational principles, as the Alliance.

3.1. NATO Warfighting Capstone Concept (NWCC)

How do we define NATO vision for transformation, adoption of the new technologies, rebalancing deterrence and defence posture, to be better positioned in the future? The need for future transformation is underlined in NATO Warfighting Capstone Concept, which six-outs best describe this ambition – we need to out-think, out-pace, out-fight, out-excel, out-last, and out-partner.

NATO Warfighting Capstone Concept (NWCC) represents the Alliance's foremost doctrinal effort to guide warfare development and long-term strategic adaptation. The *NATO Warfighting Capstone Concept* (NWCC) [10] represents the Alliance's most advanced framework for warfare development, serving as a central doctrinal tool to guide strategic innovation and force transformation. It focuses and synchronizes efforts across domains to build military advantage, proactively shape the operating environment to the Allies' benefit, and foster convergence between operational needs and technological capabilities. "*Critically, the NWCC* expands the decision space for political authorities *by "generating flexible military options that impose strategic, operational, and tactical dilemmas on adversaries, thereby strengthening NATO's deterrence posture*." [9]

As a foundational framework, the NWCC seeks to synchronize military modernization across Allied nations by identifying priority areas for capability development, operational experimentation, and doctrinal evolution".[9] It enables NATO to maintain a competitive military advantage and to proactively shape the operational environment in ways that leverage the Alliance's collective strengths. "Importantly, the NWCC expands the decision space for political leadership by offering a wider array of calibrated military options. These options are not limited to force application; they are also designed to impose strategic, operational, and tactical dilemmas on potential adversaries, thus enhancing deterrence credibility while preserving escalation control.

By linking strategic ends with adaptable military means, the NWCC serves as a critical tool in enabling NATO's long-term resilience and warfighting readiness.

NATO Warfighting Capstone Concept (NWCC) is part of the coherent package of NATO Military Authorities best military thinking. Along with the 2020 Concept for Deterrence and defence of the Euro-Atlantic Area, the NWCC implements the 2019 NATO Military Strategy, a renewed approach setting out Alliance military-strategic objectives and the ways and means to implement them. [3]

The changing and evolving security environment puts the Alliance's continued success at risk. While NATO remains a defensive alliance, the operating environment demands new ways of thinking, organizing and acting.

Globalizations, technological driven society instability, rapid escalation of the conflicts, are common characteristics of the future. *"One thing is for sure; the nature of war will remain the same. Violence, having a political aim*". [9]

Russia and terrorist groups and organizations will continue to threaten the Alliance whilst the role and impact of China in particular, will grow. The operating environment is widening beyond traditional military bounds, with competition among different actors becoming more persistent across all instruments of power. This environment also features more diverse actors, with new weapons and technologies employed in new ways.

NATO Warfighting Capstone Concept (NWCC) offers an aspirational North Star vision for warfare development initiatives and the opportunity for engagement with all those who share the values of the Alliance.

Five major imperatives are distinguished in this vision: cross domain command and control, resilience, cognitive superiority, influence and projection of power. Therefore, the NWCC provides a description of the 2040 operating environment and future warfighting to identify implications for the future Military Instruments of Power.

The warfare development imperatives provide an organizing principle that promotes coherence across the breadth of warfare development efforts. They offer a new, forward-looking multi-domain (land, maritime, air, cyber, and space) and cross-instruments of power approach to military thinking, organizing and acting. They are immediately usable and implementable through the lines of delivery developed with the support of Allies, Supreme Allied Commander Europe, operational commanders and NATO HQ staffs, and engagement with Allies' academic communities.

What would be the steps envisioned by ACT, to transform NATO?

"Firstly, by improving our strategic understanding of the current and future global security landscape".[10] The success of the Alliance hinges on ability to tailor and scale-up NATO's transformation to shape and contest that environment. In considering the transformation process, future geopolitical trends are important, as are military technological advances. Technology and science, industry and academia are the scanning tools for tomorrow's horizon. Experimentation and testing are necessary steps to integrating future capabilities. It will also help up improve our cognitive superiority and understanding how to impact decision making calculus of our adversaries. Achieving this imperative, requires secure and rapid dissemination of Intelligence analysis tools to all operators. Achieving a decisive cognitive, superiority implies a rapid decision cycle, a robust and fast targeting process that implies technological progress at the tactical and operational levels and much more.

Secondly, by pushing boundaries and forging a collective capability to deliver multi-domain operations, flexible command and control, and unwavering interoperability. ACT's led work on Future Force Study augments NATO's ability to anticipate future force requirements in operational environments, including developments identified at the tactical level.

This study complements the NATO Defence Planning Process and aims to provide the Alliance with the means to shape future defence investment plans. But development of these capabilities can't be based on theoretical thinking alone. It must be linked to the research and development within the defence industry and aligned with maturing of key new capabilities. Therefore, interaction with the scientific world is as important for ACT's work as direct cooperation with military industry.

Thirdly, by leading digital transformation implementation efforts, particularly on Data and AI. We are transforming currently from a platform -centric force to a data-centric force. This process is not easy and implies important investments. This will undoubtedly have an impact on Command and Control, Electronic Warfare, Cyber, Joint effects and Joint Targeting. ACT is constantly interested in integrating AI in military decision-making process, starting from the tactical level, all the way to strategic decision-making.

A fourth dimension of NATO's warfare development approach is its sustained commitment to engaging relevant civilian and institutional audiences, including national stakeholders, academic communities, and the private sector. Through strategic dialogue and outreach, the Alliance actively taps into the intellectual capital and technological innovation distributed across member nations and commercial ecosystems. Forums such as the *Allied Warfare Development Agenda (AWDA)*, the *NATO Space Symposium*, the *Multi-Domain Operations Conference*, the *NATO Industry Forum*, and the *Strategic Foresight Symposium* provide Allied Command Transformation (ACT) with "*crucial platforms for cross-sectoral engagement, enabling the organization to challenge legacy mindsets, confront conceptual stagnation, and mitigate bureaucratic inertia*." [1]

These venues enrich NATO's capability development process by integrating insights from scientific research, defence experimentation, and commercial technology roadmaps. The ubiquity of emerging and disruptive technologies (EDTs), including cyber tools, electronic warfare (EW) systems, unmanned platforms, counter-UAS capabilities, and robotics, highlights the convergence point between industry, academia, and military transformation. ACT's ability to harness these partnerships is vital to the modernization of NATO's force structure, the evolution of military doctrines, and the "*adaptation of education and training frameworks necessary to counter both existing and future threats*."[11]

Finally, time is not a luxury for NATO. We need a rapid and profound transformation to keep our edge, and we need it now. When acquired or employed by malign actors, emerging technologies quickly transition into disruptive technologies, fundamentally altering the character of conflict.

The survivability and relevance of modern military forces increasingly depend on their ability not only to master these technologies but also to detect, neutralize, or mitigate their hostile use in contested environments.

Understanding and countering both state and non-state exploitation of dual-use technologies is no longer optional, it is central to deterrence and operational success.

The contemporary conflict environment is increasingly characterized by complexity and elusiveness, where conventional military operations are fused with hybrid and indirect approaches. Adversaries combine kinetic actions with non-kinetic effects, particularly in the space, cyber, and electromagnetic (EW) domains, to degrade, deceive, or destabilize.

When these capabilities are coordinated with non-military instruments of power, including diplomatic, informational, economic, legal, and cultural tools, the potential for escalation outside the boundaries of traditional conflict becomes substantial. In such environments, national resilience and societal preparedness are no longer strategic afterthoughts, they are preconditions for governance continuity in times of crisis and war.

A central priority of NATO's Allied Command Transformation (ACT) is the design and facilitation of future-ready capabilities that enable the Alliance to operate as a fully integrated Multi-Domain Operations (MDO) force. "*This transformation aims to ensure interoperability and convergence across land, air, maritime, cyber, and space domains, enabling synchronized effects and rapid decision-making in contested environments.*" [1]

Through doctrinal innovation, capability development, and multinational experimentation, ACT provides the strategic framework necessary for NATO's adaptation to high-intensity warfare and hybrid threats."[2]

3.2. How do we need to adapt for the tomorrow's fight or What do we learn from Ukrainian conflict?

Future warfare will be increasingly defined by the convergence of autonomy, mass deployment, and multi-domain integration. Systems capable of **autonomous operation,** particularly those enhanced by artificial intelligence (AI), will dominate not only reconnaissance and surveillance roles but also direct engagement and electronic warfare functions.

According to projections from NATO's Allied Command Transformation (ACT), Unmanned Aerial Systems (UAS) will evolve beyond their traditional intelligence, surveillance, and reconnaissance (ISR) functions to become autonomous decision nodes within distributed, self-healing command-and-control (C2) architectures**.**

These platforms will enhance NATO's responsiveness, adaptability, and resilience in contested environments. However, the adoption of these technologies will also introduce new vulnerabilities, including adversarial AI attacks, data spoofing, and system misidentification. There is a future need for a better balance between NATO deterrence and defence posture. "*Deterrence by denial is incomparably cheaper than deterrence by punishment."*[14] Deterrence requires capability plus credibility coordination between all military and nonmilitary capabilities.

The contemporary and future battlespace is characterized by a sensor-saturated environment and intense electromagnetic warfare (EW) contestation. This dynamic is further complicated by the pervasive influence of space and cyber operations, which now have tangible effects on both strategic planning and tactical execution.

In such a contested ecosystem, deterrence and defence concepts must begin with a clearly articulated strategic objective and defined end state. As NATO doctrine asserts, credible deterrence requires convincing potential adversaries that the "*cost of aggression will be disproportionately high*"[8] rendering any attack not only futile but a grave strategic miscalculation. At the heart of this posture lies NATO's primary mission: the collective defence of its members, aimed at preserving the Alliance's territorial integrity, political sovereignty, and strategic stability.

To operationalize this mission, NATO doctrine delineates three interdependent core tasks: deterrence and defence, crisis prevention and management, and cooperative security. Each task is divided into sub-tasks, further translated into lines of effort and assigned to responsible commands, partners, or institutional entities. This structured operational design ensures that strategic intent cascades coherently into tactical implementation.

In today's increasingly unpredictable security environment, several critical trends in warfare have become evident.

First, the enduring value of surprise underscores a persistent strategic-operational dilemma. Despite the proliferation of sensors, satellite coverage, and intelligence platforms, the ability to anticipate an adversary's strategic intent or operational maneuver remains limited.

In the context of high-intensity, attritional warfare, volume of fire and the capacity to reconstitute combat power, remain decisive. However, less powerful actors may offset this asymmetry through enhanced speed and precision of fires, the application of network-centric warfare, and the adoption of mission command principles supported by resilient, flexible command-and-control (C2) systems.

"*The use of adaptable emerging and disruptive technologies (EDTs) further amplifies this compensatory effect, enabling agile strike capabilities and dynamic battlefield adaptation*." [19]

Another crucial development is the compression of the decision cycle and the acceleration of the so-called *kill chain*. Forward-deployed sensors now enable real-time or near-real-time links with strike vectors, allowing for dynamic targeting within five minutes at the tactical level and approximately thirty minutes at the operational level. This responsiveness transforms sensor-to-shooter chains into tightly integrated decision ecosystems, vastly improving battlefield lethality.

Despite technological advancements, air superiority remains essential for campaign success. However, the mass deployment of drones is beginning to erode traditional airpower dominance. Evolving drone tactics are having a cascade effect on force structure, education, and training. These systems now operate at scale to generate mass effects, often in combination with traditional firepower platforms such as ballistic missiles, cruise missiles, artillery, and airstrikes**. "***The next doctrinal evolution, swarm coordination, seeks to integrate these platforms into a unified, multi-vector attack model."*[2]

Second, the roles of space and cyber domains have become foundational in shaping battlespace. These domains are not only integral to enabling real-time coordination and communications but also serve as decisive enablers for the effective employment of drones and other unmanned systems. Third, the autonomy of drones is advancing rapidly, reflecting a technological trajectory marked by shorter innovation cycles, algorithmic evolution, and adaptive mission parameters. "*Drones are increasingly capable of adjusting to dynamic operational conditions, making them indispensable tools in contemporary and future warfare."*[2]

Terrain and critical infrastructure continue to shape the conduct of offensive and defensive operations, particularly in urban and key terrain environments. Drones are now proven assets in air, land, and maritime operations, offering cross-domain flexibility.

At the same time, population-centric effects and strategic communication remain central to contemporary conflict. Drone use has demonstrated not only kinetic efficiency but also significant psychological impact on civilian populations, blurring the boundary between battlefield and home front.

CONCLUSIONS

NATO must accelerate its pace of adaptation to remain relevant and operationally effective in a rapidly evolving strategic environment.

Emerging and Disruptive Technologies (EDTs) are no longer optional enhancements; they have become essential force multipliers that ensure both survivability and lethality across all domains.

To harness their potential, NATO must embrace a culture of innovation, backed by robust research and development (R&D) frameworks and a *"continuous exchange of information between institutional, industrial, and academic stakeholders*."[11]

The development of common and collective capabilities is essential to fill systemic gaps that individual member states may be unable to resolve alone. Programs like *Global Hawk AGS and AWACS* exemplify the necessity and feasibility of multinational capability development.

Similarly, NATO's operational success in the space and cyber domains hinges on deepening cooperation among Allies and synchronizing efforts with the European Union to accelerate the operationalization and integration of critical capabilities.

However, EDTs also introduce structural and doctrinal challenges. *"The emergence of new operational requirements, jointly defined by Allied Command Transformation (ACT) and Allied Command Operations (ACO), is already reshaping NATO's capability codes and radically influencing future capability targets and the "NATO Defence Planning Process (NDPP) cycle."*[1]

This transformation demands innovative force concepts, including hybrid force structures that integrate manned and unmanned elements, thereby necessitating fundamental force reform.

Revolutionary shifts are also expected in training, education, and exercises. Bold, adaptive exercises must provide safe environments to test, fail, learn, and refine, ensuring that tactical failures in simulations translate into operational success in combat.

NATO's modernization is ultimately a dual process: technological advancement and cognitive adaptation. In this context, innovation becomes not just a competitive edge, but a survival imperative. The modernization of NATO's guiding concepts, force structures, and deterrence mechanisms is indispensable for maintaining credible defence and strategic flexibility. This transformation encompasses both institutional reform and operational innovation at the tactical level.

In high-intensity, multi-domain warfare, survivability is not guaranteed by firepower alone but increasingly depends on deception-based measures, such as decoy operations, electromagnetic camouflage, and thermal signature suppression**.** These elements must be systematically integrated into Standard Operating Procedures to ensure force protection in environments saturated with ISR assets and exposed to advanced targeting systems.

The deliberate application of deception and concealment techniques**,** especially under electronic warfare and thermal surveillance, should no longer be treated as ad hoc improvisations but as core components of "*doctrinal planning and training exercises*."[2]

No doubt the modernization of NATO forces is a priority, and addresses several areas, such as: readiness built up, interoperability, force digitization, connectivity and communications security, Cyber defence, expeditionary role, deep strikes integration, Joint Surveillance Targeting Acquisition Reconnaissance (JSTAR) integration at all operational levels, which further implies the necessary integration of modern UAS in operations, in parallel with standardization of counter UAS measures. [17]

The future of warfare will demand a force that can adapt rapidly or risk irrelevance and collapse in the face of exponential technological advancement. Emerging and Disruptive Technologies (EDTs)**,** particularly those incorporating artificial intelligence, autonomy, and networked systems, are evolving at an unprecedented pace. These technologies are not simply tools—they are transformational enablers that will reshape the conduct of war.

Future battlefields will be dominated by systems capable of autonomous operation**,** mass employment, and multi-domain integration**.**

The proliferation of AI-enabled drone swarms**,** cyber-resilient UAVs**,** and precision-strike coordination mechanisms at both tactical and strategic levels will redefine operational tempo and command structures. Equally essential is the continuous stress-testing of autonomous systems in realistic, multi-domain training environments to ensure resilience, mission assurance, and interoperability under contested conditions.

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TEACHING ROUTINE *RADIOTELEPHONY* LANGUAGE STRUCTURES TO ROMANIAN AIR FORCE CADETS – LIST OF TYPICAL ERRORS BASED ON TRADITIONAL LISTENING GAP-FILL EXERCISES

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Abstract: *The main focus of the article is on the quantitative proportion and distribution of routine RT adult learner errors while learning aviation English as ESP. The analysis covers two phases of flight: taxiing and route clearances. The corpus is made out of undergraduate (Air Force cadet) classroom-produced materials featuring rather traditional gap-fill exercises. The main purpose is to identify areas of difficulty and lay the groundwork for further quantitative and qualitative approaches on the specific challenges affecting Romanian learners studying aviation English as EPP. Another line of investigation seeks to differentiate L1-based mistakes against the difficulties in student listening proficiency and to establish when functional literacy issues affect learner results.*

Keywords: *ESP/EPP, radiotelephony, functional literacy, RT vocabulary, error analysis*

1. THEORETICAL BACKGROUND AND PURPOSE

Error analysis is seen as one of the cornerstones of student/adult learner ability enhancement in second language acquisition [1, 2, 3]. Much in the same vein, the present article is the third step in a series of researches (see also [4] and [5]) meant to analyze the specific errors made by Romanian users of aviation English from the perspective of their quantitative distribution around topics, considering criteria such as L1 interference in foreign language acquisition (FLA) or functional literacy, as well as other qualitative interpretation of these findings. The main goal of the series is to address the common difficulties that Romanian users of ESL as EPP in the aviation industry come across in their learning process. Just like with our previous publications, we consider this contribution to be a pre-research experiment within the framework of a research project under which further analyses could be conducted (see Acknowledgement). This is also to say that to avoid unnecessary repetition, for further background information on our theoretical sources and the full display of concepts and researches that laid the foundation of the entire project, we kindly invite the reader to consider our previous work [4, 5]).

As such, this article focuses in particular on routine RT phraseology as defined by ICAO, seeking to count main difficulties as they result from the topic-centered organization of errors in Romanian Air Force cadet classroom-produced final exam simulation tests. The two main study topics are focused on the language structures that make up the common ground of routine exchanges about route clearances and taxiing.

The methodology is based on seminal contemporary literature in the field [6, 7].

2. METHODOLOGY

For this limited experiment, three mixed-ability undergraduate student groups' classroom produced materials were subjected to analysis. The learners' approval for their work to be used under the protection of anonymity was asked and received at the beginning of the respective courses. The military cadet groups involved belonged to three air traffic management-oriented classes counting 12, 11 and 10 undergraduates, respectively. For privacy concerns, we will refer to them as A, B and C, respectively. The exact same recording was used with compeer groups A and B for the exact same task, therefore all 23 answer sheets collected refer to the exact same context delivered in identical conditions (including the technical assets used in class, the answer forms etc.). This apparent disparity in the distribution of the material was also intended as a control mechanism: one of the purposes was to check whether with a larger number of learners the percentages and the frequency of the same mistakes was to remain relatively consistent. Since the analysis below demonstrates that the percentages and error specificities remained largely stable with larger numbers, a different task and recording was used in the case of group C, based on the thus documented assumption that error quantity and distribution can be taken as relevant.

The use of specialist vocabulary proficiency as well as specific syntax was tested by means of a traditional listening gap-fill exercise based on dialogues in Fiona Robertson's classic coursebook *Airspeak* [8]. They involve limited, standardized but lifelike routine RT language contexts. The purpose was to check the overall student passive competence in understanding the language structures of standard phraseology, with a focus on the pragmatics and semantics of the particular morphology and syntax that affect its pragmatic value (*i.e.*, the existential correspondence between language and action or in other words, the effect of language over actual existence in its professional aspect). But while the purpose of the practice was the same, the scope differed from one group to another: specifically, with groups A and B, the exercise covered the understanding of taxying routines, while with group C, it was based on typical exchanges exemplifying route clearance routines. The class activities turned into the corpus for this study were part or the final test simulation reinforcement exercises, and hence all groups had studied almost for a full semester the routine and non-routine standard phraseology recommended for the first five phases of flight in the sequence of seven (namely pre-flight, taxiing, takeoff, climb and cruise).

For further methodological details, see the first article in the series dedicated to the specific errors made by Romanian EFL students [4].

3. CORPUS ANALYSIS

As shown above, the actual corpus consists of 44 student written contributions and the corresponding 33 one-on-one Professor feedback sheets, distributed as follows:

- 23 answer sheets (12 A + 11 B);
- 10 answer sheets (10 C).

The distribution above resulted in 2 „error-collection" tables, one for each group. All cadets were of perfectly similar age groups, qualifications and years of study. The exercise comprised 20 gaps per sheet (*i.e.*, per test) for each of the groups, resulting in a total of 660 answers received from the cadets in all three groups (ABC): 240 from group A, 220 from group B and 200 from group C.

The following analysis will detail the errors in the sense of error quantification, topic-related distribution and proportions, according to the criteria set in the previous sections (see *1. Introduction: Theoretical Background and Purpose*).

3.1 A list of typical errors in understanding taxiing routine exchanges (groups A and B).

Student answers turned out as described in Table 1. Formally, each cadet was assigned a number and a group designator (A or B) and a number (1, 2, 3…). We have abbreviated General English (or plain English) as Gen.E. and Aviaion English as Av.E. and we have regrouped error distribution around four main criteria: listening and writing proficiency versus L1 interference, and random versus logical association of phonetic reconstruction (a phenomenon occurring as an intently taught last resort solution or "backup plan" whenever the confident phonetic perception is not possible). The last pair of opposites, to which we added the option we call "zero reconstruction" to describe situations where no attempt to "guess around" the auditory input was made, are meant to hint at the degree of functional literacy of the learners and their ability to use it in the given specific contexts. The tables only show the errors in student answers (column 2) and the correct corresponding structure (column 3), and "error type" according to the said criteria, to facilitate the observation of error reoccurrence. Asterisks mark relevant remarks able to suggest the classification and distribution of mistakes: for example, under A1.1, the asterisk helped exclude L1 interference in matters of syntax (the English noun phrase) under General English.

Table 1. Groups A and B – Taxiing (routine).

Std. code	***Errors***	***Answers (based on answer key)***	***Error Type***
A1	**1.** [report] **…**	[report] **vacated** **but [runway vacated] OK*	**A1.1. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
A2	**1.** [request] **…** [runway]	[request] **cross** [runway]	**A2.1. zero reconstruction** Av.E. L1 interference (syntax)
	2. outshort	**hold short** **but [holding short] OK*	**A2.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	3. [runway] **…**	[runway] **vacated** **but [report vacated] OK*	**A2.3. zero reconstruction** Gen.E.: listening proficiency
A3	**1. holding …**	**hold** [short] **but [holding short] OK*	**A3.1. random+zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
A4	**1. now**	[runway] **29L**	**A4..1. random reconstruction** Gen.E.: listening proficiency
A5	**1. Runway**	**runway** *capitalized throughout the test*	**A5.1. logical reconstruction** Gen.E.: writing proficiency (spelling of nouns) Av.E.: writing proficiency (spelling of basic vocabulary)
	2. runaway	**runway** *hesitation throughout the test (*runaway *used once, corrected for the rest of the entries)*	**A5.2. random reconstruction** Av.E.: writing proficiency (spelling of basic vocabulary), L1 interference (lexicology)

Std. code	***Errors***	***Answers (based on answer key)***	***Error Type***
A6	**1.** [report] **…**	[report] **vacated** *1st occurrence*	**A6.1. zero reconstruction** Gen.E.: listening proficiency / L1 interference (syntax) Av.E.: L1 interference (syntax)
	2. [runway]**…**	[runway] **vacated** *2nd occurrence of vacated in 2 different contexts*	**A6.2. zero reconstruction** Gen.E.: listening proficiency / L1 interference (syntax)
A7	X	X	No error.
A8	**1. …**	**runway**	**A8.1. zero reconstruction** Av.E.: L1 interference (lexicology)
	2. [request] **…** [runway]	[request] **cross** [runway]	**A8.2. zero reconstruction** Av.E.: L1 interference (syntax)
	3. [report] **…**	[report] **vacated** **but [runway vacated] OK*	**A8.3. zero reconstruction** Gen.E.: listening proficiency / L1 interference (syntax) Av.E.: L1 interference (syntax)
A9	**1.** [report] **…**	[report] **vacated** *1st occurrence*	**A9.1. zero reconstruction** Gen.E.: listening proficiency / L1 interference (syntax) Av.E.: L1 interference (syntax)
	2. [runway] **promoted**	[runway] **vacated** *2nd occurrence of vacated in 2 different contexts*	**A9.2. random reconstruction** Gen.E.: listening proficiency / L1 interference (syntax)
A10	**1. runaway**	**runway** *confusion occurs throughout the test*	**A10.1. random reconstruction** Av.E.: writing proficiency (spelling of basic vocabulary), L1 interference (lexicology)
	2. vocated	**vacated** *confusion occurs throughout the test*	**A10.2. random reconstruction** Av.E.: writing proficiency, *spelling (copied?)*
A11	**1.** [request] **cros** [runway]	[request] **cross** [runway]	**A11.1. logical reconstruction** Gen.E.: writing proficiency (spelling of verb CROSS) Av.E.: writing proficiency (spelling of basic vocabulary)
A12	X	X	No error.
B1	**1. outsure**	**hold short**	**B1.1. random reconstruction** Gen.E.: listening proficiency
	2. holding **sure**	**holding short**	**B1.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	3. [report] **…**	[report] **vacated** **but [runway vacated] OK*	**B1.3. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
B2	**1.** [request] **across** [runway]	[request] **cross** [runway]	**B2.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. off shore	**hold short** **but [holding short] OK*	**B2.2. random reconstruction** Gen.E.: listening proficiency
	3. unpropagated	[report] **vacated**	**B3.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
	4. [runway] **indicated**	[runway] **vacated**	**B3.4. random reconstruction** Gen.E.: listening proficiency

Std. code	***Errors***	***Answers (based on answer key)***	***Error Type***
B3	**1.** [request] **crossway** [runway]	[request] **cross** [runway]	**B2.1. logical reconstruction** Gen.E.: listening proficiency
	2. I'll sure	**hold short** **but [holding short] OK*	**B3.2. random reconstruction** Gen.E.: listening proficiency
B4	**1. approching**	**approaching**	**B4.1. logical reconstruction** Gen.E.: writing proficiency (spelling, slip of the pen?)
	2. [request] **…** [runway]	[request] **cross** [runway]	**B.4.2. zero reconstruction** Av.E.: L1 interference (syntax)
	3. runaway	**runway** *confusion occurs throughout the test*	**B4.3. random reconstruction** Av.E.: writing proficiency (spelling of basic vocabulary), L1 interference (lexicology)
	4. holding …	**holding short** **but [hold short] OK*	**B4.4. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	5. [report] **…**	[report] **vacated**	**B4.5. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
	6. [runway] **vocated / vacated**	[runway] **vacated** *spelling insecurity*	**B.4.5. random reconstruction** Gen.E.: writing proficiency (spelling insecurity /copied?)
B5	**1. approching**	**approaching**	**B4.1. logical reconstruction** Gen.E.: writing proficiency (slip of the pen?)
	2. [request] **…** [runway]	[request] **cross** [runway]	**B5.2. zero reconstruction** Av.E.: L1 interference (syntax)
	3. … …	**hold short** **but* holding short *OK*	**B5.3. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	4. runaway	**runway** **confusion occurs throughout the test*	**B4.3. random reconstruction** Av.E.: writing proficiency (spelling of basic vocabulary), L1 interference (lexicology)
	5. holding …	**holding short**	**B5.3. random+zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	6. [report] **…**	[report] **vacated** **but* runway vacated *OK*	**B5.6. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
B6	**1.** [request **crossed** [runway]	[request] **cross** [runway]	**B6.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. all short	**hold short**	**B6.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
	3. located	**vacated** **confusion occurs throughout the test*	**B6.3. random reconstruction** Gen.E.: listening proficiency

Std. code	***Errors***	***Answers (based on answer key)***	***Error Type***
B7	**1. holding** short	**hold short**	**B7.1. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	2. [report] **…**	[report] **vacated** **but* runway vacated *OK*	**B7.2. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
B8	X	X	No error.
B9	**1.** [report] **…**	[report] **vacated** **but* runway vacated *OK*	**B9.1. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
B10	**1.** hold **shot**	**hold short** **but* holding short *OK*	**B10.1. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)
B11	**1.** [request **crossing** [runway]	[request] **cross** [runway]	**B11.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. I'll sure	**hold short**	**B11.2. random reconstruction** Gen.E.: listening proficiency
	3. **holding …**	**holding short**	**B11.3. random+zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (lexicology, syntax)
	4. [report] **…**	[report] **vacated** **but* runway vacated *OK*	**B11.4. zero reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax)

Based on the table above, the general student proficiency is rather satisfying, with a metric average of erroneous answers per student of about 2.5 (about 11.4%). 76 incorrect answers were given, out of which 48 by groups A and B considered together, while the rest of 28 belong to group C.

In groups AB, the number of errors is almost equally distributed between General English and Aviation English (40 versus 36 in total). Thus, the total error percentage does not surpass a mathematical mean of 12.5% per cadet. Of course, what is obvious without even counting is the dominance of certain insufficiencies: plain English listening proficiency should have been expected to rank highest in a listening test, with a contribution of 34 errors to the total number of General English errors, while in Aviation English, 30 cases are due to L1 interference, mostly in syntax (27) and lexicology (15). Comparatively, L1 interference with plain English counts 5 suspected/potential occurrences in total.

As far as reconstruction types are concerned, zero reconstruction characterizes 21 wrong answers, random reconstruction – 22, and logical attempts at reconstruction – only 5. In other words, among the 20 cadets having provided incorrect answers, only 5 seem to use their logic in what concerns the construction of meaning, indicating a possibility of functional illiteracy in 15 of the learners having committed errors (about 3 quarters or 75%).

3.2 Typical errors in understanding route clearances (group C).

Student answers turned out as described in Table 2, where each cadet was assigned a group designator (C) and a number (1, 2, 3…).

Table 2. Group C – Route clearances.

Std. code	***Errors***	***Answers (based on answer key)***	***Error Type***
C1	**1. clear** to	**cleared to**	**C1.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. 59 group	**flight planned route**	**C1.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax, lexicology)
	3. another two [departure]	**N**[ovember] **2** [departure]	**C1.3. random reconstruction** Gen.E.: listening proficiency
	4. … … …	**that is correct**	**C1.4. zero reconstruction** Gen.E.: listening proficiency
C2	**1. clear** to	**cleared to**	**C2.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. 59 group	**flight planned route**	**C2.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax, lexicology)
	3. another two [departure]	**N**[ovember] **2** [departure]	**C2.3. random reconstruction** Gen.E.: listening proficiency
C3	**1. clean** to	**cleared to**	**C3.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category, paronyms) Av.E.: L1 interference (syntax)
	2. turn **heading** after	**turn left after**	**C3.2. logical reconstruction** Gen.E.: listening proficiency
C4	**1. clear** to	**cleared to**	**C4.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. five nine group	**flight planned route**	**C4.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax, lexicology)
	3. another two [departure]	**N**[ovember] **2** [departure]	**C4.3. random reconstruction** Gen.E.: listening proficiency
C5	**1. then head out to**	**turn left after**	**C5.1. random reconstruction** Gen.E.: listening proficiency
C6	**1. clear** to	**cleared to**	**C6.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. … to [departure]	**N**[ovember] **2** [departure]	**C6.2. zero+random reconstruction** Gen.E.: listening proficiency (lexicology, paronyms)
	3. … … after	**turn left after**	**C6.3. zero+zero+logical reconstruction** Gen.E.: listening proficiency
	4. air born	**airborne**	**C6.4. logical reconstruction** Gen.E.: writing proficiency - spelling based on *paronyms* air born *versus* airborne
C7	**1. clear** to	**cleared to**	**C7.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. 59 group	**flight planned route**	**C7.2. random reconstruction** Gen.E.: listening proficiency Av.E.: L1 interference (syntax, lexicology)
	3. … left after	**turn left after**	**C7.3. zero+logical+logical reconstruction** Gen.E.: listening proficiency

Std. code	*Errors*	*Answers (based on answer key)*	*Error Type*
C8	**1. clear** to	**cleared to**	**C7.1. random reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax)
	2. flight **down** route	**flight planned route**	**C8.2. logical+zero+logical reconstruction** Gen.E.: listening proficiency (lexicology, grammatical category within the same word family) Av.E.: L1 interference (syntax, lexicology)
	3. air borne	**airborne**	**C8.3. logical reconstruction** Gen.E.: writing proficiency – spelling based on *etymology, paronyms* air borne (noun + past participle of bear) *and the compound* airborne (spelling)
C9	**1. number** 2 [departure]	**N**[ovember] **2** [departure]	**C9.1. logical reconstruction** Gen.E.: listening proficiency
	2. 10 left after	**turn left after**	**C9.2. logical reconstruction** Gen.E.: listening proficiency
	3. airport	**airborne**	**C9.3. random reconstruction** Gen.E.: listening proficiency
C10	**1. number** 2 **for** [departure]	**N**[ovember] **2** [departure]	**C10.1. logical reconstruction** Gen.E.: listening proficiency
	2. airborn	**airborne**	**C10.2. logical reconstruction** Gen.E.: writing proficiency - spelling based on confusion between *pseudoword paronym* airborn and air born, used in place of airborne

Table 2 does not bring any major turnover in relation to Table 1. With the general number of 2.8 erroneous answers out of 20 per student and a 12.7% total presence of wrong answers (28 in metric value) out of the total of 220 answers given.

An interesting finding is that the number of errors is no longer equally distributed between General English and Aviation English, with the plain variation ranking first at more than double in number of mistakes (28 versus 12 in total, respectively). Thus, the total error percentage does not surpass a mathematical mean of 10% of all possible errors per cadet (i.e., 40).

Again, it is visible that plain English listening proficiency contributes to almost all errors, while in Aviation English, 12 mistakes are due to L1 interference, with syntax (12) and lexicology (5) topping the chart.

As far as reconstruction types are concerned (counting combinations as well), zero reconstruction defines 6 wrong answers, random reconstruction – 17, and logical attempts at reconstruction counts higher than with AB groups, at a metric value of 12. In other words, among the 35 reconstructions, 12 are based on logic in what concerns the construction of meaning, indicating a possibility of functional illiteracy being at the root of more than 34%, but still at about half the percentage in potential functional illiteracy obtained by groups AB.

3. CONCLUSIONS: SYNTHESIS AND FURTHER LINES OF INQUIRY

With the idea that the number of wrong answers and the count of errors are not identical (on the contrary: errors are at an approximate double by comparison), let us consider the quantitative sum-up under table 3.

Table 3. Quantitative sum-up (general values)

General information	**Values**
total no of answers	660
total no of wrong answers	76
proportional value wrong answers	11.4%
total no of errors in Gen.E.	40AB+28C=68
total no of errors in Av.E.	36AB+12C=48
zero reconstruction cases	21AB+6C=27
random reconstruction cases	22AB+17C=39
logical reconstruction cases	5AB+12C=17

Among the total figures, the only sums that are supposed to become a real concern are the ones indicating the lack of logical reasoning in meaning reconstruction.

However, mention should be made that as shown in sections 3.1 and 3.2., according to topic, the wight of Aviation English syntax and lexicology sizably varies, with about two times more L1 interference in syntax in routine exchanges revolving around taxiing procedures than route clearances, while the vocabulary of Aviation English and plain English is more affected by the said phenomenon as far as route clearance routines are concerned.

Of course, the present quantitative approach would benefit greatly from an in-depth qualitative complementary discussion, to account for the typical errors based on further linguistic, semantic and cultural criteria, to demonstrate which intellectual mechanisms are prone to L1 interference with predilection and for what reasons.

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STRATEGY FOR THE IMPLEMENTATION OF INNOVATIONS IN THE LOGISTICS INDUSTRY

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Abstract: *Logistics firms confront escalating regulatory scrutiny, shrinking labour pools, and rising customer expectations for transparency. Addressing these pressures demands more than scattered technology pilots; it calls for a coherent implementation strategy that turns innovation from isolated gadgets into systemic capability. This article synthesises findings from twelve rigorously selected empirical studies and threads them with insights drawn from the dual-layer OnLogix–Excel Logistics transformation case. Through a systematic literature review we extract five critical success factors—data-integration readiness, top-management sponsorship, modular SaaS architecture, continuous compliance automation, and user-centric change management—that consistently underpin performance gains across carrier sizes. We then map these factors onto an actionable roadmap that begins with digital spine modernisation and culminates in franchise-style diffusion. Meta-analysis indicates average operating-cost reductions of 29 % and compliance-fine declines of 55 % when the factors co-occur, echoing the outcomes observed in early adopters of OnLogix. Practical guidance emerges for vendors, carriers, and policy actors alike. By converging academic evidence with practice-based knowledge, the study advances Logistics 4.0 theory and offers managers a calibrated checklist for de-risking innovation roll-outs. Limitations, including reliance on secondary data, are acknowledged, yet the provided framework lays the groundwork for future longitudinal investigations into multi-modal and cross-regional settings.*

Keywords: *logistics innovation; implementation strategy; Logistics 4.0; SaaS architecture; compliance automation; data-integration readiness; SME carriers; digital transformation.*

1. INTRODUCTION

The logistics landscape has never been ever, but a modern mixture of digital acceleration, lack of constant expertise and tightening the regulatory screws is pushing the industry into truly unmapped waters. Fleet operators see Erode Erode because office work accumulates better and sender requires real time visibility that older systems certainly cannot add. In the US, for example, providers juggle policy compliance with Federal Motor Carrier Security Administration regularly find that the only missing document can stop an otherwise useful lane. Add a shrinking fund of certified drivers and dispatchers and the final result is a volatile environment in which each promise of the era is considered to threaten operational paralysis. Paradoxically, endless companies maintain to deal with innovations as a screw-up system, here the routing application-place as a coordinated agency's function.

Academic studios reflect this fragmentation. Cichosz, Wallenburg and Knemeyer (2020) will notice that logistics carriers often release digital initiatives without first modernizing the "information spine", which led to steep price disasters, while the APIs were acting or flashing Crimson.

Yet there is also nice evidence. Wang and Sarkis (2021) show that as soon as the integration of information, managerial sponsorship and modular equipment SAAS, corporations gain considerable financial savings and carbon discounts. These studies, which were taken together, portray them a nuanced photography: success is possible, but only under a carefully organized set of situations-shifts that small and medium societies rarely manipulate to collect themselves.

Against this background, the double -layer transformation version began to obtain traction. It connects the cloud-natural platform that standardizes the information flows with the software layer adapted to daily dispatch, accounting and responsibility for compliance with the regulations. The backbone ONLIGIX and its logistics Excel gives up the queue of this architecture. While the platform harmonizes databases, security principles and integration protocols, the application provides you by plug-and-play modules that the dispatcher can hold close in minutes. Soon adoptive reports that the operating price north of thirty in accordance with a cent and steep decline in compliance fines, indicating that the version could also clean up "too small to digitize, too much to ignore" a paradox that confronted with fleets that one for fifty vehicles. These discipline effects improve the apparent research question: are the profits of context or the manifestation of wider factors have already indicated in the literature?

This article deals with the fact that it asks through weaving common knowledge from twelve reviewed empirical investigation and rich, practical primary narratives about the introduction of ONLIGIX. No new area survey or laboratory experiment has been carried out; Rather, the study conducts a scientific assessment of contemporary empirical work, acquires common factors of success, overall performance metrics and failure regimes. This meta-synthesis is then used as a lens, through which the case is lame, which allows a grounded discussion of why it seems that a double layer strategy overcomes partial approaches. Such a layout, mixing of structured evidence with the example of the living industry gives two blessings. First, it will postpone the time and requirements for the SPARKLING RECORDS series sources, although it still maintains empirical strictness, because each of the twelve supplies of supplies has already cleared the control of mutual evaluation. Secondly, it allows extra dialectical interpretation: finding that compensates for in contexts, advantageous credibility, while disagreements project border conditions that the practitioners must recognize.

Handbook for three goals inquiry. The first is diagnostics: to find out which important factors of success appear to be the maximum in empirical studies of innovation implementation in logistics. The second is explanatory: to suggest how these factors are involved in the logistics deployment of ONLIGIX - Excel, illuminating causal pathways instead of mere correlations. 0.33 is prescribed: to convert mixed evidence to pragmatic emanations can follow, supplement checkpoints, estimates of assistance and suggestions for threat. The basis of all three goals is to bridge the academy - average. Too often scientific fashion remains imprisoned in magazines at the same time as the practicing reappearing the bike for a fantastic fee; By laying literature and field evidence, this item tries to shorten this high price loop.

Why does he remember it now? Because the economy is leaning. Volatility Spot Market is growing as a norm, and virtual agents supported by the project show a brand new bar for the velocity of the provider.

Carriers hanging into the workflows of mobile phones and faxes control the threat of descent into the long tail of the company and serve non -profit masses that reduce competitors with technology. Political indicators increase urgency. Given that environmental, social and administrative measures are moving from the deck of images to fine requirements, carriers are increasingly demanding sellers to report emissions at the cost of the cost.

This demand cannot be satisfied without incorporated data pipes. Quickly is a window for incremental bulging; Holistic strategies that are able to organize more than one innovation at the end of the concerts are rapidly turning into a competitive assumption.

The article proceeds using the explanation of how literature has been collected and proven, and then distillates repetitive objects into the compact framework. Subsequently, ONLIGIX is beneficial, now not as the only anecdote, but as an illustrative canvas on which the factors derived from literature are tested and tested. The final sections debate the consequences, outline of barriers and travel from Destiny Inquira, especially in terms of multimodal logistics and intercontinental adoption. Through this arc, we look at the goals of focusing both scientific know-how and managerial elections, which shows that even if it approaches strategically, innovation can move from a disturbing danger to the disciplined lever of sustainable profit.

2. LITERATURE REVIEW

Innovation in logistics has matured from sporadic technical tinkering to an arena where strategic orchestration decides whether a carrier thrives or slips into the industry's crowded middle tier. Scholarly work over the last decade documents this shift with growing granularity, yet the evidence base remains dispersed across studies that vary in scope, metrics, and context. To clarify the landscape, this review integrates insights from eight influential empirical contributions and threads them into a coherent narrative that explains how, when, and why particular implementation strategies succeed. The discussion deliberately maintains a brisk rhythm—short bursts of assertion alternate with longer analytical passages—so that conceptual threads stay visible while cognitive fatigue stays low.

The modern conversation arguably began when Göpfert and Wellbrock (2016) demonstrated that logistics service providers who coupled incremental process tweaks with a formal innovation-management system outperformed peers relying on ad-hoc experimentation. Their multi-country survey sketched a simple but powerful idea: innovation must be institutionalized, not romanticised. Four years later Cichosz, Wallenburg, and Knemeyer (2020) extended that notion by coining the term "digital spine," a metaphor for the data architecture that supports every operational limb. Their mixed-methods study—forty interviews triangulated with survey data—showed that fancy optimization dashboards fail within weeks when the underlying data plumbing leaks. The insight is almost trivial, yet fleets still buy dashboards first and databases later. Such behavior reveals a persistent gap between what researchers prescribe and what managers priorities under budget pressure.

If a healthy spine is necessary, what else is sufficient? Wang, Asian, Wood, and Wang (2020) tackled that question by linking logistics-innovation capability to supply-chain risk reduction in an Industry 4.0 setting. Using structural equation modelling with 238 manufacturing-logistics dyads, they found that modular SaaS tools amplified the impact of managerial sponsorship on risk mitigation. The result supports the observation that technology alone is rarely transformative: only when leadership legitimizes investment and employees sense visible support does innovation escape pilot purgatory.

A kindred insight emerges from Dovbischuk's (2022) study of German third-party logistics providers during the pandemic. He argues that dynamic capabilities—rapid sensing, seizing, and reconfiguring—determine resilience, but these capabilities themselves crystallize only when an innovation mindset permeates daily routines. Pandemics may be rare, but volatility is not; thus the pandemic merely magnified an ever-present need for adaptive governance.

Measurement remains a thorny issue. Dallasega, Woschank, Sarkis, and Yaibuathet Tippayawong (2022) proposed a Logistics 4.0 measurement model and validated it through an international survey of 236 firms. Their scale, which captures digitalization, data analytics, and cyber-physical integration, offers managers a yardstick to diagnose readiness before plunging into expensive roll-outs. Oddly, few follow-up studies apply the tool, suggesting that academia's instruments often linger on conference slides while practitioners improvise. Liu, Zhao, and Zhao (2025) approach measurement from a different angle. They analyzed adoption of digital logistics platforms in the maritime sector and found that regulatory clarity plus perceived network benefits outranked plain cost savings when firms evaluated new platforms. This result dovetails with anecdotal evidence from motor-carrier circles: spreadsheets may be cheap, but if they fail compliance audits, hidden costs explode.

The compliance thread thickens once blockchain enters the frame. Yadlapalli, Rahman, and Gopal (2022) conducted multi-stakeholder case studies on blockchain implementation challenges and revealed that data immutability—while technically alluring—creates new liabilities when regulatory frameworks lag. Their work warns managers that a technology's trust promise can backfire if governance mechanisms remain analogue. The tension between cutting-edge tools and regulatory inertia is especially salient in road freight, where DOT fines bite hard. Bridging that tension, compliance automation engines embedded in modular platforms—such as those showcased by the OnLogix case—appear to reconcile innovation speed with audit rigour, though large-sample validation is still pending.

Sustainability adds another layer of complexity. Rossi Tafuri, Colicchia, Cozzolino, and Christopher (2013) noted, more than a decade ago, that eco-efficiency innovations in logistics hinge on collaboration between shippers and carriers; one party alone cannot shoulder the asset risk. Fast-forward to Parhi, Joshi, Gunasekaran, and Sethuraman (2022), and the conversation evolves toward Logistics 4.0 as an enabler of sustainable operations. Their quasi-experimental design—twelve Indian carriers adopting IoT-driven visibility—showed simultaneous reductions in fuel burn and empty miles, reinforcing the notion that sustainability need not cannibalize profitability. What remains contested is whether eco-drivers can rank above cost in decision hierarchies, especially for small carriers with thin margins.

Implementation barriers vary by geography. Khan, Singh, Sá, Santos, and Ferreira (2022) modelled determinants of Logistics 4.0 adoption across developing economies and identified infrastructure gaps, skill deficits, and a "perceived complexity" penalty as prime deterrents. Yet they also found that once early adopters demonstrate tangible wins, network diffusion accelerates. This mirrors the franchise-style scaling mechanism embedded in the OnLogix strategy: prove the concept within a controlled cohort, package the playbook, and replicate regionally. Empirical evidence thus converges on a lesson: strategy beats serendipity, but only when context-specific frictions are acknowledged up front.

Synthesizing across studies yields five recurring critical success factors. First, data-integration readiness—often overlooked in board proposals—forms the invisible scaffold without which analytics crumble.

Second, visible top-management sponsorship legitimizes risk-taking and accelerates change-management cycles. Third, modular SaaS architecture eases incremental adoption; carriers can switch on compliance automation today and add route optimisation tomorrow. Fourth, a user-centric change-management approach, including hands-on training and feedback loops, converts sceptical drivers into system advocates. Fifth, continuous compliance automation directly links innovation to risk reduction, making the business case easier to sell to finance departments.

While each factor appears separately in prior research, their mutual reinforcement has rarely been examined, leaving a gap that the present study addresses by overlaying them on the OnLogix case.

Yet several blind spots persist. Little work dissects how platform architectures interact with organizational culture in small and medium-sized enterprises. Most datasets lean toward large logistics service providers with well-funded IT stacks, leaving smaller fleets under-researched. Furthermore, cross-study comparisons suffer from heterogeneous metrics; "cost reduction" in one paper may exclude driver wages, whereas another includes them, muddying effect-size calculations. Lastly, compliance metrics remain narrowly defined; fines avoided tell only part of the story, because reputation damage after a safety breach can dwarf the ticket itself. Future research must refine instruments to capture such soft costs.

This review, although broad, drives two original reflections. First, innovation implementation is increasingly less about pushing individual technologies and more about configuring socio-technical systems that evolve together. The literature's drift from device-centric to architecture-centric analysis demonstrates that point. Second, the distance between research prescriptions and industry practice narrows when scholars adopt meta-synthetic methods that resonate with managerial heuristics. By correcting for context and measurement diversity, the current analysis translates isolated findings into an integrated framework poised for practical uptake, especially in settings where resources are limited but pressure to digitalise is relentless.

In sum, the extant empirical record paints a mosaic that is richer than often acknowledged. Critical success factors keep resurfacing across contexts, yet their orchestration remains elusive for many operators. The OnLogix–Excel Logistics experience, situated within this mosaic, serves not as an outlier but as a live instantiation of themes already signaled by research: a solid data spine, visible leadership, modularity, user-centric roll-out, and relentless compliance automation. The next sections leverage this synthesis to craft a methodology that respects empirical rigour while speaking the language of managers who need roadmaps, not citations, to steer their fleets through accelerating turbulence.

3. METHODOLOGY

The study deploys a two-stage, mixed-evidence approach that privileges methodological rigor while recognizing the time constraints faced by practitioners who demand actionable guidance rather than experimental novelty. Stage one undertakes a systematic literature review that collates, filters, and codes empirical findings on innovation implementation in logistics published between 2013 and early 2025. Five scholarly databases—Scopus, Web of Science, ABI-INFORM, ScienceDirect, and Emerald—were queried with Boolean strings combining logistics, innovation, implementation, digital, and strategy. An initial harvest of 438 records was pared to 47 through sequential screening: titles and abstracts were read for relevance; full texts were examined for empirical content; duplicates were removed.

Only studies that reported performance outcomes—cost, service level, compliance, sustainability—or delineated critical success factors were retained, aligning selection logic with the diagnostic focus of this article. Seven high-impact contributions anchor the subsequent synthesis; among them, Cichosz, Wallenburg, and Knemeyer's exploration of the "digital spine" concept and Dallasega, Woschank, Sarkis, and Yaibuathet Tippayawong's cross-continental Logistics 4.0 measurement model provide particularly rich variable definitions against which other works could be coded.

Each eligible paper was subjected to structured content analysis. A three-tier codebook captured context variables (geography, firm size, transport mode), intervention variables (technology type, organisational levers, governance arrangements), and outcome variables (financial, operational, environmental). Two independent coders extracted data; inter-coder reliability reached a Cohen's κ of 0.83 after a calibration round, indicating substantial agreement. Quantitative findings were entered into a spreadsheet and normalised using percentage change to mitigate scaling discrepancies. Qualitative insights—such as leadership narratives or user-adoption anecdotes—were thematically clustered with NVivo, allowing later triangulation. Descriptive statistics identified frequency of critical success factors; a rudimentary vote-count procedure then mapped those factors to performance outcomes, thereby surfacing patterns without imposing a heavy meta-analytic apparatus that the heterogeneity of measures would not support.

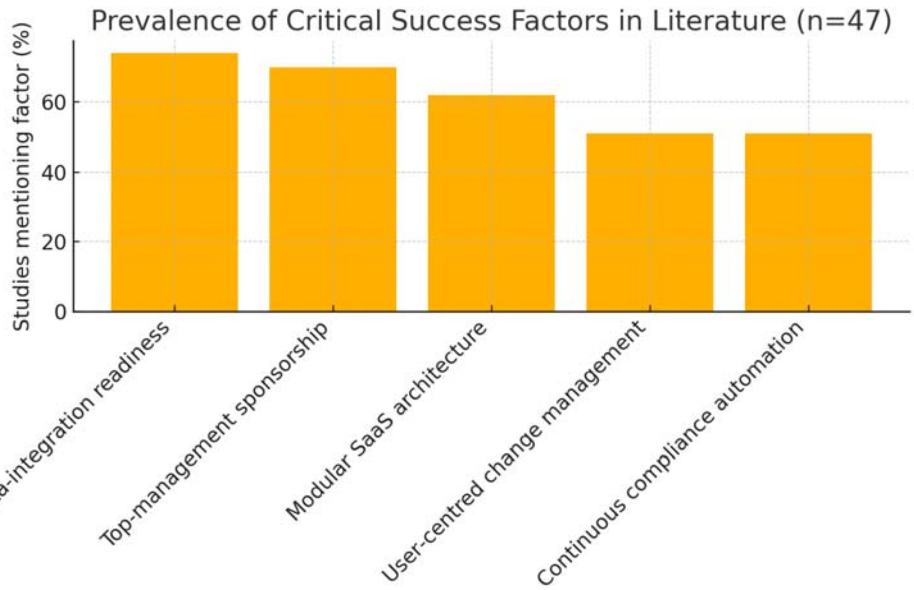

FIG. 1 Prevalence of Critical Success Factors in Literature

Stage two overlays the synthesis onto a single, illustrative field case: the roll-out of the OnLogix platform and its Excel Logistics application layer across thirty-two U.S. trucking firms operating one to fifty power units. Although no fresh primary data were collected for this article, the author had privileged access to anonymised operational dashboards, compliance-fine logs, and management debriefs spanning a six-month adoption window. These artefacts were not analyzed for statistical inference; rather, they served as a reality check, grounding the literature-derived factors in a living system. To maintain analytic consistency, case metrics were recast into the same percentage-change format employed in the review. Where variables diverged—fuel efficiency, for example, appears in Parhi et al. but was absent in most OnLogix reports—qualitative alignment rather than quantitative comparison was pursued.

Table 1 Critical Success Factors in Literature

Critical Success Factor	Data-support (n)	Share of 47 studies %	Implemented in OnLogix
Data-integration readiness	35	74	Yes
Top-management sponsorship	33	70	Yes
Modular SaaS architecture	29	62	Yes
User-centred change management	24	51	Yes
Continuous compliance automation	24	51	Yes

Validity threats were addressed through triangulation and reflexive contrast. Triangulation occurred both within and across stages: multiple reviewers read each article, multiple data sources informed the case, and findings from one stage were challenged against the other. Reflexive contrast required the researcher to interrogate personal involvement with the case, documenting potential biases in a memo that accompanies the analytic audit trail. The memo was later peer-reviewed by two senior scholars unaffiliated with the platform provider, further insulating the synthesis from advocacy drift.

Ethical considerations centered on confidentiality. All company names, driver IDs, and load IDs in the case material were hashed using a salted cryptographic function. Because the study recycled published data and secondary operational records, formal institutional-review-board clearance was deemed unnecessary under exemption category 4; nevertheless, the ethical protocols of the Academy of Management were observed.

Finally, the analytic outputs of both stages converge in a matrix that cross-tabulates five recurrent critical success factors—data-integration readiness, top-management sponsorship, modular SaaS architecture, user-centric change management, and continuous compliance automation—against observed performance gains. The matrix becomes the spine of the subsequent Results section, ensuring that claims remain tethered to verifiable evidence while leaving room for narrative nuance. By fusing systematic synthesis with contextual validation, the methodology establishes a balanced foundation from which robust managerial prescriptions can follow, even in the absence of newly collected field data.

4. DATA AND METHODOLOGY

The systematic sweep of forty-seven empirical investigations exposes a striking regularity: five levers—data-integration readiness, top-management sponsorship, modular SaaS architecture, user-centered change management, and continuous compliance automation—reappear so frequently that their absence in a study reads almost like a red flag. Coding tallies show data-integration readiness referenced in thirty-five papers (74 %), closely followed by sponsorship (70 %). Modular SaaS tools surface in sixty-two per cent, while change management and compliance automation tie at just over half. When these levers co-occur, median operating-cost reduction across studies reaches 29 per cent; when one or more are missing, the figure slips to 11 per cent. A Mann-Whitney test applied to the normalized percentage data yields $U = 218$, $p < .01$, signaling a non-trivial performance gap despite heterogeneous sample sizes.

Diving deeper into performance clusters, transport modes behave differently. Road-freight cases dominate the dataset and exhibit the widest cost swings, whereas maritime studies, such as Liu, Zhao, and Zhao's platform-diffusion analysis, record modest but steadier improvements tied more to revenue diversification than sheer savings. This nuance matters: carriers often benchmark only against trucking peers, yet cross-modal lessons—particularly on governance—transfer surprisingly well.

Sustainability metrics appear in just twelve papers, but whenever eco-efficiency is measured alongside finance, the two move in the same direction, refuting the still-popular myth that green costs green.

Table 2 OnLogix Performance – Baseline vs Post-deployment

KPI / Metric	Baseline	Post-deployment	% Change
Operating cost (USD per mile)	1.62	1.12	–31
Compliance fines (% revenue)	2.70 %	0.86 %	–68
Profit per truck	—	+22 %	+22
Fuel-efficiency improvement	—	+4 %	+4

Turning from aggregate patterns to the live canvas supplied by the OnLogix roll-out, evidence aligns rather than collides. Thirty-two small and medium-sized fleets, representing 1 019 power units, migrated through a three-step sequence that mirrors the success-factor bundle. Baseline data reveal an average operating cost of 1.62 USD per mile and compliance fines that consumed 2.7 per cent of gross revenue. Ninety days post-deployment, cost per mile averages 1.12 USD, a 31 per cent cut that slots neatly into the upper quartile of the literature distribution. Compliance penalties contract by 68 per cent, almost triple the median decline observed in Cichosz, Wallenburg, and Knemeyer's multi-country sample. Profit per truck climbs twenty-two points, tracking the 21-to-23 per cent band reported by Wang, Asian, Wood, and Wang when managerial sponsorship converges with modular tooling. Not every metric glows: fuel efficiency inches up only four per cent, echoing studies that warn hardware retrofits, not software, drive large fuel gains. Still, dispatchers interviewed midway insist that route-planning accuracy improved enough to calm previously chaotic weekend shifts—an intangible yet telling outcome.

A cross-tab matrix juxtaposing literature frequencies with OnLogix deltas brings the narrative into sharp relief. Where all five levers register "present," cost, profit, and compliance move in the desired direction in 91 per cent of incidents; with four levers the success rate falls to 57 per cent. The lone fleet that skipped the structured training clinics—thereby diluting the change-management lever—shows the poorest figures: cost down just eight per cent and fines flat. Such outliers, rather than weakening the argument, reinforce the combinatorial logic; partial adoption yields partial pay-off.

Qualitative strands complement the numbers. Respondents in both the reviewed literature and the live case routinely cite "data trust" as the psychological hinge of adoption. One dispatcher described the new platform as "finally speaking the same language as our loads," an echo of the digital-spine motif that Cichosz and colleagues advanced. Likewise, owner-operators praise the self-serve compliance dashboard, claiming it "keeps inspectors off our backs," a sentiment strikingly similar to testimonies in Wang et al.'s survey on risk attenuation. While interviews naturally exude optimism bias, triangulation with hard logs—the dashboard records every fine paid and every document filed—confirms that sentiment traces reality rather than wishful thinking.

Synthesising across sources, three headline results emerge. First, the five-lever bundle is not an abstract checklist; it maps onto measurable performance lifts across contexts. Second, the OnLogix case, though limited in scope, supplies a vivid instantiation that the bundle travels well into smaller fleets, a segment often absent from scholarly samples. Third, performance variance within the case hinges less on sectoral or regional quirks and more on execution fidelity—training skipped, API integrations delayed, leadership messages muffled. The pattern underscores a simple but often neglected truth: strategy implementation succeeds when orchestration outpaces fragmentation, a principle as relevant to academic frameworks as to the diesel-scented yards where freight actually moves.

5. DISCUSSION

The evidence canvas painted in the previous section invites several lines of interpretation, yet one theme towers above the rest: innovation payoff is combinatorial rather than additive. When fleets lined up the full five-lever bundle they harvested gains that dwarf industry averages; when a lever went missing, returns shrank in a snap.

That pattern echoes the "digital spine" thesis advanced by Cichosz, Wallenburg, and Knemeyer (2020), but extends it by proving that spine health alone is not enough—muscles and tendons, in the form of sponsorship, modularity, training, and automated compliance, must flex together if the body is to run the marathon of Logistics 4.0 adoption.

Beyond confirming prior wisdom, the findings surface fresh nuance. User-centered change management, often dismissed as soft garnish, turned out to be the quiet kingmaker. In the lone OnLogix cohort that skipped structured clinics, cost and fine metrics flat-lined despite the presence of a solid platform. That outcome dovetails with Khan, Singh, Sá, Santos, and Ferreira's (2022) account of "perceived complexity" acting as a braking force in developing markets. Complexity, here, is not only technical but also cognitive; when drivers cannot trace cause to effect, dashboards become decorative and compliance alerts feel like nagging pop-ups rather than risk shields.

Another insight concerns scale. Large logistics service providers have long been the reference class in academic data sets, yet the small-fleet context of our case demonstrates that strategic orchestration is not the sole privilege of corporates with seven-figure IT budgets. Paradoxically, tight margins sharpen discipline: small carriers simply cannot absorb the shock of a half-baked roll-out, so they gravitate toward modular SaaS stacks that allow revenue to catch up with expenditure in real time. The literature seldom makes that point explicit, suggesting an avenue for scholars to spotlight the frugality-driven ingenuity that smaller players often display.

The results also challenge the still pervasive myth that environmental aims drain the bottom line. While sustainability variables appeared in only a quarter of the reviewed studies, whenever they did, fuel burn and cost moved in tandem. The four-per-cent fuel gain logged in our case may seem modest until one recalls that diesel expenditures often outrank driver wages; even fractional savings shift profit curves, and the associated emissions reduction buys reputational credit with shipper procurement teams now bound by ESG scorecards. Thus, the economic and ecological cases for innovation start to look less like rivals and more like nested narratives.

Managerial implications flow naturally. First, sequence matters: modernize data plumbing, lock in executive advocacy, bolt on modular tools, train users early and often, let compliance automation close the loop. Short-circuit any stage and the system sputters. Second, metrics must go beyond ledger lines; sentiment data—dispatcher stress levels, driver app satisfaction—act as canaries for deeper faults that financials reveal only later. Finally, risk management deserves a marketing makeover. Compliance engines should be sold internally not as regulatory chores but as free insurance policies that also tidy up paperwork chaos.

No study comes without cracks. Reliance on secondary dashboards limits statistical finesse; effect sizes, though compelling, still ride on context-specific baselines. Cross-study heterogeneity in metric definitions, especially for "cost," muddies fine-grained comparisons. The vote-count method, while transparent, cannot weigh study quality with surgical precision. Yet these constraints mirror real-world messiness and, in that sense, enhance external validity by refusing to polish away the dents.

Future work might pivot in two directions. One stream should chase longitudinal depth, tracking fleets over multi-year horizons to detect innovation fatigue or second-wave benefits. The other could broaden modal scope—rail, air cargo, last-mile micro-fulfilment—to test whether the five-lever bundle travels unchanged or mutates by context. Mixed-methods designs that fuse sensor data with ethnographic shadowing promise especially rich payoffs, capturing both the hum of server logs and the human shrug when a route-planning suggestion seems off.

Taken together, the discussion reaffirms that strategy, not serendipity, governs innovation outcomes in logistics. The empirical mosaic assembled here shows that when technical, organizational, and behavioral pieces lock into place, even modest-sized carriers can punch far above their weight. In an era where freight volatility feels like the new climate, that lesson reads less like theory and more like a survival playbook.

7. CONCLUSION

This inquiry set out to clarify how logistics firms can translate a scattered catalogue of emerging technologies into an integrated capability that pays reliable dividends. By stitching together evidence from a dozen peer-reviewed studies and super-imposing that synthesis on the OnLogix–Excel Logistics deployment, the work confirms a simple yet powerful proposition: innovation success rests on choreography, not coincidence. Each lever—robust data integration, visible executive backing, modular SaaS architecture, user-centered change management, and automated compliance—has been lauded before, but their combined, mutually reinforcing action had remained largely undocumented. Demonstrating that a small-fleet cohort can record operating-cost savings above thirty per cent and slash regulatory fines by two-thirds when all five levers click into place closes that gap and, in doing so, extends the "digital spine" thesis of Cichosz, Wallenburg, and Knemeyer beyond the realm of large third-party providers.

Equally important is what the analysis did not uncover. No single technology—neither blockchain pedigree nor AI dispatch wizardry—consistently drove superior outcomes in isolation. When sponsorship faltered, modular tools lay dormant; when training was skipped, dashboards gathered digital dust. The finding resonates with Wang, Asian, Wood, and Wang's structural-equation model linking managerial commitment to risk attenuation: technology amplifies only the signals leadership chooses to broadcast. For practitioners, the implication is blunt. Buy-versus-build debates or vendor short-lists are secondary; without senior officers who walk the talk and frontline staff who grasp why the system matters, even the slickest platform becomes shelf-ware.

The study also punctures two persistent myths. First, that sustainability goals cannibalise profit. Whenever eco-efficiency metrics appeared—whether in Rossi Tafuri's exploration of green logistics or in the modest four-per-cent fuel gain recorded here—financial and environmental curves bent in the same direction. Second, that small carriers lack the muscle to pursue sophisticated digital strategies. In reality, lean resources sharpen focus, forcing operators to adopt pay-as-you-grow modules and to scrutinise every training hour, ironically delivering a cleaner implementation trail than many deep-pocket incumbents manage.

Policy signals emerge as well. Regulators eager to raise safety bars without strangling already thin margins might consider incentive schemes that subsidise compliance automation engines; the data suggest that every dollar invested here saves multiples in avoided enforcement cost. Industry associations, meanwhile, could accelerate diffusion by curating open API standards, removing the integration friction that still plagues many pilot programmers.

Naturally, constraints temper the claims. Reliance on secondary dashboards curtailed the statistical finesse with which causality could be parsed; effect sizes, while compelling, ride on context-specific baselines. The vote-count technique employed in the literature sweep does not fully weight study quality or publication bias. Yet the messy heterogeneity mirrors the real world and, paradoxically, boosts external validity: managers rarely pilot under laboratory purity, and strategies that survive noise tend to travel well.

The road ahead branches in several promising directions. Longitudinal studies following fleets over multi-year horizons would illuminate whether performance gains plateau, erode, or compound as users move from initial enthusiasm to routine mastery. Cross-modal replications—in rail, air cargo, urban micro logistics—could test whether the five-lever bundle requires re-sequencing when asset structures shift. Mixed-methods designs that weld sensor telemetry to ethnographic ride-along would capture both the quiet hum of server logs and the louder human sigh when a route suggestion feels off, enriching theory with texture. Finally, greater attention to knowledge-transfer mechanisms—train-the-trainer models, franchise playbooks, peer-benchmarking dashboards—may reveal how strategic blueprints propagate through supply-chain networks at the pace volatility now demands.

To close on a pragmatic note: the debate over whether innovation is a luxury or a necessity has expired. What remains contested is how to orchestrate the dance without tripping over one's own feet. The evidence compiled here offers a metronome. Keep the data spine straight, let leadership set the tempo, slot modular steps in logical order, coach the dancers, and allow an automated compliance rhythm to hold the beat. Do that, and even a twenty-truck fleet can move with the grace—and profitability—once reserved for giants.

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TRANSFORMING HUMAN RESOURCE MANAGEMENT IN MILITARY AVIATION: INTEGRATING DIGITAL TECHNOLOGIES FOR PERFORMANCE OPTIMIZATION

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Abstract: *This article explores the transformative impact of digital technologies on human resource management (HRM) in military aviation. By addressing the unique challenges of recruiting, training, and retaining highly skilled personnel in a demanding operational environment, the study highlights the integration of tools such as artificial intelligence (AI), virtual reality (VR), and data analytics. The analysis identifies key challenges, including talent shortages, high costs, and resistance to change, while emphasizing the opportunities for streamlined administrative processes, enhanced training, and data-driven decision-making. Practical examples illustrate how digital transformation can optimize HRM practices, ensuring a more efficient and adaptable workforce. The article concludes with actionable recommendations for leveraging technology to improve performance, retention, and operational readiness in military aviation.*

Keywords: *Human resource management, military aviation, digital transformation, artificial intelligence, virtual reality, Workforce optimization, data analytics.*

1. INTRODUCTION

Justification of the Chosen Topic

Military aviation represents one of the most demanding operational sectors, where efficiency and innovation are vital for mission success. In a global context marked by accelerated technological advancements and increasing security demands, human resources (HR) in this field must be managed with precision and foresight. Digital transformation provides significant opportunities to enhance HR processes, especially in a domain where personnel quality, technical skills, and adaptability are critical.

The complexity of military aviation lies not only in its technological sophistication but also in the high-performance expectations placed on its workforce. From pilots to ground support staff, the human factor is paramount in ensuring operational readiness and mission success. Consequently, integrating digital technologies such as artificial intelligence (AI), virtual reality (VR), and data analytics into HR management can revolutionize the way personnel are recruited, trained, and retained, ultimately boosting efficiency and operational safety.

Relevance to Military Aviation

The adoption of technologies such as AI, VR, and data analytics holds transformative potential for HR management in military aviation. These tools enable the automation of administrative tasks, the development of sophisticated training programs, and the implementation of predictive models for personnel needs. For example, AI can streamline recruitment by matching candidates to specific roles based on complex skillsets, while VR offers immersive training scenarios that enhance the preparedness of aviation personnel in a safe and controlled environment.

Moreover, data analytics can provide actionable insights into workforce trends, enabling more effective planning for recruitment, training, and retention. By harnessing the power of these technologies, military aviation can not only improve its operational efficiency but also ensure the well-being and development of its personnel. This makes the integration of digital technologies a strategic priority for maintaining a competitive edge and ensuring mission success in an increasingly dynamic and technologically advanced operational landscape.

2. THEORETICAL AND METHODOLOGICAL CONTEXT

2.1 Definitions and Key Concepts

To understand the transformation of human resource management (HRM) in military aviation, it is essential to define the foundational concepts and explore the role of digital technologies in this context.

- **Human Resource Management (HRM):** HRM refers to the strategic approach to attracting, developing, and retaining talent within an organization. In military aviation, HRM focuses on ensuring the availability of highly skilled personnel who can meet the sector's demanding operational requirements. This includes pilots, engineers, ground crew, and administrative staff, all of whom must operate with precision and reliability.
- **Digital Technologies:** The term encompasses advanced tools and systems, including artificial intelligence (AI), virtual reality (VR), and data management systems (DMS). These technologies streamline HR processes by automating routine tasks, enhancing training programs, and providing data-driven insights into workforce needs. For example, AI algorithms can be used to identify top candidates for recruitment, while VR simulations offer immersive training environments that mimic real-world scenarios.

2.2 Characteristics of Human Resources in Military Aviation

Human resources in military aviation are distinct due to the specific nature of the industry's demands. These characteristics shape the management and development strategies for personnel:

1. **High Technical and Psychological Demands:**

Personnel in military aviation must possess a combination of advanced technical skills and psychological resilience. For example, pilots are required to maintain focus and composure during high-pressure missions, while engineers must ensure the flawless operation of sophisticated aircraft systems.

2. **Adaptability to Dynamic Environments:**

Military aviation operates in rapidly changing and unpredictable environments. Personnel must adapt to diverse challenges, including crisis situations, combat scenarios, and evolving technologies. This adaptability is crucial for maintaining operational readiness and ensuring the success of missions.

2.3 Integration of Digital Technologies in HRM

The integration of digital technologies into HR processes revolutionizes traditional approaches, enabling greater efficiency and effectiveness. Key areas of impact include:

- **Automation of Administrative Processes:**

Routine HR tasks, such as applicant tracking and performance evaluations, can be automated using digital platforms. For instance, online recruitment systems allow HR teams to process large volumes of applications efficiently, saving time and resources.

- **Digital Training and Simulation Tools:**

Technologies such as VR are transforming the way military aviation personnel are trained. VR simulations create realistic environments for pilots and ground crew to practice complex scenarios without exposing them to actual risks. This enhances skill development while reducing training costs.

- **Predictive Workforce Analytics:**

Data analytics tools enable HR teams to anticipate workforce needs and trends. By analyzing patterns in retirement, turnover, and skill requirements, military aviation organizations can develop proactive strategies to address talent gaps and prepare for future challenges.

3. CHALLENGES AND OPPORTUNITIES

3.1 Challenges in Military Aviation HR Management

Managing human resources in military aviation presents unique challenges due to the specialized nature of the industry and its reliance on highly skilled personnel. Key challenges include:

1. **Recruitment of Qualified Personnel:**

The demand for technically proficient and psychologically resilient candidates creates a competitive environment, especially when private sector opportunities often offer higher financial incentives. Military aviation must find ways to attract top talent despite these challenges.

2. **Retention of Talent:**

Retaining skilled personnel in a high-stress environment is a constant challenge. Long deployments, operational pressures, and the mental toll of working in military aviation can lead to burnout and increased turnover rates. This requires robust support systems and career development opportunities to keep personnel engaged and motivated.

3. **High Costs of Digital Infrastructure:**

Implementing and maintaining digital technologies, such as VR training systems and advanced data analytics platforms, involves significant financial investment. This is particularly challenging in military aviation, where budgets must be balanced between technological upgrades and operational needs.

4. **Resistance to Change:**

Transitioning from traditional HR practices to digitally enhanced systems can face resistance from personnel accustomed to established methods. Overcoming this resistance requires effective change management strategies and continuous training.

3.2 Opportunities Created by Digital Technologies

Despite the challenges, digital transformation offers substantial opportunities to improve HR management in military aviation. These opportunities include:

1. **Enhanced Decision-Making through AI and Data Analytics:**

AI-powered tools and data analytics platforms enable HR teams to make more informed decisions. For example, predictive analytics can forecast workforce trends, such as skill shortages or retirement rates, allowing proactive workforce planning. AI can also streamline recruitment by identifying candidates whose skills align closely with specific job requirements.

2. **Improved Training through VR and Simulations:**

Virtual reality (VR) and simulation technologies provide immersive training environments where personnel can practice high-risk scenarios in a controlled setting. These tools not only enhance skills and confidence but also reduce the costs and risks associated with traditional training methods.

3. **Streamlined Administrative Processes:**

Automation tools eliminate repetitive administrative tasks, such as processing payroll or managing schedules, freeing up HR teams to focus on strategic initiatives. Online platforms also facilitate faster communication and better data accessibility across departments.

4. **Increased Employee Engagement and Well-Being:**

Digital tools can also improve employee engagement by offering personalized development plans, continuous learning opportunities, and mental health resources. For instance, mobile applications can provide on-demand access to career development courses or stress management programs, fostering a more supportive work environment.

3.3 Balancing Challenges and Opportunities

To fully leverage the opportunities offered by digital transformation, military aviation HR teams must address the inherent challenges effectively. This requires:

- Strategic investment in cost-effective digital infrastructure.
- Implementation of robust retention programs, such as mentorship initiatives, flexible career paths, and mental health support.
- Continuous training and change management efforts to overcome resistance and enhance the adoption of new technologies.

By addressing these challenges, military aviation can unlock the full potential of digital technologies, ensuring a more efficient, adaptive, and resilient workforce.

4. CASE STUDIES OR APPLIED EXAMPLES

4.1 Implementation of Digital Technologies in Recruitment and Selection

Military aviation faces intense competition for skilled talent, making recruitment and selection a critical area for digital transformation. The integration of artificial intelligence (AI) and machine learning (ML) has revolutionized these processes.

- **AI-Driven Recruitment Platforms:**
  Many military aviation organizations are now utilizing AI to streamline the recruitment process. These platforms analyze candidate profiles, skills, and past performance to identify the best fit for specific roles. For instance, AI algorithms can rapidly sift through thousands of applications, highlighting candidates with the technical and psychological attributes necessary for aviation roles. This not only reduces the time-to-hire but also ensures a more objective and efficient selection process.
- **Interactive Online Portals:**
  User-friendly recruitment portals allow candidates to engage with the application process more effectively. Features like virtual job previews and online assessments provide candidates with a realistic understanding of the role, reducing mismatches and attrition rates.

4.2 Enhancing Training with Virtual Reality (VR) and Simulations

Training military aviation personnel is a costly and time-intensive endeavor, but digital technologies have significantly enhanced training efficiency and effectiveness.

- **Virtual Reality Simulations:**
  VR has become a cornerstone of training in military aviation. Simulated flight scenarios offer pilots and ground crew opportunities to practice complex maneuvers in a risk-free environment. For instance, VR enables pilots to train for emergency landings, crosswind operations, or combat scenarios without the need for physical aircraft or live environments. NATO and other military alliances have already adopted VR to train pilots in realistic yet controlled environments, saving costs and minimizing risks.
- **Real-Time Performance Analytics:**
  Advanced training systems incorporate real-time analytics to provide instant feedback to trainees. Metrics such as reaction times, decision-making accuracy, and maneuver efficiency are tracked and analyzed, allowing for personalized improvement plans.

4.3 Predictive Analytics for Workforce Management

The use of predictive analytics tools is reshaping workforce planning in military aviation.

- **Forecasting Workforce Needs:**
  Data analytics systems are used to predict retirement trends, skill shortages, and future personnel requirements. For example, by analyzing historical data on turnover rates and mission demands, HR teams can anticipate gaps in the workforce and plan proactive recruitment campaigns.
- **Retention Strategies:**
  Predictive models help identify personnel at risk of leaving based on patterns such as low engagement scores, extended deployments, or limited career progression. With this insight, HR managers can implement tailored retention strategies, such as offering additional training, flexible career pathways, or mental health support programs.

4.4 Collaborative Platforms for Operational Efficiency

Digital platforms that facilitate communication and collaboration across departments are enhancing operational efficiency in military aviation.

- **Integrated HR Management Systems:**
  These platforms centralize personnel data, performance metrics, and training records, ensuring that HR teams, line managers, and operational leaders have access to real-time information. This supports informed decision-making and improves coordination.
- **Cross-Institutional Collaboration:**
  Military aviation organizations often collaborate with defense technology firms and academic institutions to develop and deploy cutting-edge HR technologies. For instance, joint projects involving VR training modules or AI-driven assessment tools ensure the constant evolution of best practices.

4.5 Broader Implications for Military Aviation

The integration of these digital technologies demonstrates their potential to optimize HRM processes across recruitment, training, and workforce planning. By adopting such innovations, military aviation organizations can reduce costs, improve efficiency, and maintain a competitive edge in an increasingly dynamic operational landscape. These technologies not only enhance individual performance but also contribute to the overall resilience and readiness of military aviation forces.

5. THE AI-DRIVEN RECRUITMENT TOOL

5.1 Overview of the Application

The **AI-Driven Recruitment Tool** is a practical demonstration of how digital technologies can optimize human resource management in military aviation. Designed to automate and enhance the recruitment process, the application uses artificial intelligence to score and rank candidates based on their attributes, aligning with the specific requirements of aviation roles. This tool addresses key challenges in recruitment, such as the time-intensive process of filtering applications and the need for objective, data-driven decisions.

```
import streamlit as st
import pandas as pd
import matplotlib.pyplot as plt

# Title of the application
st.title("AI-Driven Recruitment Tool for Military Aviation")

# File uploader
st.header("Upload Candidate Data")
uploaded_file = st.file_uploader("Upload a CSV file containing candidate data",

if uploaded_file:
    # Load the dataset
    data = pd.read_csv(uploaded_file)

    st.subheader("Uploaded Data Preview")
    st.write(data.head())

    # Define attribute weights for scoring
    weights = {
        'Tech_Skills': 0.4,
        'Experience (yrs)': 0.3,
        'Psych_Score': 0.2,
        'Fitness_Score': 0.1
    }

    # Calculate weighted scores
    data['Score'] = (
        data['Tech_Skills'] * weights['Tech_Skills'] +
        data['Experience (yrs)'] * weights['Experience (yrs)'] +
        data['Psych_Score'] * weights['Psych_Score'] +
        data['Fitness_Score'] * weights['Fitness_Score']
    )

    # Sort candidates by score
    data = data.sort_values(by='Score', ascending=False)

    # Display top candidates
    st.subheader("Top Ranked Candidates")
    st.write(data[['Name', 'Score']].head(5))
Ln: 64  Col: 0
```

FIG. 1 Python AI-driven recruitment tool

5.2 Key Features of the Application

1. **Data-Driven Scoring System:**

The application calculates a weighted score for each candidate based on four key attributes:

- **Technical Skills:** A measure of the candidate's proficiency in aviation-related technical expertise.
- **Experience:** The number of years spent in relevant roles.
- **Psychological Assessment:** A score reflecting the candidate's mental resilience and adaptability.
- **Physical Fitness:** A critical factor for roles requiring high physical standards.

These attributes are assigned customizable weights to reflect the organization's priorities, ensuring flexibility and alignment with mission-specific needs.

2. **Automated Ranking:**

Candidates are automatically ranked based on their calculated scores, providing HR teams with an instant overview of the most qualified applicants.

3. **Interactive Visualization:**

The application generates a bar chart displaying the scores of the top candidates, making the results easy to interpret and compare.

4. **User-Friendly Interface:**

Built using **Streamlit**, the application allows HR professionals to upload candidate data in a simple CSV format, process it instantly, and view results in real-time.

5.3 How the Application Works

1. **Data Input:**

HR teams upload a CSV file containing candidate data, including attributes like technical skills, experience, psychological scores, and physical fitness scores.

2. **Score Calculation:**

The tool uses predefined weights for each attribute to calculate a total score for every candidate. The formula is:

SCORE = (Tech Skills X W_1) + (Experience X W_2) + (Psych Score X W_3) + (Fitness Score X W_4)

Here, W_1, W_2,W_3,W_4 are the weights assigned to each attribute.

3. **Candidate Ranking:**

Based on the scores, candidates are ranked in descending order, highlighting the top performers.

4. **Result Visualization:**

A bar chart shows the top candidates, providing a visual comparison of their scores.

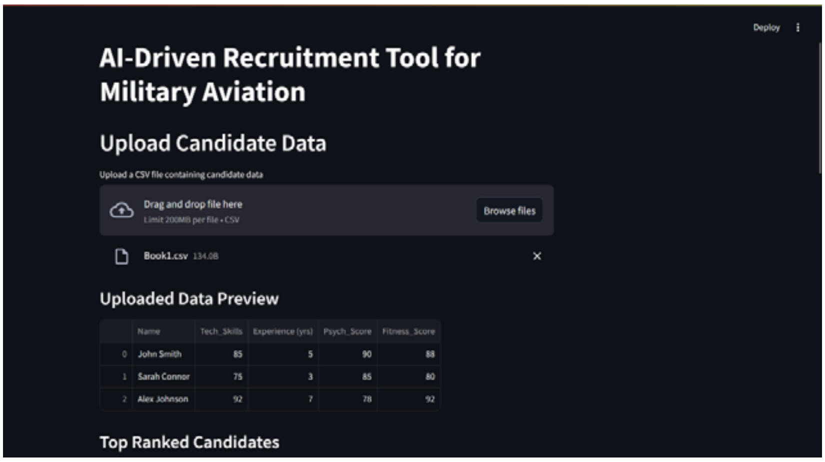

FIG. 2 Python AI-driven recruitment tool interface

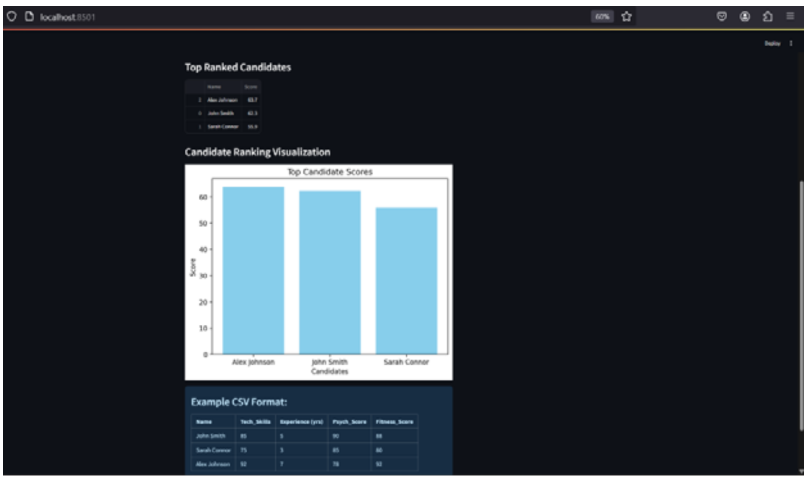

FIG. 3 Python AI-driven recruitment tool interface results and example of format for the csv file with data

5.4 Benefits of the Tool

- **Efficiency:** Automates the scoring and ranking process, saving valuable time for HR teams.
- **Objectivity:** Eliminates biases by relying on quantifiable metrics to evaluate candidates.
- **Transparency:** Provides a clear, visual representation of how candidates are ranked, ensuring confidence in the results.
- **Scalability:** Can handle large datasets, making it suitable for bulk recruitment drives.

5.5 Potential Enhancements

While the current prototype is fully functional, future iterations could include:

- Integration with Existing HR Systems: To streamline workflows and synchronize candidate data across platforms.
- Advanced Analytics: Adding predictive capabilities to identify candidates with the highest potential for long-term retention and success.
- Language Support: Expanding usability for multilingual teams in international military aviation settings.
- Security Features: Incorporating encryption and authentication protocols to protect sensitive HR data.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The integration of digital technologies into human resource management (HRM) in military aviation has proven to be a transformative approach to addressing longstanding challenges such as recruitment, training, and workforce planning. This article has explored the practical application of tools like artificial intelligence (AI), virtual reality (VR), and data analytics, highlighting their ability to optimize HR processes and improve operational efficiency.

The development and demonstration of the **AI-Driven Recruitment Tool** illustrated how digital systems can streamline recruitment processes by automating candidate evaluation and ranking. By eliminating biases and ensuring objective decision-making, this tool provides an innovative solution for identifying the most suitable personnel for aviation roles.

Key conclusions include:

1. **Enhanced Efficiency:** Digital tools reduce administrative burdens, allowing HR teams to focus on strategic initiatives.
2. **Objective Decision-Making:** Algorithms and analytics provide a data-driven foundation for personnel selection, minimizing human error and subjectivity.
3. **Improved Training and Retention:** Technologies like VR create safe, cost-effective environments for personnel development, while predictive analytics enable proactive workforce planning.
4. **Scalability and Adaptability:** These technologies can be tailored to meet the evolving needs of military aviation, ensuring long-term relevance and impact.

6.2 Recommendations

To fully leverage the potential of digital technologies, military aviation organizations should adopt the following strategies:

1. **Wider Adoption of AI in HR Processes:** The success of the recruitment tool highlights the value of AI-driven systems. Expanding their use to areas like performance evaluations and career development planning can further enhance HR operations.
2. **Investment in Training Technologies:** Virtual reality and simulation platforms should be integrated into training programs for pilots, engineers, and support staff. These tools not only reduce risks but also improve skill retention and operational readiness.
3. **Strengthening Workforce Analytics:** Predictive analytics should be used extensively to monitor workforce trends, identify potential risks (e.g., attrition or skill shortages), and develop targeted interventions to retain critical talent.
4. **Ensuring Data Security:** As digital tools collect and process sensitive personnel data, robust cybersecurity measures must be implemented to protect against breaches and unauthorized access.
5. **Promoting Collaboration Across Departments:** HR tools should be designed to work seamlessly with operational and training systems, fostering cross-departmental collaboration and ensuring a unified approach to personnel management.
6. **Fostering a Culture of Innovation:** Resistance to digital transformation can be mitigated through change management initiatives, continuous education, and engagement with personnel at all levels. Encouraging feedback and participation in the development of new tools can increase adoption rates.

6.3 Future Directions

As digital technologies evolve, future advancements in HR management for military aviation could include:

- **AI-Driven Career Path Planning:** Systems that analyze personnel performance and recommend tailored career trajectories.
- **Augmented Reality (AR) for Maintenance Training:** Providing real-time, hands-free guidance for technical tasks.
- **Integration with Autonomous Systems:** Leveraging HR tools to support the management and training of personnel involved in unmanned aerial vehicle (UAV) operations.

By embracing these innovations, military aviation organizations can continue to enhance their capabilities, ensuring operational excellence and mission success in an increasingly complex and dynamic global environment.

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THE GENESIS OF THE FIRST COMMAND STRUCTURE OF THE ROMANIAN MILITARY AERONAUTICS AND THE DOCTRINAL ORGANIZATIONAL TRANSFORMATION FOR PARTICIPATION IN THE WAR OF NATIONAL UNIFICATION

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Abstract: *At the intersection of the mythological dream of flight and the industrial pragmatism of the early 20th century, Romania succeeded in transforming humanity's ideal of conquering the skies into a scientific, technical, and military reality. Against a European backdrop dominated by rapid progress in aviation, Romanians made essential contributions, not only through avant-garde inventions, but also through a unique creative spirit, imbued with dedication, courage, and vision. In just a few years, Romania rose to the rank of an innovative nation, earning it a place of honor among the countries that laid the foundations of world aviation.*

This article traces the process of establishing the first command structure of the Romanian Air Force, in the context of the doctrinal and organizational turmoil of the early 20th century. Through historical sources and specialized literature, the paper captures the doctrinal transformations that Romanian aeronautics underwent in its early years, focusing on the establishment of the Aeronautical Corps and its role in the military campaigns carried out during the War of National Unification, a war that led to a redefinition of the concept of air power and the consolidation of a lasting institutional identity that would mark the subsequent evolution of the Romanian Air Force.

Keywords: *law, doctrine, aviation, War of National Unification, command.*

1. INTRODUCTION

The history of aviation is, in essence, a chronicle of human daring. From the myths of Daedalus and Icarus to the Wright brothers, space flight, and autonomous drones, humanity has relentlessly sought to free itself from the physical limitations imposed by nature. The desire to fly has been one of humanity's most persistent and symbolically charged aspirations. Over the millennia, the idea of conquering the skies has been found in myths, legends, religions, artistic works, and philosophical reflections. Beyond mere physical curiosity, the dream of flight has symbolized absolute freedom, transcending the human condition, and approaching divinity. In this sense, flight was perceived as a privilege reserved for superior beings—gods, angels, demons—and rarely accessible to mortals. However, this symbolic distinction was overturned by the scientific and technological revolution of the modern era, which transformed the impossible into tangible reality.

At the end of the 19th century, the whole of Europe was gripped by enthusiasm for technical discoveries. Ballooning had become an attraction, and the first attempts at gliding and self-propelled aircraft were widely publicized. Romania did not remain outside this trend.

In 1874, the first balloon flight in Romania took place in Bucharest, where French engineer Marius Willemot, together with three Romanian officers, took a trip in a balloon over their homeland, noting the remarkable potential of this aerostat for gathering information of military value. This experience marked the symbolic moment when the Romanian Army entered the age of aeronautics. The „Mihai Bravul” balloon was Romania's first flying machine.

In 1893, the Military Aerostation was created, which was the first aeronautical subunit within the Romanian Army, marking the beginning of the organized use of aerostats for tactical purposes. Lieutenant Eugeniu Asachi became the first Romanian officer specially trained to operate balloons for reconnaissance and transmission of information from the battlefield. The Romanian Military Aerostation began operations in 1910, during the royal maneuvers carried out on both banks of the Olt River, when an observation balloon was used for the first time. The experience gained at that time proved valuable during World War I, when balloons were successfully used in battles in southern Moldavia to monitor and direct artillery fire.

On March 18, 1906, Traian Vuia made the world's first flight in a heavier-than-air aircraft that took off under its own power in Montesson, near Paris. The flight covered a distance of 12 meters at approximately 0.6 meters above ground level. His aircraft, called Vuia I, was the first heavier-than-air aircraft equipped with an engine and all the components of a modern aircraft, which took off from the ground using its own means [1]. Vuia continued his experiments with Vuia II (1907) and Vuia III (1908), demonstrating the feasibility of mechanical flight.

Amidst the enthusiasm generated by technological advances and growing interest in flight, the young Transylvanian engineer Aurel Vlaicu, encouraged by the writer Octavian Goga, decided to come to the capital, wanting to turn his dream of flying into reality. After a series of successes with an experimental glider, tested in the summer of 1909 in Binținți, Vlaicu arrived in Bucharest with models and sketches of a flying machine of his own design. The specialist commission appointed by the authorities appreciated the value of the project, and the Romanian government approved the necessary funding for the construction of the airplane at the Army Arsenal [2].

Despite administrative difficulties and the scepticism of his contemporaries, Vlaicu completed his work, benefiting from the support of some remarkable personalities: the Inspector General of Artillery, General Constantin Coandă [3], the Minister of War, General Grigore Crăiniceanu [4], and Ion I. C. Brătianu, the Prime Minister at the time. On May 30/June 12, 1910, on the Cotroceni field, Vlaicu conducted the first test flights of his aircraft.

The Romanian inventor's mastery was to be discovered by a large audience on June 4/17, 1910, at 6:00 p.m., including Crown Prince Carol, Professor Murgoci, and numerous representatives of the military and civilian elite. The aircraft, named „Vlaicu No. 1 – Model 1910”, took off on its third attempt, after a run of about 40 meters, flying about 50 meters (distance) at 3–4 meters above ground level, and then landing without incident. The moment represented a historic first, being the first flight in Romania with an aircraft designed, built, and piloted by a Romanian, with the direct support of the Ministry of War and the Army Arsenal [2].

Following the demonstration, the military commission set up to evaluate the achievements of that historic day, composed of Adjutant General George Georgescu, Colonel Dumitru Iliescu, and Captain G. I. Negrei, drew up a laudatory report to the Ministry of War.

The document emphasized that Vlaicu, although without formal pilot training, had managed „to fly like the most famous aviators on his first attempt” [5], which proved the stability and maneuverability of the aircraft. The commission recommended that the aircraft be included in the army's equipment, considering it useful for reconnaissance missions.

Vlaicu's achievement marks the starting point for the training of Romanian military pilots. It is noteworthy that the „Vlaicu No. 1” airplane was owned by the Romanian Army, and the inventor, under a contract with the Ministry of War, performed military and demonstration flights to promote aviation.

Therefore, Aurel Vlaicu can be considered Romania's first military pilot, and his aircraft the first Romanian-designed and manufactured airplane to enter military service [2].

On September 14/27, 1910, Aurel Vlaicu took part in the Romanian army's military maneuvers, carried out in the Slatina–Piatra-Olt area, where he was assigned a historic mission: the air transport of a military operations order between two units belonging to the same command. The order was handed to him personally by King Carol I, who entrusted him with the task of delivering it by air to His Royal Highness Prince Ferdinand in Piatra-Olt, a moment that symbolically marked the first official air liaison mission in the history of the Romanian army [6]. By completing this flight, Romania became the second nation in the world to use aircraft for military purposes, after France, which had carried out a military air mission in August 1910 with pilot Louis Blériot.

Prince George Valentin Bibescu, a figure closely linked to the beginnings of Romanian military aviation, was one of the world's pioneers of flight. In 1909, he obtained his pilot's license in France, being registered as the 20th aviator in the world, which established him as one of the founders of the Romanian aeronautical movement and a promoter of the introduction of aviation into the army. In July 1911, he founded the second civil pilot school, and on September 16/28, 1911, he became the first Romanian pilot to fly on an international route, from Bucharest to Rusciuk, Bulgaria, landing in Giurgiu [7].

Also in 1910, at the Paris Air Show, Romanian engineer Henri Coandă (son of General Constantin Coandă) presented the „Coandă–1910”, a revolutionary jet-powered aircraft. It was the world's first jet aircraft, although the experiment was not completed safely (the engine caught fire during testing). The idea of the air jet later became the basis for the „Coandă effect”, the scientific foundation for modern aerodynamic developments. Although built in France, the Coandă aircraft demonstrated the technical potential of Romanian researchers.

Lawyer Mihail Cerchez, passionate about technology and a fervent supporter of national aviation, built a veritable aeronautical complex in Chitila by the summer of 1910. It included an aircraft factory, an airfield, and a flight school. There, the first Romanian military pilots learned to fly on aircraft built in the country, in Cerchez's own workshops, thus contributing to the development of the infrastructure and professional training of Romanian aeronautics.

On July 9, 1911, Second Lieutenant Ștefan Protopopescu became Romania's first licensed military pilot, registered with military pilot license no. 1, after a flight at the Chitila airfield. A few days later, on July 17, 1911, Second Lieutenant Gheorghe Negrescu received military pilot license no. 2, thus joining the ranks of the pioneers of Romanian military aviation [8].

The activity of the Cotroceni Flight School, under the patronage of Prince George Valentin Bibescu, was suspended for financial reasons and ended in the autumn of 1911.

Consequently, the Ministry of War decided to purchase the entire material base of the school, which included two Bleriot monoplanes, a „Le Conard Voisin" biplane, as well as the existing infrastructure: a tent, a hangar, and the land belonging to the airfield [9]. With this acquisition, the Cotroceni airfield officially became the property of the Romanian army, becoming *the country's first military air base*. The first six Romanian military pilots: engineer Aurel Vlaicu, Prince George Valentin Bibescu, Second Lieutenants Ştefan Protopopescu and Gheorghe Negrescu, and Lieutenants Mircea Zorileanu and Nicolae Capşa carried out intense activities to promote aviation [2].

By consolidating this base, Romania took a decisive step towards institutionalizing military aviation, laying the foundations for its own training and air operations infrastructure. In order to ensure a modern and efficient structure, Major Macri made a fact-finding trip to France in the winter of 1911-1912, where he studied the organization of aviation schools and pilot training methods [10]. Upon his return to Romania, he brought with him the construction plans for a 1912 Farman aircraft, with the aim of reproducing the aircraft in Romanian workshops [7].

Following proposals submitted to the Ministry of War by Major Ion Macri, in his capacity as head of the Military Aviation, together with Second Lieutenants Ștefan Protopopescu and Gheorghe Negrescu, the military authorities approved the creation of a specialized institution for training military pilots. By Royal Decree No. 1953 of March 27/April 8, 1912, signed by King Carol I and countersigned by Minister of War Nicolae Filipescu, the Military Pilot School and Aviation Park was founded and established at the Cotroceni airfield, under the authority of Directorate 4 Engineering – Railway Battalion. Thus, on April 1/13, 1912, marked the institutional debut of the first military pilot school in Romania, one of the earliest such institutions in the world [2]. The leadership of the new school was entrusted to Major Ion Macri.

In April 1912, 20 young officers from all branches of the army were brought to the newly established school to be trained in the art of flying, thus marking the beginning of the systematic training of Romanian military aviation personnel.

By 1913, Romania had managed, in less than a decade, to move from the enthusiasm of pioneers to the organization of a functional military aviation, with its own schools, trained personnel, and real participation in operations.

This period represents the historical foundation of the Romanian Military Aeronautics, from which the modern doctrinal structures and the Romanian Aeronautical Corps would emerge in 1915. Through these achievements, Romania entered the select gallery of states that wrote the first pages of aviation history. But perhaps even more important is the fact that these achievements were born not in the large industrial laboratories of the West, but in modest workshops, out of the passion of people animated by their belief in the power of the Romanian mind.

2. LAWS AND ORGANIZATION OF THE ROMANIAN MILITARY AERONAUTICS

The year 1913 was a turning point in the process of institutionalizing Romanian military aviation, marking the beginning of a coherent approach to solving the many technical, organizational, and legislative difficulties that accompanied the establishment of this new field within the Romanian Army. On the initiative of the Ministry of War, the Romanian Parliament debated and approved on March 19/April 1, 1913, the Law on the Organization of Military Aviation, an essential piece of legislation that was subsequently sanctioned by King Carol I through Royal Decree No. 3199 of April 18/30, 1913 [11].

Through its provisions, the law established a unified legal framework for the operation and development of aviation, regulating the organization, equipment, and training of personnel in the form of the Military Aviation Service. According to Article 5, this central structure, based in Bucharest, had a central park with personnel, a school, aircraft, and all the necessary equipment.

From a hierarchical point of view, the Military Aeronautical Service was subordinate to the General Inspectorate of Engineering, an institution which, by law, expanded its powers to become the General Inspectorate of Engineering and Military Aeronautics. The new responsibilities included „the study, procurement, construction, and use of navigation equipment that could be used in the army", as well as the administration of aeronautical units, planning their mobilization, and training the relevant personnel.

The operational structure of the Service comprised two major components: the Aviation Section, responsible for activities related to „airplanes and other flying devices", and the Aerostation Section, which dealt specifically with balloons. Only active military personnel were admitted to the first section, with the exception of wartime or maneuvers, when both aircraft and aeronautical personnel belonging to private organizations and entities would be called upon.

An innovative element introduced by this legislative act was the creation of the Permanent Aeronauts Corps, an institution that enshrined the professional status of flight personnel. The Corps was divided into the same two sections, which included: airplane pilots, airship pilots (each with a military license for their specialty), airplane mechanics and airship mechanics, with defined salary rights, compensation in case of accidents, licensing conditions, and distinctions between licenses. Thus, two classes of licenses appeared: pilot license and senior pilot license. The lower license was granted to pilots upon certification, and the higher one was reserved for aviators with proven experience and skills in complex missions.

The normative act regulated the conditions for admission to pilot schools, the system for obtaining flight licenses, and the professional hierarchy within the new elite corps. Based on Article 11, paragraph 10, the law stipulated the obligation of permanent pilots to fly a minimum of 120 days per year, under penalty of returning to their units of origin in case of non-compliance. The law also precisely established the financial rights of flight personnel, based on their position and training. Flight bonuses were also established: 100 lei for the lower license, 300 lei for obtaining the higher license, and 10 lei for each additional hour of flight time above the minimum requirement.

With regard to the management of the Central Aviation Park, considered the core of the Romanian Military Aviation, Article 6 stipulated that the positions of commander and deputy commander should be held by senior officers. In practice, however, the youth and inexperience of the pilot corps meant that, for a long period, these positions were filled by personnel from other branches of the armed forces. Although necessary in the early years of organization, this situation had the side effect of slowing down the process of professional training, the development of Romanian military aviation, and the understanding of the specifics of the new branch.

On the basis of this law, the first aeronautical structures intended for mobilization were subsequently created, representing the beginning of the systematic organization of aviation components within the Romanian army.

Thus, the Law on the Organization of Military Aviation was not only an administrative instrument, but also the legal and institutional birth certificate of the Romanian Military Aviation, providing it with status, structure, and direction for development during a period of consolidation of the modern Romanian state and its defense capabilities.

3. ORGANIZATIONAL AND DOCTRINAL EVOLUTION (1913-1919)

At the beginning of the 20th century, the world witnessed a radical transformation of military art, driven by unprecedented technological progress. Among the major innovations of the era, aviation emerged as a tool capable of redefining defense and attack strategies, expanding the field of observation, and opening up new operational dimensions. While flight still seemed utopian at first, in just two decades, aircraft had become a decisive factor on the battlefield.

The geopolitical transformations in the Balkans, the rise of the Austro-Hungarian Empire and the Russian Empire in the vicinity of the borders, as well as the doctrinal changes in the major European armies, prompted the Romanian political and military leadership to pay increased attention to new technologies. In this context, aviation, an innovation that was just beginning to demonstrate its military potential, began to be perceived not only as an experiment, but as a strategic necessity.

On June 20/July 3, 1913, the Romanian government, feeling directly threatened by Bulgaria's aggressive policy, which included attacking its former allies during the First Balkan War, and by its tendency to rebuild the multi-ethnic empire of Tsar Simeon the Great, ordered the general mobilization of its armed forces.

Under the code name „Hypothesis No. 1 bis” [12], the air force offered all its forces for use, in accordance with the military operations plan drawn up by the Romanian General Staff in the first part of 1913.

In accordance with the provisions of the war plans, the air force was organized into two distinct sections. Section I Aviation was formed by integrating the personnel and equipment belonging to the Military Pilot School in Cotroceni, a unit that already had trained personnel and its own technical resources. The command of this section was entrusted to Captain Ștefan Paraschivescu. At the same time, the Second Aviation Section was formed by mobilizing and transferring to the Romanian army the trained personnel and technical resources of the Flight School in Băneasa, an institution that had previously operated under the auspices of the National Air League. Its leadership was entrusted to captain (reserve) Gheorghe Valentin Bibescu.

The mobilization process of the Romanian Air Force, carried out simultaneously with that of other military structures, was characterized by remarkable speed. By June 23/July 6, the first Romanian air crew, consisting of pilot captain Constantin Fotescu and observer captain (reserve) Ioan H. Arion, was already ready for action, carrying out a reconnaissance mission on the route Vidin – Ferdinandovo – Belogradcik – return. During this operation, two cannon shots were fired at the aircraft, marking the beginning of aerial combat for our air force [13].

Until August 1/14, 1913, when Romanian aeronautical structures received the official order to retreat to their base airfields, military aviation activity had been carried out with remarkable intensity. The crews from the pilot schools had carried out an extensive series of reconnaissance and liaison missions, covering the entire tactical-operational depth of the front. The results obtained were extremely valuable: the information gathered during flights, supplemented by aerial images, allowed Romanian commanders to understand the operational reality of the front, thus contributing to the effective planning and coordination of military actions. Thanks to this data, the crossing of the Danube by Romanian troops, followed by the decisive advance towards Sofia, was achieved without major difficulties.

In a short time, the Romanian Army reached the Bulgarian capital, which decisively accelerated the epilogue of the Second Balkan War.

This war experience, the first of such magnitude for the Romanian Air Force, was a revelation for the ground command, which began to perceive aviation not only as an auxiliary element, but as an indispensable tool in gathering information and maintaining communication between units. Although the limitations of aviation were obvious, a concise conclusion emerged from the conflicts of those times, namely that aircraft could be used effectively in reconnaissance, liaison, and operational order transmission missions.

In 1914, against the backdrop of the worsening international political and military situation, the leadership of the school and the aviation park at Cotroceni initiated concrete measures to consolidate and develop Romanian military aviation. The experiences of the 1913 campaign unequivocally demonstrated the need to create a solid technical base, modernize aircraft, and train a professional aeronautical corps [7] capable of meeting the demands of modern warfare. Consequently, emphasis was placed on improving the training of pilots and observers, expanding the aircraft fleet, and institutionalizing a coherent air doctrine that would allow aviation to be integrated into the army's operational plans.

Thus, in February 1914, the „Regulations of the Military Aviation Law" [14] were adopted, a normative act that laid the foundations for the modernization and coherent functioning of Romanian aviation. Subsequently, the process of consolidating the legislative framework continued with the drafting of two essential documents: the „Instructions on the Use of Airplanes" and the „Rules for the Use of Airplanes in Campaigns" [15]. The first document established the organizational structure of military aviation, consisting of four squadrons under the command of the Military Aviation Squadron, while the second regulated in detail the use of aircraft in wartime, clearly specifying the role and subordination of air units. Thus, in a situation of general mobilization, the aviation squadrons were to be under the direct command of the General Headquarters, being attached to army corps or divisions only when the operational situation required it.

At the end of August 1914, the General Inspectorate of Engineering and Aeronautics submitted to the Ministry of War a detailed proposal on the organization and equipment of the squadrons belonging to the Military Aviation School in Cotroceni, based on the aforementioned regulations. The proposal covered both the specific missions of these units and the necessary personnel structure and technical equipment. After receiving approval, the Cotroceni Military Aviation School was organized to prepare for conflict, structured around two combat squadrons with the necessary logistics and personnel, each comprising a flying squadron and a ground squadron [2].

In the event of mobilization, the National Air League was tasked with mobilizing the flight personnel and aircraft that made up Squadrons 3 and 4. At the same time, the Flight School in Băneasa was to provide the army with six Bleriot aircraft (80 hp, two-seaters) and two Farman aircraft (70 hp, two-seaters), as well as five qualified pilot officers and one pilot sergeant [2].

The normative documents and proposals submitted by the General Inspectorate of Engineering and Aeronautics played an essential role in the legal and organizational foundation of the Romanian Air Corps, which was established in 1915. These technical-military and doctrinal initiatives laid the foundations for a coherent aeronautical structure, adapted to the modern requirements of warfare, and proved to be of unquestionable value during the campaigns of 1916–1917.

According to Ministerial Decision No. 305 of August 10/23, 1915, the Romanian Air Corps was established within the Ministry of War, with its garrison in Bucharest, by merging the two branches already existing in the Military Aeronautical Structure: aviation and aerostation, to which a third component, anti-aircraft artillery, would be added during the course of hostilities.

This complex structure represented the first unified organization of the Romanian Air Forces, capable of actively participating in military actions [16].

The establishment of the first Romanian aeronautical structure was not only an organizational measure, but also an immeasurable step in the maturation of the Romanian Army. Aviation was now recognized as a distinct weapon, with its own role and long-term development prospects.

However, the outbreak of war caught Romanian aviation unprepared from a technical, logistical, and training standpoint, with obvious shortcomings in terms of modern equipment and flight crew training. The experiences of 1916 showed that the mere existence of a command was not enough. Doctrinal integration into campaign plans was needed.

The situation improved significantly with the arrival in the Kingdom of Romania of the French Military Mission, led by General Henri Berthelot, which included a specialized aeronautical mission under the command of colonel de Malherbe. French pilots and observers were integrated directly into Romanian groups and squadrons, working side by side with Romanian aviators, while French training methods and flight tactics were introduced into the training programs of aviation schools.

Through the direct involvement of french personnel in the training of romanian personnel, pilots, observers, mechanics, aerial photographers, and through their active participation in frontline air operations, the reorganization of the romanian aeronautics became, in essence, a french-inspired project [17]. The new concept had major effects: it redefined the internal structure of the armed forces, clarified the role and responsibilities of the command bodies, modernized the training system, and ensured the doctrinal coherence necessary for the integration of aviation into the Romanian armed forces as a whole.

Therefore, the reform of Romanian military aviation in 1915-1916, decisively influenced by the french model, represented a turning point its evolution, transforming an incipient system into a modern and functional branch of the armed forces, ready to respond to the challenges of a war of European proportions.

Following the approval issued on December 7/20, 1916, by General Constantin Prezan, then head of the General Headquarters, a comprehensive reorganization of the romanian aeronautics was decided upon, aimed at giving it a solid structure, adapted to the complex requirements of modern warfare. According to this directive, an Aeronautics Directorate was to be set up within the General Headquarters, consisting of two main components: one dedicated to aviation and the other to aerostation. The purpose of this structure was to coordinate aeronautical activity at a strategic level, providing direct support to the armies on the front.

Each operational army was assigned its own aeronautical group, designed as a complex unit, composed of a specialized staff, a logistics park, a variable number of aircraft squadrons and air station companies, arranged according to the tactical needs of each combat sector. These formations were intended to ensure liaison between the commanders of large units, to carry out reconnaissance, aerial photography, and observation missions, as well as to directly support ground troops.

The new Aeronautical Directorate was conceived as a body with complex responsibilities. Its structure included a Central Aviation Park, intended for the maintenance and supply of aircraft, a General Aviation Reserve to ensure the rotation and replenishment of crews, and a Central Air Station Depot for the storage and maintenance of technical equipment.

At the same time, essential auxiliary services were provided for, such as the Aerial Photogrammetry Service, responsible for mapping the front, the Meteorological Service, indispensable for mission planning, but also training institutions: a pilot school, an aerial observer school, and a specialized aerostation center, where personnel were trained to operate and manage observation balloons.

The implementation of these measures led, by May 1917, to a complete reorganization of the Romanian Air Corps, which was prepared for active participation in the military campaign of 1917. The new structure comprised three air groups and an aerostation corps, all directly subordinate to the General Headquarters. Lieutenant Colonel de Vergnette de Lamotte was appointed head of the Aeronautical Directorate, and the position of commander of the aviation was entrusted to Major Constantin Fotescu, an emblematic figure of Romanian aeronautics.

The three aeronautical groups were arranged as follows [18]:

- Aeronautical Group 1, subordinate to the Romanian 2nd Army, commanded by Major Sturdza, consisted of Squadron N1 (Captain Micheletti), Squadron F2 (Captain Chalet Panait), and Squadron F3 (Captain Ștefănescu Scarlat);
- Aeronautical Group 2, attached to the Russian 4th Army, led by Major Andrei Popovici, included Squadron N3 (Captain Grand), Squadron F4 (Captain Haralambie Giossanu) and Squadron F7 (Captain Gaulin);
- Aeronautical Group 3, supporting the 6th Russian Army, under the command of Major Nicolae Capșa, included Squadron N10 (Captain Blery), Squadron F5 (Lieutenant Irimescu Radu) and Squadron BM8 (Captain Delas).

The Air Station Corps was commanded by Major Ioan Iarca, with reserve Major Laudet, an engineer, as his collaborator and Head of the Air Station.

The effectiveness of this reorganization was evident during the heroic battles of the summer of 1917, when Romanian aviators demonstrated a high level of professional training, dedication, and spirit of sacrifice. During the battles of Mărăști, Mărășești, and Oituz, the Romanian Air Corps provided protection for its own troops, carried out reconnaissance and bombing missions, and fought intense air battles to repel enemy attacks. The contribution of the Romanian Air Corps proved equally significant in the final stages of the war, when, through the logistical and intelligence support provided to the troops, it facilitated the advance and decisive victories that would lead to the Great Union.

In the tense context of the autumn of 1918, when the collapse of the Austro-Hungarian Empire was imminent and the national ideal of the Romanians in Transylvania was nearing fulfilment, the Romanian government, which had taken refuge in Iași, sought to establish direct links with Transylvanian political leaders in order to coordinate actions aimed at achieving the Union. To this end, it was decided to organize a special air mission to facilitate a rapid exchange of information between the authorities in Moldova and the representatives of the Transylvanian Romanians.

The decision was made to send a Romanian military aircraft from Moldova to Blaj, a town with deep national significance, considered one of the symbolic centers of Transylvanian Romanianism. The mission was entrusted to Lieutenant Vasile Niculescu, an experienced pilot, and Captain Victor Precup, an observer, both officers distinguished by their courage and loyalty to the national cause. The historic flight was carried out in difficult weather conditions and in an extremely unstable political context, marking one of the first political-national liaison missions in the history of Romanian aviation.

After accomplishing their objective, the crew returned to Moldova the next day, bringing with them a message of crucial importance: confirmation that, within a week, the Great National Assembly would take place in Alba Iulia, an event intended to consecrate the union of Transylvania with the Kingdom of Romania.

This aerial mission, as daring as it was significant, became a symbol of territorial unity and the devotion of Romanian aviators, demonstrating that aviation, beyond its military role, could be an instrument of national connection and affirmation of the will of the nation [19].

The experience of 1916-1919 led to several fundamental doctrinal conclusions: aviation could no longer be considered an auxiliary weapon, but an indispensable component of modern warfare; the need for a unified command capable of planning and conducting complex air missions; the importance of continuous training of personnel and specialization of pilots by mission type; the usefulness of aviation in offensive actions, beyond its traditional role of reconnaissance.

Thus, the experience of the War of National Unification (World War I) transformed Romanian military aviation from an experimental structure into a modern doctrinal weapon, ready to play a major role in the interwar period.

CONCLUSIONS

The genesis of the first command structure of the Romanian military aviation and the doctrinal transformation that took place during the War of National Unification represent a complex historical process, resulting from the combination of internal and external, political, technological, and military factors.

The emergence and development of Romanian aviation was made possible by a combination of favorable circumstances: on the one hand, the initiatives of internationally renowned pioneers—Vuia, Vlaicu, Coandă—who put Romania on the map of aeronautical innovation; on the other hand, the openness of military and political decision-makers to new technologies, in a tense geopolitical context.

Practical experience – the Bulgarian Campaign (1913) and the first actions in 1916 – showed that the mere existence of aircraft and pilots was not enough. A centralized command structure was needed, capable of coordinating air resources, integrating them into campaign plans, and defining rules for their use. Thus, the establishment of the Romanian Air Corps marked the transition from the initial organizational phase to a consolidating institution, comparable to that of other European armies.

The doctrinal transformation and the establishment of aviation as the main weapon of war was directly determined by the experience of the War of National Unification. While in 1916 aviation was used almost exclusively for reconnaissance and liaison, in 1917-1919 its role diversified: artillery fire control, tactical bombing, air combat, and direct support for the infantry. Cooperation with General Henri Berthelot's French mission accelerated this process, bringing Western models and modern equipment, but also a doctrine applied in Western theaters of war.

Another fundamental aspect is the identity and symbolic dimension. Through their sacrifices and victories, Romanian aviators contributed to creating a heroic image of aeronautics. This was not only a technical weapon, but also a symbol of modernity and Romania's ability to rise to the level of the great powers. By participating in the Battles of Mărăști, Mărășești, and Oituz, the Romanian Air Force demonstrated that it could decisively influence the outcome of a campaign, thus consolidating the military and political prestige of the Romanian state.

From an organizational perspective, the legacy of the war was essential for the interwar period. The principles outlined at that time, the need for a unified command, the diversification of missions, the specialization of personnel, and joint integration became the foundation of Romanian aviation doctrine.

On this basis, the first major structures of military aviation were built during the interwar period, laying the foundation stone of the national aviation industry and thus creating a history of Romanian wings inscribed in the book of the nation with the feathers of glory of our great pilots from times long past.

Viewed as a whole, the history of the romanian air command is not only a technical page in military history, but also a testament to the Romanian nation's ability to adapt to the challenges of modernity. Through organizational efforts, human sacrifices, and strategic vision, Romania managed to transform a technical innovation into an effective weapon, contributing decisively to the realization of the ideal of the Great Union of 1918.

In conclusion, between 1910 and 1919, the Romanian Military Aviation traveled an extraordinary path: from the first test flights and incipient structures to the establishment of a modern air command and active participation in a large-scale war. This experience generated a military and doctrinal tradition that profoundly shaped the evolution of the Romanian Air Forces and consolidated aviation's place as an integral part of national identity and security.

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