AFASES 2025

Scientific Research and Education in the Air Force

ISSN, ISSN-L: 2247-3173
DOI:10.19062/2247-3173.2025.26

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INTERNATIONAL SCIENTIFIC COMMITTEE

CONTENTS

THE ROLE OF THE RAKOVSKI NATIONAL DEFENCE COLLEGE IN INCREASING THE RESILIENCE OF THE NATIONAL SECURITY SYSTEM

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DOI: 10.19062/2247-3173.2025.26.1

Abstract: *The paper discusses an approach to implement an effective contribution of the Rakovski National Defence College (RNDC). The aim of the study is to contribute to the overall efforts to increase the resilience of the national security system of the Republic of Bulgaria. The strategic documents that form the framework of this publication and define the definitions related to the topic of resilience of the national security system are examined. Presented are the main requirements for national resilience contributing to NATO's collective capability in this area.*

Keywords: *Resilience of the national security system, Basic requirements for national resilience.*

1. INTRODUCTION

The protection of life and health of citizens, ensuring the stability and security of public life are among the main tasks of the modern state. These tasks are clearly outlined in the main strategic documents forming the national security system [1].

Crises directly or indirectly threaten the national security which determines the relevance of the issues of counteracting the sources of threats and minimizing the negative consequences when one of them occurs. Moreover, a proactive approach is needed at the state level, i.e. ensuring high resilience of the national security system. The issue of resilience is not only a national issue, but is part of the new NATO 2022 Strategic Concept adopted in 2022 to further strengthen the Alliance's defence capabilities [2].

The strategic documents that specify the framework of this publication, form the understanding and define the definitions related to the topic of the national security system resilience and are NATO 2022 Strategic Concept, NATO's Concept for Deterrence and Defense of the Euro-Atlantic Area and NATO Warfighting Capstone Concept [3].

2. PURPOSE

The main purpose of this publication is to propose an approach for effective contribution of the RNDC in the overall efforts to enhance the resilience of the National Security System of the Republic of Bulgaria.

3. ACTUALITY

The establishment and development of a functioning national security system and its resilience is a problem not only for the Republic of Bulgaria, but also for the other member states of the Alliance. The adopted principle of resilience is enshrined in Article 3 of the North Atlantic Treaty. NATO's main goal is to guarantee the freedom and security of its member states through political and military means. In order to realize this goal, each member state must develop capabilities that ensure its resilience to events of different nature, such as natural disasters, disruption of critical infrastructure, or attack of a hybrid or armed nature [4]. Alliance's resilience is the individual and collective capability of each country to be prepared to withstand, respond to, and recover quickly and adequately from the shocks of a crisis. The readiness of the civilian component is a central pillar of this resilience and a critical factor in the Alliance's collective defence. Civilian component readiness has three main functions: consistency of management, uninterrupted essential services to the population and civilian support to military operations. These critical characteristics have been translated into seven baseline national resilience requirements against which allies can measure their readiness levels.

To accomplish their missions, armed forces, especially in times of crisis and/or conflict, depend significantly on the private sector for transport, communications, energy supply and logistical support. The resilience of the civilian component ensures its readiness to sustain impacts and shocks in order to be able to continue to support the armed forces at all times.

NATO's collective capacity to resist any form of armed attack is ensured through the following national resilience requirements [NATO - Topic: Resilience, civil preparedness and Article 3]:

- Assured government continuity and critical government services: for example, the ability to make decisions and communicate with citizens during a crisis;
- resilient energy supplies: ensuring uninterrupted energy supplies and having back-up management plans;
- capability to deal effectively with uncontrolled movement of people;
- resilient food and water resources: ensuring resilience and security of supply;
- the capability to manage health crises and events with significant casualties: ensuring that civilian health systems can manage and that there are sufficient reserves of medical supplies;
- resilient civilian communications systems: ensuring that communications and information networks can function and have sufficient spare capacity to operate in crisis conditions;
- resilient transport systems: ensuring that NATO forces can move quickly through Alliance territory and that civilian authorities can rely on secure transport networks.

The new NATO 2022 Strategic Concept, adopted in June 2022, is an expression of the Alliance's new direction. It reflects the challenges in the security environment facing the Alliance and defines its main tasks. The Concept condemns the actions of the Russian Federation violating the norms contributing to a stable and predictable European security order [5, 9]. The NATO Strategic Concept is supported by two military concepts that define the direction for NATO adaptation. These are NATO's Concept for Deterrence and Defence of the Euro-Atlantic Area and the NATO Warfighting Capstone Concept.

The concept of deterrence and defence is the result of the Alliance's consistent efforts to strengthen its deterrence and defence posture. It reflects Allied agreement on a new force model to strengthen and modernize NATO's force structure, and is one of the driving forces behind the creation of the new generation of NATO military plans [6].

NATO's Concept of War offers a broader vision that supports the further development of NATO capabilities to provide decisive military advantage in the face of modern strategic competition and the adaptation of the military instrument of power looking forward to 2040. The Concept supports the Alliance's capabilities to anticipate and counter strategic shocks and surprises, to manage the consequences, and to withstand and ultimately prevail over adversaries. This requires a multi-layered approach involving mutually reinforcing "layers" of military and civilian resilience as an expression of NATO's overarching resilience agenda. This highlights the importance of continuity of command, military structures and processes, reserve forces, and ensuring a balance between capabilities and capacities.

4. ANALYSIS OF THE CONDITION

The management of modern crises requires a change in the attitude of institutions towards security. This requires the involvement of all institutions, including those of the military-educational system and business, in the creation of strategic tools and mechanisms for adapting management approaches related to the preparation of the state for action in the face of permanent crises of various nature.

Analyses of the national security system of the Republic of Bulgaria show a critical level of capability deficits caused by objective and subjective characteristics of the economic, public, food, social and administrative-managerial systems of the state, which are different in nature and intensity [7]. These deficits have a strong negative impact on the state's capability and capacity to deal successfully with emerging crisis situations. Without a doubt, the new conditions and environment require a redefinition of security as a concept, and hence the definition of new approaches to solving problems. All this is linked to resolving a number of issues, including the issue of increasing the experience and professionalism of the management staff. It is therefore necessary to take a number of measures to improve the state of all public spheres of the state. This includes improving the national security system (including the military and non-military components), including raising the quality of education and training of personnel for state management. The implementation of these tasks is done by taking a number of measures to update the normative base and optimize the curricula [8].

5. EXPERIENCE OF THE RNDC IN ENHANCING THE RESILIENCE OF THE NATIONAL SECURITY SYSTEM

Rakovsky National Defence College is a well-established educational and research institution that supports the building and development of the crisis management and disaster response capabilities. The RNDC has significant experience in building personnel in the field of national security and specifically in strengthening civilian resilience. A central pillar in the training of specialists is the Master's degree in Protection of Population and Critical Infrastructure. It is intended for specialists with a university degree and a Bachelor's or Master's degree in a specialization outside the field of higher education in security and defence.

Rakovsky National Defence College also conducts a two-week specialized course "Crisis Management". Trainees may be civilian employees holding or appointed to hold managerial and expert positions in ministries and departments, bodies and organizations of the central and territorial administration. The aim of the course is to acquire knowledge and skills on the theoretical and applied basics and on analyzing and using the crisis management tools in the new security environment.

The course contributes to the development of new capacities for anticipation, planning and management of crises and crisis situations. It provides a professional qualification in the skills of leadership of large complex social organizations and crisis and emergency management.

The topic of resilience is also included in the curricula of other courses, such as Strategic Defence Management, Staff Course for Officers of All Troops, Public Relations, Protection of Population and Infrastructure in Emergencies, etc.

A key precondition for achieving the institutional resilience of the National Security System is the effective implementation of the lessons learned process. In this regard, the RNDC offers the Lessons from Practice course. The aim is to enhance and systematize learners' knowledge and skills to adequately address change factors by proposing appropriate solutions based on experience. It also builds and maintains expertise to enable methodological and scientific accompaniment of the Lessons from Practice process, the latter in the form of specific analyses.

RNDC is part of the Consortium of the National Scientific Programme "Security and Defence", where it is a leading scientific organization with a strong scientific contribution on the subject of the resilience of the National Security System.

The RNDC also has traditions in organizing and conducting scientific forums on the described topic. Examples of this are the hosting of the scientific conference with international participation held on 30 and 31 October 2023 on "Shared Resilience in Southeast Europe", as well as the panel discussion held on 08.04.2025 on "Enhancing National Resilience: Progress, Challenges and the Way Forward".

6. VISION FOR CHANGE

The contributions of the RNDC to the improvement of the resilience of the national security system is related to the unification of theory and practical experience in the assessment of the security environment, the leadership of the defence and armed forces, the management of security resources and the use of science in the development of future leaders in the country. The uniqueness of the RNDC is that it manages to combine knowledge in the military and civilian domains or military and non-military projection of state power through the undergraduate, masters and doctoral programmes in the scientific area of Security and Defence. This uniqueness implies a search for new approaches to improve the contribution of the RNDC to increase resilience in the national security system.

Rakovsky National Defence College can provide a broad and interdisciplinary training centered around the concept of understanding security as a system of bodies and organizations for the protection of national security, civil security of the population and infrastructure in emergency situations, the defense of the country, including the established civil protection system. The various courses offered by the academy focus on providing knowledge in such important areas of modern society as infrastructure protection, disaster and emergency response, economics, management, protection from terrorism, etc., which broadens the scope of conceptual views and understandings of the application of population and infrastructure protection in national security.

The RNDC's contribution to enhancing the resilience of the national security system can be expressed specifically in the following:

- Participation of experts from RNDC in working teams on the problems of increasing resilience in the national security system;
- Organization and participation in events such as: workshops, round tables, situation games, seminars and scientific conferences.

This idea can be implemented by involving prominent personalities and experts from relevant ministries and departments, the armed forces, academia and the non-governmental sector, relevant to the issues related to enhancing resilience in the national security system;

- Training in bachelor, master and doctoral programmers. The RNDC, as a national educational institution with a long tradition in higher education, should train and prepare officers and students in this subject area in various doctoral, master's and bachelor's degree programmes, as well as expand and deepen cooperation with educational and research institutions from the country and NATO member states;
- Training in specialized courses. The RNDC should expand the implementation of its activities to a greater extent by preparing and improving the qualification of personnel from and for the public administration. This can be done by broadening the subject area, enriching the topics of the courses and orienting them towards practical applicability, as well as promoting them among stakeholders.
- Research projects. The RNDC, and in particular the Institute for Defence Advanced Research Institute (DARI) which is part of it, should establish itself as a research centre for security and defence studies, military art, strategic leadership and military history. It should expand its capacity to carry out research projects in the field of national and international security and to organize scientific and professional forums with themes responding to complex defence and security challenges.

CONCLUSIONS

The critical level of the capabilities of the National Security System of the Republic of Bulgaria in terms of resilience reveals the need to redefine security as a concept adequate to the new conditions and security environment. A similar thesis requires the choice of an approach to overcome these deficits, the basis of which should be the establishment of a link between the education system and the national security system through sustainable mechanisms for training personnel and innovative approaches aimed at risk management. The approach must meet the basic requirements for national resilience, be sufficiently generic and respond to the specific needs of public organizations and business.

In this regard, the vision of the military education system to enhance the resilience of national security should focus on: 1) The formation of human capital with competencies, critical thinking and adaptability that are vital for the management of contemporary threats; 2) The provision of interdisciplinary training with a holistic approach to challenges; 3) Civic-patriotic education to form values critical for social stability such as national identity and responsibility; 4) Training focused on adaptation to global challenges that integrates knowledge of cyber security, counter-terrorism and hybrid threats, as well as other risks relevant to the security environment; 5) Training implementing international standards to enhance interoperability with NATO and EU partners.

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INFORMATION - A WEAPON OF WAR

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DOI: 10.19062/2247-3173.2025.26.2

Summary: *Beginning with how a top secret agency (SOE) accomplished its dangerous task during World War II of coordinating subversion and sabotage against the enemy by any means necessary - using disguise, deception, bribery, explosives (sometimes disguised as objects such as a dead rat or a bottle of chianti) guerrilla warfare - and even assassination, the research highlights the crucial role of information in national security and how information has been strategically used to influence decisions, manipulate perceptions and gain advantage in a variety of areas, from military warfare to economic and political competition.*

The research also highlights that in the context of globalization and technological advancement, information has become a key strategic resource, as important as material or human resources. The ability to control the flow of information, to disseminate correct information or misinformation and to protect one's own information has become a determining factor in the success or failure of any strategic action.

Thus, the research highlights the various forms of the use of information as a weapon such as information warfare, media warfare, cyber warfare, electronic warfare, influence operations, counterintelligence and emphasizes the importance of developing robust national information security strategies that include measures to protect, detect and respond to information threats. It also emphasizes the need for public education on information literacy and resilience to disinformation.

In conclusion, the research demonstrates that information has been and is a fundamental component of power, and understanding and strategically managing it is essential for the security and prosperity of any entity, be it state, organizational or individual. It also, in this context, emphasizes the need to train specialists capable of understanding the importance, effectively managing and properly using this "weapon" - information.

Keywords: *information, information warfare, weapon, Vera Atkins, SOE.*

1. INTRODUCTION

With the development of automated data processing systems and, subsequently, computer networks, new forms of warfare have emerged and developed extremely rapidly, such as: sabotage with computer viruses, blocking, filtering or diverting data and information, hacking into computer systems and monitoring the information activities of adversaries and/or other partners who pose some information risk, cyber attacks. Along with manipulation and propaganda, these are part of what specialists call information warfare. The main characteristics of specific information warfare weapons are: invisibility, passivity of action, remote controllability, accessibility (they are easily available and cheaper).

In the new type of warfare, information is not just a necessity, it becomes a major element of the art of war, a formidable weapon for the one who possesses, protects, processes and manages it effectively. It can help win a conflict, military or otherwise, before hostilities visibly break out.

Knowledge has a double valence, firstly theoretical "to have knowledge", and then practical "to know how to do", meaning control over a set of information, which after the processing process gives the beneficiary the ability to act. It can thus be said that knowledge is based on information, on which the satisfaction of the individual's basic and higher needs largely depends.

The need and effort for survival have given information a defensive value, by supporting man in his relationship with his environment, in order to know, anticipate and avert dangers. Its usefulness in discovering and exploiting vital resources gave information economic value. These two values have been accentuated as the various productive activities have emerged and developed, giving information the value of a security resource.

To benefit from the advantages of knowledge, man has had to protect information, i.e. to keep it secret and to use this resource as the basis of any economic, political or military strategy. From this point of view, information has always been a formidable weapon, and today their degrees of use and accessibility have only accentuated this characteristic. The thirst for information that characterizes the modern globalized world has led to fundamental changes in the means of transmitting information, including what we call social media. An eloquent example is the social networking site Twitter, which since 2009 has changed its greeting from the neutral "how are you?" to the more precise "what's going on?".

Information as a weapon can take the form of propaganda, in which information at odds with unfolding events can be both true and false. The forms of propaganda are constantly adapting due to the changes imposed by technology, globalization and social media/virtual media.

This new reality has led Dennis Murphy and James White to assert that "The historical use of information as power was primarily limited to nation-states. Today a blogger can impact an election, an

Internet posting can recruit a terrorist, and an audiotape can incite fear in the strongest of nation-states, all with little capital investment and certainly without the baggage of bureaucratic rules, national values (truthful messaging), or oversight"[2]. Thus, through today's technology, information has become a weapon within the reach of every individual. This weapon can take various forms, from the truth of social movements, to the propaganda of terrorist organizations, all a matter of perception. But what cannot be denied is that easy access to information has opened a window to a new category of risks.

When the possession of information and its use for one's own interests means power, we can speak of an information-power binomial. In this context, information is obtained, possessed and protected by public means, but above all by specialized, secret means and practices as old as history itself, and is used to inform decisions of vital interest.

At the same time, information can only serve the needs of the community if its owners and users base their interests on social needs. Otherwise, vitally important information is diverted from its normal purpose and transformed not only into a tool for maintaining power, but also into a tool for realizing individual or group interests. Moreover, in order to be able to decide and act in accordance with his needs and interests, man needs a wealth of information which gives content and direction to his actions and gives him identity as the subject of social relations. Without this information, human freedom of expression and action is limited or distorted.

Information has acquired the quality of being a substitute for other economic resources, of circulating at high speed, conferring advantages to the possessor. Societies that have paid attention to the processing and use of information have moved rapidly towards the information society. This has also been due to the fact that information, unlike other economic resources, is extensible to the limits of human capacity and time, due to its natural power of diffusion, its ability to be reproduced in time of use, its possibility of being transmitted, and its use as exchange value in transactions.

The value, the usefulness of information and the price for obtaining it have historically turned it into a means of aggression or defense (weapon), on which the triad was built to know - i.e. to gather information; to prevent the adversary from knowing you - i.e. to carry out counter-intelligence activity; and to make the adversary wrong or misinformed - i.e. to disinform him. This triad confirms the scale and complexity of the means used to maintain priority, maintain exclusivity over information, and protect it severely by maintaining secrecy over information of vital interest to a community.

State-political practice confirms that, in the context of the explosion of information technology, these weapons cause greater damage than conventional warfare. At the same time, information or, to be more precise, intelligence is an instrument of national power, through which vital national interests are promoted and defended, first and foremost, but also other types of state interests, as is also revealed by the development of information as a weapon (military specialization). The information tool is primarily intended to provide decision-makers with the necessary support for the adoption of the best decisions. This function is attributed to institutions specialized in obtaining and protecting information. It also plays a central role in preventing one of the most serious risks to national, regional or international security - international terrorism.

The relevance of the information tool as an instrument of the state can be highlighted by examples from the history of the last century, when information power was used as a weapon of war.

2. SPECIAL OPERATION EXECUTIVE (SOE)

A brief foray into history reveals that in June 1940 Britain was driven off the continent by Hitler's conquering armies. As the British stared the invasion in the face, a group of unconventional warriors planned a new form of war. With an order from Winston Churchill to set Europe on fire, this top secret agency was given the dangerous task of coordinating subversion and sabotage against the enemy by any means necessary - using disguise, deception, bribery, explosives (sometimes disguised as objects such as a dead rat or a bottle of chianti), guerrilla warfare - and even assassination.

Created in 1940 to carry out espionage, sabotage and reconnaissance operations in the territories occupied by Nazi Germany and to support local resistance movements, SOE aimed to launch combat operations by means other than classic warfare and by relying on the power of information.

SOE was nicknamed Churchill's Secret Army and had around 13.000 members, 3.200 of whom were women. SOE operatives operated in France, Belgium, Greece, Greece, Albania, Yugoslavia, Italy, etc., as well as in East Asia and were infiltrated by parachute or submarine transport, communicating with the command center by radio hidden in suitcases.

The SOE has had a significant impact on modern intelligence agencies, influencing the methods of special operations, espionage and sabotage used today. After its disbanding in 1946, many of SOE's tactics and strategies were taken over by MI6 and other Western intelligence agencies.

Among the most important influences of the SOE on modern intelligence services are infiltration and sabotage techniques, support for resistance movements, clandestine operations (the SOE demonstrated the effectiveness of covert operations, leading to the development of specialized units such as the CIA's Special Activities Center), innovations in espionage technology.

In addition, the SOE was active in Spain during the Second World War, where it conducted economic intelligence operations against German interests.

Today, many of the principles of SOE are applied in intelligence operations, particularly in counter-terrorism and hybrid warfare.

SOE conducted many daring operations during the Second World War, making a significant impact on the Allied war effort. Among the most important missions were:

- Operation Foxley - A British plan to assassinate Adolf Hitler at his residence in Obersalzberg (Operation Foxley was based on intelligence about the German leader's daily habits). Although not implemented, it demonstrated the SOE's ability to devise operations to eliminate enemy leaders. Only a few SOE operations were undertaken in Germany, mainly due to the high dangers and lack of support from the local population. After June 6, 1944 [3], the Austrian and German sections of SOE was reorganized and enlarged. Operation Periwig, a plan to simulate the existence of a large anti-Nazi resistance movement in Germany, was carried out despite the restrictions imposed by SIS (Special Intelligence Service)[4] and SHAEF (Allied Expeditionary Forces)[5]. It was an operation of disinformation and psychological warfare mounted by the Special Operations Executive (SOE) in the last months of World War II, beginning in November 1944. The main aim was to create the illusion of a widespread anti-Nazi resistance movement inside Germany in order to induce confusion, paranoia and divert German security resources.

- Sabotage of the Norsk Hydro plant - An SOE team destroyed heavy water production facilities in Norway, preventing Nazi Germany from developing nuclear weapons. The Norsk Hydro plant in Vemork, Norway, was the target of crucial sabotage operations by Allied forces and Norwegian resistance. The plant was the only one in Europe to produce heavy water in significant quantities, an essential element the Nazis considered vital to their nuclear research program to develop atomic weapons. The Norsk Hydro sabotage is considered one of the most successful and daring sabotage operations of the Second World War.

- Support to the French Resistance - SOE provided arms, equipment and training to resistance groups, contributing to the success of the Normandy landings. SOE operations in France were run by two sections based in London. Section F was under direct British control, while Section RF was under the control of the government-in-exile of Free France led by Charles de Gaulle. Agents of French origin operated mainly in the RF Section. On May 5, 1941, Georges Bégué was the first SOE agent parachuted into Nazi-occupied France to send a radio report and to greet the next agent parachuted into France. Bégué was a qualified radio operator, a vital skill for maintaining liaison between field agents and SOE headquarters in London. Known as Georges One, he was the first SOE radio operator in France. Between May 1941 and August 1944, more than 400 agents were sent to France. Among them were weapons, sabotage instructors, couriers, escape organizers, liaison officers and radio operators.

The SOE included several women (mainly recruited for first aid). Section F sent 39 officers to France, of whom 13 fell in the line of duty. On May 6, 1991, a monument was unveiled in Valençay in the department of Indre, in memory of the 91 agents and 13 female agents of the SOE who gave their lives in the struggle for the liberation of France.

- Operations in the Balkans - SOE worked with Yugoslav and Greek partisans to destabilize Nazi forces in the region.

After the defeat of Yugoslavia by Axis forces in 1941, the country disintegrated. In Croatia there was a strong pro-fascist movement, the Ustaše, but in the rest of the country two resistance movements emerged: the monarchist Chetniks led by Draža Mihailović and the pro-communist Yugoslav partisans led by Josip Broz Tito. The SOE at first supported the Yugoslav government-in-exile and through it the ethnic ethnicists. It soon became clear, however, that the Chetniks were less effective than the communist partisans, and evidence emerged that the Chetniks had collaborated with the Germans in certain regions in the fight against the communist partisans. Although relations between the SOE and the communist partisans had its tense moments during the war, many historians believe that British support was a decisive factor in keeping communist Yugoslavia in the neutral camp during the Cold War. Notable missions include Operation Bullseye (the first SOE mission in Yugoslavia) and missions involving Fitzroy Maclean, who played a crucial role in establishing the link with Tito.

Greece was defeated by the Axis powers after the Greeks had fought fiercely for several months. At the end of 1942, SOE organized the first operation in Greece. The British commando group made contact with the two Greek guerrilla groups operating in the target area - the communist-oriented Greek People's National Liberation Army (ELAS) and the nationalist Greek Republican National League (EDES). With the help of these two organizations, the SOE commandos succeeded in partially destroying the Gorgopotamos railway viaduct on 14 November 1942. Unfortunately, relations between the two resistance groups and the British soon became strained. EDES received most of the SOE's aid, but ELAS managed to capture much military materiel when Italy signed the armistice with the Allies and the Italian army in Greece disbanded. ELAS and EDES became belligerent parties in a civil war in 1943. Several SOE liaison officers were executed during this period by undisciplined ELAS units. SOE's last action was the evacuation of several hundred unarmed EDES fighters to the island of Corfu, lest they become victims of ELAS's revenge.

The main objectives of the SOE in the Balkans were support and unification of local resistance movements, sabotage, intelligence gathering, psychological warfare, diversion of enemy forces.

- In Asia - SOE operated in Burma, Malaya and China, organizing sabotage and supporting resistance movements against Japan. In early 1941, SOE prepared an action plan for Southeast Asia. As in Europe, after the Allies suffered a series of military failures, SOE began to participate in the formation of local resistance groups in territories occupied by the Japanese Empire. Some of these resistance organizations played a major role not only during the war but also in the post-war period.

- An SOE delegation parachuted into Romania in 1943 with several objectives. The first was to penetrate the higher levels of political and military decision-making in Romania. The operation was a masterful combination of propaganda and disinformation, a mixture of truths only partially spoken, in which one can easily fall prey to the myths of espionage[6]. Although it began with the capture of its agents, it had a significant impact on the course of events in Romania during World War II. It facilitated crucial communication between the Allies and Romanian decision-makers, indirectly contributing to the August 1944 coup d'état and Romania's change of sides, an event that shortened the war by several months and had major implications for the fate of Eastern Europe.

These missions demonstrated the effectiveness of SOE in guerrilla warfare and clandestine operations, influencing modern intelligence strategies.

SOE was also tasked with encouraging and facilitating espionage and espionage behind enemy lines and to serve as the central coordinating point for the resistance movement in the British Isles (Auxiliary Units) in the event of the Axis Powers invading the United Kingdom.

The SOE set up a covert branch, the ISRB (Inter Services Research Bureau), which was responsible for creating equipment used in secret warfare and for producing radios, weapons, explosive devices and booby traps used by SOE agents or special troops.

People from a wide variety of social classes and socio-professional backgrounds fought as SOE agents in enemy-occupied territory. The main quality of the agent was a good knowledge of the country in which he was to operate and the language, all the more so in the case of agents whose mother tongue was not the language of the state in which they were to be infiltrated. Agents of mixed parentage, dual nationality or polyglots were highly sought after by the SOE. This was particularly true for France. Many of the agents of Section F were proletarians or sometimes even with a background in the underworld.

Members of the armed forces of occupied countries who had escaped from prison, been exiled or discharged became an important source of agents. In other cases, the agents were mainly loyal to the exiled guvnor, and the SOE was seen more as a means to the end - the liberation of the country from foreign occupation. The inability of the SOE to control such agents often led to dissatisfaction, distrust and even conflict between the British and the governments-in-exile fighting alongside the Allies against the Axis.

SOE hired many Canadians, relying on the direct support of the Canadian government, and adopted an entirely new position in the clandestine struggle against the Axis, ignoring all contemporary social convention. Thus, SOE recruited recognized homosexuals, people with rich criminal records or who had been convicted by military tribunals. Although some of these people might have been considered a security risk, the SOE was prepared to ignore almost any social convention in its struggle against the Axis. Despite such variety, which might suggest security risks to clandestine operations, there is no known case of siding with the enemy.

SOE was forced to develop a wide range of equipment for clandestine combat agents. An SOE agent working clandestinely in enemy territory needed clothes, documents made in such a way as not to arouse suspicion. SOE had a number of workshops for making clothing and for forging identity documents, food cards, or other products such as cigarettes.

In the course of its work, SOE managed a range of important and critical information during the Second World War that had a significant impact on the conduct of the war. It collected data on German troop movements, military installations, equipment and enemy logistics. This information was vital for planning Allied operations and anticipating enemy tactics. SOE agents also investigated and reported on the rail networks, roads, ports, and other transportation routes used by German forces for supply and mobilization. This data helped plan sabotage missions. The SOE worked with various resistance groups throughout Europe, gathering information on their structures, leaders, capabilities and activities. This collaboration facilitated the coordination of sabotage and anti-occupation actions. The SOE also gathered details of factories and industrial plants that produced military resources or equipment for the Nazis. Sabotaging these facilities was a priority to reduce the enemy's ability to sustain the war. Intelligence managed by SOE was essential for the coordination of Allied operations, including the invasion of Normandy. The intelligence SOE provided helped synchronize actions between the various Allied forces involved. By managing this information, SOE was able to achieve its strategic objectives and influence the outcome of the war in favor of the Allies.

3. CASE STUDY - VERA ATKINS

Vera Atkins was born in 1908 in Romania into a family of Jewish origin. Her father, a successful businessman, and her mother, who was of French descent, provided Vera Atkins with a cosmopolitan and cosmopolitan upbringing. The Atkins family moved to France when Vera was young and she spent much of her childhood there. She learned French, a language that would prove crucial to her later career.

However, it was Vera Atkins' academic achievements and exceptional language skills that made her stand out from the start.

After studying in Paris, she moved to London in the 1930s to continue her studies and start a career. But, like millions of others, Vera's life was turned upside down when World War II broke out, and the career she thought destined for her would soon change. Atkins was recruited before the war by Canadian spymaster Sir William Stephenson of British Security Coordination. He sent her on fact-finding missions to Europe to provide Winston Churchill with information on the growing threat from Germany.https://en.wikipedia.org/wiki/Nazi_Germany

In 1941, Vera Atkins was recruited by the Special Operations Executive to help in the world of espionage, covert operations and intelligence gathering. Vera Atkins was initially employed as a secretary, but her outstanding language and organizational skills quickly caught the attention of her superiors. She was soon appointed SOE liaison officer, responsible for managing a network of agents who were parachuted behind enemy lines to carry out sabotage and gather vital intelligence. Her role required not only meticulous diligence, but also an innate understanding of human psychology, as she had to manage agents from all levels of society, ensuring they were well prepared for the dangerous missions they were about to undertake. Atkins served as a civilian until August 1944, when she was commissioned as a flying officer in the Women's Auxiliary Air Force. In February 1944 and she was naturalized as a British citizen. Subsequently, she was appointed as an intelligence officer.

Atkins' main role at SOE was the recruitment and deployment of British agents in occupied France. She was in charge of the SOE agents who worked as couriers and wireless operators for the various circuits set up by SOE. Atkins was in charge of the housekeeping tasks relating to the agents, such as checking their clothing and documents to ensure they were suitable for the mission, liaising with members' families and ensuring their pay was received.

One of the most remarkable aspects of Vera Atkins' role in SOE was her responsibility for the recruitment and training of female agents, a task that was both innovative and challenging. Many of these women were young and inexperienced, but they were involved in some of the most dangerous missions imaginable.

Women trained by Vera Atkins were often sent to Nazi-occupied Europe to carry out sabotage, gather intelligence and organize resistance cells. These women spies worked in dangerous conditions, living undercover for months, often with little support.

Vera's ability to recruit and manage these women was extraordinary, and many of her recruits became legendary figures in the espionage world. One of her most famous recruits was Noor Inayat Khan [6], a young Muslim woman of Indian origin who became the first female radio operator in Nazi-occupied France.

Noor's bravery and her capture and execution by the Nazis left a lasting impression on Vera Atkins, who was devastated by the loss of her agent, but continued her work with renewed determination to thwart Nazism.

In conclusion, Vera Atkins used intelligence consistently and effectively in all aspects of her work in the SOE, from selecting and training agents, to monitoring missions and investigating the fate of the missing.

Her attention to detail, exceptional memory, and ability to analyze information were essential to the success of SOE operations and to her post-war efforts to shed light on the fate of the lost agents.

4. FROM CLASSIC WARFARE TO INFORMATION WARFARE

Information warfare is a modern form of conflict that includes information warfare, media warfare, cyber warfare, electronic warfare and, usually, the use of digital technologies to influence, destabilize or control information flows.

Information warfare includes various tactics such as computer virus sabotage (creating and spreading malicious software to affect the functioning of computer systems), blocking, filtering or diverting data (manipulating information flows to prevent access to certain resources or to redirect information to unauthorized sources), hacking (illegally accessing networks to obtain sensitive information or to monitor adversaries' activities), cyber-attacks (cyber-attacks that may have destructive purposes, such as deleting data or disabling critical infrastructure). These methods are often combined with manipulation and propaganda to influence public opinion or destabilize adversaries.

It is a constantly evolving field, and cybersecurity specialists are constantly working to develop solutions to protect against these threats.

In modern warfare the specific form of conflict is waged by fully specialized forces using specific means such as smart computer/information systems capable of operating in a permanent mode by specific means. In this confrontation, information is used both as a weapon and as a shield, without resorting to traditional armed force or limiting its use as far as possible.

The aims of the two types of warfare, classical and informational, differ fundamentally in nature, scale and methods.

The aim of the Second World War was to**:**

- Territorial and geopolitical objectives: The Axis powers aimed to expand territory, create empires and establish regional or global hegemony. The Allies aimed to stop aggression and restore sovereignty to occupied states.
- Ideological: The conflict was marked by the clash between totalitarian ideologies (fascism, Nazism, Japanese militarism) and democracy, as well as expansionist and racist ideologies.
- Resource control: Securing access to strategic natural resources has been an important factor for some powers.
- Changing world order: the war led to a major reconfiguration of global power.

The purpose of the information wars concerns:

- Influencing public opinion and behavior: the main aim is to shape the perceptions, attitudes and decisions of individuals and groups, both internally and externally.
- Undermining trust and polarizing society: The aim is to erode trust in institutions, exacerbate social and political divisions and create chaos and instability.
- Manipulating democratic processes: interference in elections, disinformation campaigns and discrediting democratic systems are frequent targets.

- Strategic and political advantage: Modern wars can be used to gain political, economic or military advantage without resorting to direct armed conflict.
- Erosion of the opponent's ability to respond: Through misinformation and manipulation, the aim is to paralyze the decision-making process and weaken the opponent's ability to respond.

Consequently, the following differences can be identified between the two types of wars:

- World War II was an open military conflict, with physical battles and massive loss of life and resources. Information wars are mainly fought in cyberspace and in the cognitive sphere, targeting people's minds.
- While the Second World War involved armies, airplanes, tanks and bombs, modern wars use fake news, propaganda, social networking, cyber attacks and other techniques to manipulate information.
- The victims of World War II were mainly soldiers and civilians killed or physically injured. In modern wars, the victims are citizens whose opinions are manipulated, whose trust is undermined and whose democratic processes are disrupted.
- World War II was an open and visible conflict. Modern wars are often clandestine and difficult to attribute, making it difficult to identify the aggressor and counter attacks.
- World War II was a global conflict directly involving most of the world's states. Modern wars can have a global scale thanks to the internet, but often target specific targets or population groups.

In conclusion, while the Second World War was a physical conflict for territory, power and ideology, today's modern wars are subtle conflicts for mind and information control, with the aim of influencing public opinion, undermining trust and gaining strategic advantage.

Although both types of warfare are based on information, the forms of modern warfare are fundamentally caused by the components of the information age, namely technical progress in weaponry and military concepts and, on the other hand, the leap forward in communications and its modes of manifestation, namely the internet and satellite communication, which have made the media and social media not only facilitators but also manifestations of modern warfare. What was once clearly structured and defined as global security in relation to national security or public order and the safety of the individual is now in mutual communication. The result is that modern warfare is multidimensional, encompassing internal and external aspects, of peace or conflict, targeting military threats or threats from civilian entities (hakirs, terrorism, organized crime, etc.).

5. THE NEW DIMENSION OF INFORMATION AS A COMBAT WEAPON

The US intelligence community has conducted a global threat assessment for 2025, highlighting a complex and dangerous security landscape. This assessment identifies various threats to US health, safety, critical infrastructure, industries, wealth, and government, a situation that can be generalized globally. The main conclusions of the assessment include:

- State and non-state adversaries: Seeking to undermine the economic and military power of the US;

- Transnational terrorist and criminal organizations: Directly threatening US citizens;
- Cartels: They are responsible for over 52.000 deaths from synthetic opioids in 2024 and have facilitated the arrival of nearly three million illegal migrants;
- Cyber actors and intelligence services: They target US wealth, critical infrastructure, telecommunications, and media;
- State support for non-state groups: China and India are mentioned as sources of precursors and equipment for drug traffickers;
- Military threats from state adversaries: They possess weapons capable of striking the US mainland or disabling vital systems in space;
- Revisionist powers (Russia, China, Iran, North Korea): They challenge US interests globally through asymmetric and conventional tactics, promoting alternative systems in commerce, finance, and security, while avoiding direct war;
- Cooperation among adversaries: Increases their strength against the US and pressure on other global actors to choose sides.

The 2025 Intelligence Community Report underscores its commitment to monitoring, assessing, and warning about these complex threats, providing critical information to US decision makers [8].

Thus, as the above assessment shows, the challenges facing societies have changed, with national security taking on a new dimension and information, closely linked to national security, being a particularly important value.

National security "refers to the dynamic giant system composed of artificial space, social space, biological space, information space, natural space, cosmic space and all the carriers in the spaces owned by a nation in a state free from danger, harm and serious loss, guided by the coexistence and sustainable development of the nation and the safety of its people with the world in a given period of time".

In the new context of national security, information as a weapon can have two meanings, one positive-defensive (defense, development, progress) and one negative-attack (aggression, destruction).

In a negative sense, information as a weapon can be defined as the strategic and intentional use of information (in all its forms, including news, data, narratives, images, videos and even misinformation or disinformation) by hostile state and non-state actors to undermine national interests, destabilize society, erode trust in institutions, manipulate decision-making processes and achieve objectives that threaten the security, sovereignty and functioning of the state.

This definition emphasizes the following key aspects of information:

- Strategic and deliberate: The use of information is not incidental, but is planned and executed with the specific purpose of adversely affecting national security.
- Multiple forms: information weaponry includes a wide range of tactics, from spreading fake news and propaganda, to data manipulation, cyber-attacks targeting sensitive information, creating divisive narratives and exploiting online platforms to amplify hostile messages.
- Undermining national interests: the ultimate aim is to damage the fundamental interests of the state, such as territorial integrity, political independence, economic stability, social cohesion and the security of citizens.
- Destabilization of society and erosion of trust: cyber attacks often aim to create internal divisions, polarize public opinion, spread fear and distrust of state institutions (government, military, intelligence services, media).

- Manipulating decision-making processes: through disinformation and influence campaigns, attempts are made to alter national political, economic and social decisions in favor of hostile actors.
- Hostile state and non-state actors: Threats can come from rival states, terrorist organizations, extremist groups, sponsored cyber actors, and even domestic actors with subversive agendas.

The characteristics of information as a weapon in the new information and national security context relate to the following:

- Information space vulnerability: Increased reliance on the internet and digital platforms creates a large information space that is vulnerable to cyber attacks.
- Speed and amplification: Social networks and online media allow manipulated information to be disseminated quickly and widely, often beyond the capacity to check and counteract.
- Anonymity and difficulty of attribution: Hostile actors may operate anonymously or through intermediaries, making it difficult to identify and hold the source of the attack accountable.
- Exploiting psychological and social vulnerabilities: cyber attacks are based on exploiting cognitive biases, emotions (fear, anger), social polarization and lack of media literacy.
- Hybridization with other threats: Information warfare is often integrated into hybrid strategies, combining with cyber-attacks, political meddling, economic influence operations and even physical subversion.
- Challenging reality and truth: A central element is undermining trust in facts and credible sources of information, creating an environment of uncertainty and confusion that paralyzes response.

Information has thus acquired "the quality of substituting itself for other economic resources, of circulating at high speed, conferring advantages to the possessor. Societies that have paid attention to the processing and use of information have moved rapidly towards the information society. This has also been due to the fact that information, unlike other economic resources, is extensible to the limits of human capacity and time, thanks to its natural diffusive power, its capacity to be reproduced during use, its ability to be transmitted, and its use as a transaction exchange value"[9].

Also, taking into account the danger generated by information used improperly or in a negative sense, information security becomes a major problem facing society, which needs to find solutions and take urgent action.

6. CONCLUSIONS

In the new national security context, information has become a formidable weapon, capable of eroding the foundations of the state, destabilizing society and compromising national interests without resorting to traditional armed conflict. Combating this threat requires a comprehensive and coordinated approach, which involves building societal resilience, improving media literacy, actively countering disinformation and strengthening the state's cyber and information security capabilities.

Transnational criminal and terrorist organizations pose a major threat to citizens, national security, and prosperity.

Transnational criminals, terrorists, and other non-state actors endanger the lives of citizens, national security, and internal and external power. Transnational criminal organizations produce and traffic illicit drugs, endangering lives. They are also involved in human trafficking, cyber operations, money laundering, and incitement to violence, all of which threaten national security. Citizens, both at home and abroad, face increasingly diverse, complex, and decentralized terrorist threats. These can come from terrorist organizations or from individuals and small cells that initiate or inspire attacks. Large-scale illegal immigration has strained national and local infrastructure and resources, while facilitating the free movement of known or suspected terrorists.

In this current geopolitical context, information has evolved from a simple communication tool into a sophisticated and ubiquitous weapon, capable of profoundly influencing global power dynamics and posing a significant threat to national and international security. It should be noted that the use of imagological weapons to control the minds of adversaries has always been used as a preliminary and preparatory phase for actual warfare. This structuring of forms of attack was maintained until the middle of the last century in all military conflicts, including the two great world wars.

However, of particular importance was and is the purpose for which information is used so that it is not diverted from its normal purpose and transformed not only into a tool for maintaining power but also into a tool for realizing individual or group interests or as a destructive weapon.

The relevance of the information tool of the state is highlighted both by the current situation we find ourselves in and by the examples that history provides us with when information has been used to organize, start, conduct and win wars.

As a consequence, the development of an information security strategy accompanied by a continuous process of education and training in the field of intelligence analysis can help to avoid many of the dangers associated with the misuse of information, especially information as a weapon.

Also, the development of a national project of education and training in the field of information analysis -Intelligence- can contribute to the organization of a National Intelligence Education and Training System based on educational programs and intelligence analysis, in a modern concept, adapted to the dynamics of the security environment. In addition, it appears that it is more productive to view education, training, coaching and specialization as integrated elements/components of a continuous system and not as separate activities carried out in universities on the one hand and intelligence institutions and structures (agencies/services) on the other hand.

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PROACTIVE LEARNING- SHIFTING TOWARDS A MORE INNOVATIVE HIGHER EDUCATION

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DOI: 10.19062/2247-3173.2025.26.3

Abstract: *Modern higher education is no longer limited to the preparation of narrow specialists for a specific field of activity, but to the development of the personality of each student, increasing his professional competence and effectiveness and above all creating proactive and motivated citizens who participate in public life. The emphasis is shifting from learning large amounts of information to learning ways of continuously acquiring new knowledge and learning skills; forming habits of independent (creative) rather than reproductive thinking.. The new educational paradigm is a strategy of education for the future, its essence being the transition from mastering the volume of information to developing critical thinking, learning to solve problems and actively working with information in an increasingly complex world*

This paper looks at the revised approaches to education, which is seen as a process of knowledge creation resulting from the application of research methods, rather than as a process of mere knowledge and skills transfer. The main characteristic of knowledge is its timeliness and relevance - the learner learns it not because the curriculum requires it and not because it is necessary to know it, but because this knowledge allows to solve real problems in real conditions of activity. In this way, learning becomes practically oriented and evolves into lifelong learning.

Keywords: *innovative higher education, proactive learning, critical thinking*

1. INTRODUCTION

The modern socio-economic environment is characterized by accelerated rates of social development, massive economic change, the growth of new knowledge, and changing information and production technologies. In today’s world successfully finding and keeping the job you want in a dramatically changed job market is becoming an ever-increasing challenge. Diplomas are no longer seen as a decisive indicator of professional qualifications, and cognitive skills are giving way to the so-called 21st century applied skills, building on relevant, highly specific, professional competences. In the age of the Internet and electronic means of storing information, formal human knowledge ceases to be significant. The new information society forms a new value system in which the availability of knowledge, skills and habits is a necessary but insufficient result of education. The individual is required to have the skills of orientation in information flows, mastering new technologies, self-learning, searching for and using the missing knowledge, possessing such qualities as universality of thinking, mobility, activity, initiative, flexibility, creativity. These characteristics determine the readiness and, above all, the ability of a person to receive lifelong education, to acquire new technologies, new practices of independent and group work, to work in conditions of increased information load and time deficit.

Accordingly, today's higher education focuses on maintaining and refining a range of productive skills, including the ability to communicate effectively, coordinate, adapt, work under pressure and solve problems. According to the Magna Charta Universitatum signed in Bologna in 1988, "the mission of universities to disseminate knowledge to younger generations implies that, in the modern world, they must serve society as a whole; that the cultural, social and economic future of society requires a special and significant investment in continuing education". The change of the educational paradigm from learning for life to lifelong learning shifts the main emphasis from the assimilation of a significant amount of information to the mastery of ways to continuously acquire new knowledge and skills for learning, the development of creative and critical thinking. The traditional principle of forming knowledge, skills and habits is complemented by the principle of forming competence. The personal-developmental orientation of educational processes as a leading trend of modern innovative changes in the educational sphere determines the transition from authoritarian-communicative to humanitarian-communicative interaction of the subjects of educational activity. Modern higher education is not limited to the preparation of narrow specialists for a specific field of activity, but to the development of the personality of each student, increasing his professional competence and effectiveness and above all creating proactive and motivated citizens who participate in public life. When defining the objectives and selecting the content of education, it is necessary to search for an optimal combination of the already established traditional approaches and the introduction of new information components aimed at forming the experience of personal activity on an information basis, conditioning the requirements for the individual in the information society.

When assessing the competitive ability of a specialist, it is not so much the volume and quality of the available knowledge that is crucial, but the level of competences that should ensure his preparation for life in modern society. Therefore, the assessment of both the level of preparation of the specialist for future professional activity and the process of obtaining higher education itself can be carried out in competence categories

One of the promising approaches to address the challenges facing the modern education system is the competency-based approach to education quality management. The implementation of the ideas of the competence approach in education at the beginning of the XXI century is conditioned by the following factors: the pan-European and world trend of integration and globalization of the world economy; the need for harmonization of the architecture of the European education system; the ongoing in recent years change of the educational paradigm; the richness of the conceptual content of the term competence approach; the educational policy resulting from the recommendations of the Council of Europe.

2. REVISED APPROACHES TO EDUCATION

The phenomenon of learning becomes a dynamically changing process with the revision of its methodological foundations, its main focus being the necessity to prepare not carriers or holders of information, but active users. In order to solve this task, an educational system is needed that allows, but also obliges the person to continuously learn in an increasingly complex world. The educational paradigm is shifting from learning for life to lifelong learning (LLL) in the transition to a new type of society. The emphasis is shifting from learning large amounts of information to learning ways of continuously acquiring new knowledge and learning skills; learning habits of working with information, forming habits of independent (creative) rather than reproductive thinking; the formation of knowledge, skills and habits is complemented by the formation of competences.

The new educational paradigm is a strategy of education for the future, its essence is in shifting the main focus from mastering the volume of information to independent (critical) thinking, learning to solve problems, developing habits of working with information in an innovative way.

The reproductive system of training, in which , on the one hand, the teacher reproduces and "re-transmits" to the learner a sum total of knowledge, then controls its absorption and, on the other, the learner "absorbs" knowledge, then reproduces it in a situation of control, does not allow the formation of the learner's corresponding personal characteristics. That is why in the world educational practice the orientations are changing, the concepts of modernization of the educational system appear. The essence of these changes boils down to the following: approaches to education are being revised, which is seen as a process of knowledge creation resulting from the application of research methods, rather than as a process of knowledge and skills transfer. The main characteristic of knowledge is its timeliness and relevance - the learner learns it not because the curriculum requires it and not because it is necessary to know it, but because this knowledge allows to solve real problems in real conditions of activity. In this way, learning becomes practically oriented and evolves into lifelong learning.

Approaches to the role of the teacher and the learner in the learning process are also being reviewed. The main role of the teacher is not to continuously guide and regulate the learning activity, but to create optimal conditions that support the cognitive, communicative and personal activity of the learners. Learners become initiative subjects of the educational process as they create a system of knowledge together with the teacher, analyze and process information, engage in project activity and experimentation, gain their own experience and fill it with personal meaning.

Education aims not only to provide knowledge, but also to modify the human attitude towards the environment, ensuring its adaptability in constantly changing conditions. And this largely depends not on the acquired knowledge, but on the ability to use it in the practical activity of the learners. The labour market dictates the need to modernise the higher education system by strengthening its vocational component. A special role here is played by the foreign language, the knowledge of which at the modern stage is a mandatory attribute of the successful specialist. The new times, the new conditions of professional activity require a revision of both the general methodology and the specific methods and means of foreign language training. Integration processes in different spheres of politics, economy, culture, ideology, pose the problem of intercultural communication and mutual understanding of participants belonging to different cultures. In connection with the fact that each non-linguistic higher school has its own professional orientation and is related to a specific industry, it is imperative to carry out the selection of the content and methods of training of foreign-language professional communication of students, including in the situational range of subject areas corresponding language and speech material reflecting the specifics of their future professional activity

An important structural component of the relevant professional competence is communicative competence, which includes the development of skills in 4 types of speech activity: speaking, listening, reading, writing. The formation of communicative competence also implies other competences: linguistic (learning the norms of language and being able to use them in a given situation), language (knowledge of language, mastery of the meta-linguistics of linguistics) and cultural (knowledge of the language and culture of the people). The concept of communicative competence was introduced by D. Hymes [1] in 1960, who launched the idea that the purpose of language learning is to be able to use language to carry out communication and that communicative competence is distinguished by linguistic, psychophysical and social characteristics.

Hymes was reacting to Chomsky's famous distinction between the **competence** of "an ideal speaker-listener, in a completely homogeneous speech community, who knows its language perfectly," on one hand, and "errors (random or characteristic) in applying his knowledge of the language in actual **performance,**" on the other[2] (Chomsky, 1965, p. 3). Hymes [3] (1972) recognised this distinction as a contemporary interpretation of a tradition leading back to Saussure and even Humboldt, and questioned the prioritisation of linguistic competence, that is, "tacit knowledge of language structure" (p. 271) over performance, or "imperfect manifestation of underlying system" (p. 272).

The competency paradigm that has emerged in the context of the modernization of higher education and in the context of the Bologna Process is oriented towards competencies and competence as the leading criterion for preparing future specialists for the unstable conditions of work and social life. The main goal becomes the preparation of not just knowledgeable, but able to dispose of this knowledge - the preparation of professionals with critical thinking, able to choose the most optimal among the many solutions, reasonably refuting the wrong ones; professionals ready for self-education, self-determination, self-development. Changing the model of supportive education oriented towards "education for life" to the innovation paradigm oriented towards "lifelong education" means that the professional must have a consciousness of himself/herself as an individual, a free, intellectually autonomous person and be capable of self-identification and self-realization in a situation of indeterminacy. The change of the educational objectives requires changes in the approaches and technologies for the organization of the learning process. A transition is needed from a centralized model of knowledge transmission through the teacher to a model centered on the student, who, with the support of the teacher, defines his/her learning goals and achieves them. The lecturer in such a model should emphasize collaborative discussions and group project activities, and apply new educational technologies oriented towards a two-way relationship with deeper interaction between the lecturer and students.

Foreign language education of students aims to develop in them not only communicative competence but also intellectual skills for working with information in a foreign language. Future specialists will have to know the scientific achievements in the country and abroad, to select material for their work, to study accompanying documentation to instruments and technologies. Therefore, the main task of foreign language education in higher education institutions is to teach students to use foreign language literature in their field of study for professional purposes, to develop the ability to express themselves in a foreign language on issues related to future profession. One of the methods of foreign language teaching is the development of students' skills of analytical-synthetic processing of information in a foreign language. These are creative processes involving comprehension, analysis and evaluation of the content of an original text to extract the necessary information. Analysis allows to separate the most valuable information from the secondary information and data, without which it is impossible to extract the main content of the original. At the same time, a process of synthesis of the text takes place, i.e. the integration into a logical whole of the main information obtained as a result of the analytical operations. This requires learners to learn to extract the main content, concisely formulate it and present it in a logical sequence, creating a secondary text. In order to accomplish this task in the process of language learning, students need to develop intellectual skills of critical thinking. As a result of the requirements for specialists in modern conditions (the presence of professional competence, the ability to navigate the information flow, the ability to make quick independent decisions, the ability to self-realization and self-learning) the importance of developing critical thinking skills is growing.

3. CRITICAL THINKING SKILLS

The study of critical thinking is relevant for the development of psychology, pedagogy, linguistics and sociology for the following reasons: thinking is inextricably linked to speech, which is the basic mechanism of thinking, speech in turn is a form of communication of people through language; critical thinking implies the development of certain habits, allowing to overcome stereotypes, to find correct solutions in one or another social or linguistic cultural situation; the study of critical thinking is necessary in connection with the fact that the English language in our time is a linguistic sociocultural dominant.

The ideas of critical thinking date back to Socrates' method of teaching through a series of questions stimulating dialogue, which teaches one to logically express one's thoughts and evaluate their credibility, developing habits of independent thinking. In the twentieth century, the necessity to develop thinking has been analyzed by psychologists, educators and sociologists (S. Brookfield, L. C. Vygotsky, G. Guilford, D. Dewey, A. H. Leontyev, D. Russell, etc.), characterizing it as a separate property of the personality, as a habit of thought activity, as a personal and socially significant phenomenon, a priority in the field of education. In 1941 in the USA the monograph of E. Glaser's "An Experiment in the Development of Critical Thinking" gives the main features of the new method: a willingness to consider and reconsider those questions on which one has already acquired an opinion by experience; knowledge of methods of constructing logical reasoning; building the habits of applying the new method.

The key habits necessary for critical thinking include: the ability to analyze and synthesize, interpret, draw conclusions, and evaluate. It is based on logic and value statements. Critical thinking is a complex integral quality of personality, a set of motivational, cognitive, activity, reflexive components, providing the processes of self-knowledge, self-education, self-realization [4]. Reflecting the socially conditioned level of student's development in educational and research activity, it is a professionally and personally significant value.

Critical thinking, capable of elevating new ideas and possibilities, is essential in problem solving [5]. The importance of knowledge of facts, laws, historical dates and events is not in doubt, but no less important is the ability to work meaningfully with information, to separate in it the main ideas, to see the relationship between them, to select the necessary and reject incorrect information, to analyze and evaluate it.

David Klooster [5] separates 5 main points in the characterization of critical thinking: 1) critical thinking is independent, everyone formulates his own ideas, evaluations and beliefs independently of others, critical thinking can exist only when it has individual character; 2) information is the starting point of critical thinking, knowledge creates reasoning, without which one cannot think critically, in order to generate complex thought one has to process facts, ideas, texts, theories, data, concepts; 3) critical thinking begins with posing the questions and clarifying the problems to be solved, the true cognitive process at each stage is characterized by the learner's striving to problem-solve and answer questions arising from his or her own interests and needs, the complexity of learning in critical thinking lies in part in helping the learner to consider an infinite variety of surrounding problems; 4) critical thinking strives for persuasive argumentation, the critical thinker finds his/her own solution to the problem and supports it with reasonable, reasoned arguments, he/she is also aware that other solutions to the problem are possible and tries to prove that the solution he/she has chosen is more logical and rational than others; 5) critical thinking is social - every thought is checked and accounted for when shared with others.

The concept of critical thinking is combined with the competence approach. The analysis of the goals and objectives set within the competency approach and the development of critical thinking in foreign language education show similarities. The technology for the development of students' critical thinking in the process of foreign language teaching is built on the basis of the systemic, cognitive-communicative, personality-oriented, activity-oriented approaches and the principles of communicativeness, text-centeredness, complementarity, controlled transition from activity in a learning situation to a life situation, reflections. The effectiveness of the development of students' critical thinking in the process of learning a foreign language is ensured by the following pedagogical conditions: formation of cognitive motives stimulating students' thinking activity; creation of a learning-research environment; integration of modern information technologies with active forms and methods of foreign language teaching (discussions, project activity, problem-based, heuristic research methods, etc.), contributing to the development of critical thinking and increasing cognitive interests.

In the process of professional language training, students should develop skills of systematic thinking, ability to generalize, analyze, perceive information; ability to construct oral and written speech in a logically correct, reasoned and clear manner; the ability to improve and develop one's intellectual and cultural level, the aspiration for continuous self-learning and self-development; the ability to find, collect and summarize factual material, to draw justified conclusions, etc. Competences are formed in the process of development of critical thinking, since competence is the ability to act successfully on the basis of practical experience, skills and knowledge in solving tasks common to many types of professional activity.

4. TECHNOLOGY FOR DEVELOPING CRITICAL THINKING

An important tool for organizing active learning is the pedagogical technology for developing critical thinking developed in the middle of the last century by the International Reading Association of the University of Northern Iowa and Hobart and William Smith Colleges. The authors of the technology are Ch. Temple, J. C. Temple, C. Steele, C. Meredith. TDCT includes goals, objectives, principles for construction, stages and conditions for creation, methods, approaches and ways of training in thinking, forms of organization of the activities of learners and ways of assessing the results. The main goal of the development of critical thinking in students is the expansion of thinking competencies for effective solution of social, scientific and practical tasks. TDCMT helps to create students' information competence, teaches them to work with information, to develop analytical abilities, to develop a critical attitude to information, helps to reveal cause-effect relationships, to separate the main from the non-essential, to express their thoughts clearly and argumentatively in oral and written form, to find solutions to problems.

Leading theoretical ideas defining the conceptual basis of TDCT are [5,6]: the philosophical-social concept of the open society (C. Popper, A. Bergson, J. Agassi); the traditions of the constructivist approach in psychology (L. S. Vygotsky, J. Piaget); the theory of cognitive flexibility (R. Spiro, R. Coulson, R. Anderson); metacognitive learning (M. Cole, D. Brunner, D. Halpern, D. Wood, B. Russell,); sociocultural theory (L. S. Vygotsky). In the practical applications of TDCT, pedagogical innovations are also used, such as the technology of full knowledge acquisition (J. Carroll, B. Bloom); the technology of multilevel learning (E. Cohen, J. Carroll) and the technology of modular learning.

TDCT has its own principles of construction, some of which are didactic, others are specific to it [7]:

1) information saturation of teaching and practical material for the use of arguments, evidence and refutations based on specific facts, data sources;

2) social conditioning of the subject of reflection - critical thinking is social, so the selection of problems, tasks, topics for discussion should be carried out through this its special property;

3) communicativeness in the process of comprehension of the problem and its discussion - critical thinking is individual and independent, but it manifests itself in group work when conducting disputes, discussions, discussing reports, the decisive importance in the comprehension of information is played by the communicative habits of the participants;

4) problematicity of the content of the material - a general didactic principle, one of the main ones in the construction of the TRCM, since problem-based and critical thinking are associated with common properties, methods and approaches of training;

5) motivation and necessity of knowledge - the main starting point of thinking activity and criticality of mind is reflection, which is possible only when the student has high motivation to learn, understand, reflect, establish the truth or obtain the result, low motivation of learners is a barrier to the development of critical thinking;

6) scientificity, reliability and accessibility of information - the basis of traditional methods of teaching is the translation of knowledge from the teacher to students, which negatively affects the research culture; the skills of not taking on trust, assessing the situation, seeking confirmation and formulating arguments help to develop learning constructed using TDCT approaches and strategies;

7) continuity of learning in thinking - universality of TDCT for all ages, high effectiveness of its use in different subject areas if the sequence of learning in critical thinking from school to university is followed.

The main theoretical tenets of TDCT boil down to: critical thinking with a necessary characteristic of a modern specialist; critical thinking can be purposefully formed in the educational process, spontaneously it can be created, but in significantly later terms after higher school; critical thinking allows not only to notice contradictions, shortcomings, gaps in the information, but also to weighted to analyze a variety of sources, to make sense of one's own position, to master a variety of strategies for working with information and solving problem situations.

TDCT has problem-based learning as its foundation; its study presupposes an understanding of the basic characteristics of critical thinking. Problem-based learning refers to the organization of the learning process in such a way that it involves the creation of problem situations in the minds of the learners under the guidance of the teacher and the organization of active independent activity of the learners, resulting in the creative acquisition of knowledge, skills, habits and the development of thinking abilities.

According to the content of solved problems there are 3 types of problem-based learning: scientific problem-solving (scientific creativity) - theoretical research, i.e. the search and discovery by the learner of a new rule, law, proof; the basis of this type is the setting and solving of theoretical learning problems; practical problem-solving (practical creativity) - the search for a practical solution, i.e. a way of applying known knowledge in a new situation, construction, invention; the basis of this type is the setting and solving of practical learning problems; creation of artistic solutions (artistic creativity) - artistic representation of reality on the basis of creative imagination; this type of training stimulates the manifestation of activity, initiative, independence and creativity in the learner, develops intuition and discursive (penetration into the essence), convergence (open) and divergence (creation) thinking, teaches the art of solving various scientific and practical problems, attempt to creatively solve theoretical and practical problems.

A key component and simultaneous drawback of problem-based learning is the dominant role of the teacher. Critical thinking development technology corrects this deficiency, starting on the path of further strengthening the active role of learners in problem-based learning. Training in TDCT is productive only if the trainer, in the process of becoming aware of his activity, is able to abandon formally established traditional ways of working.

The transition to learner-centred learning poses a significant difficulty for the teacher, transforming him or her from a mechanical transmitter of information into an acting partner in the process of knowledge acquisition. Therefore, it provides the teacher with room for professional growth and realization of their personal qualities.

5. CONCLUSION

In conclusion we can summarize that the leading trends in education in the 21st century are: informatization (conditioned by the development of the information society using global communications and by the creation of a fundamentally new information-educational learning environment); humanization (caused by the division in the 19th century of the unified culture into natural science and humanities and the need for their convergence in the new stage of development of society); technologization of the learning process (conditioned by the development of the technological approach to learning in connection with the massiveness of education, especially higher vocational education, and the introduction of pedagogical technologies); the integration of pedagogical and information technologies of education (caused by the new possibilities of information translation and computer support of the procedural part of pedagogical technology). The main focus remains on the increased attention to the independent work of students (resulting from the penetration of IT in all spheres of society) and the development of critical thinking as a complex integral quality of the personality, a set of motivational, cognitive, activity and reflexive components, ensuring the processes of its self-knowledge, self-education, self-realization. The technology for the development of students' critical thinking in the process of foreign language education is built on the basis of the systemic, cognitive-communicative, personality-oriented, activity-based approaches reflecting the need for independent improvement of qualification and acquisition of new skills throughout life.

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ENHANCING STUDENT ASSESSMENT: A DUAL-METHOD APPROACH

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DOI: 10.19062/2247-3173.2025.26.4

Abstract: *The article presents two methods for assessing students' achievements in the National External Assessment in Mathematics after the 7th grade in Bulgaria. Some advantages of analyzing the assessment using Item Responsibility Theory are shown.*

Keywords: *national external assessment, item responsibility theory, difficulty*

1. INTRODUCTION

Each stage of the Bulgarian education system concludes with a National External Assessment (NEA): administered at the end of IV-th grade, VII-th grade, X-th grade, and XII-th grade. This paper addresses the results in mathematics from NEAs conducted after VII-th grade.

Since the beginning of 2024, the exam has been structured into two distinct parts:

- The first part, lasting 60 minutes, contains 20 test multiple choice questions with a choice of answer A, B, C, D, which are scored with 2, 3 or 4 points. They contribute to a total of 65 points.
- The second part, lasting 90 minutes, contains 3 open-ended mathematical problems. Each problem includes two to four independent sub-tasks, requiring students to provide detailed written solutions. They contribute to a total of 35 points.

The maximum score for the two parts is 100.

The scoring of the tasks is predetermined by the authors of the test. They take into account the perceived difficulty of the items. Usually, these tasks are piloted in advance, and it is expected that the easier task will be evaluated with fewer points, and the more challenging ones are awarded higher point values. Table 1 shows the results after the external assessment in 2024 for the multiple-choice questions (MCQ) tasks, arranged according to the difficulty coefficient obtained from the Classical Test Theory (CTT). As it can be seen, some easy tasks (with numbers 4, 10 and 12) are evaluated with 3 points, while task # 5 is of optimal difficulty and is evaluated with 2 points. At the same time, task # 14 (evaluated with 4 points) is easier than task # 3 (evaluated with 3 points).

22.

A) …

B) Factor the polynomial $M = ax^2 - bx + 45$, where the coefficient a is the smallest value of the expression $(x+3)^2 + 1$ and $b = \frac{|-13|+(-13)^0}{(-1)^{2022}}$.

FIG.1 Condition of task 22 of NEA – 2022

For the evaluation of the extended constructed response (ECR) tasks, the authors of the test develop a scoring rubric, assigning a specific number of points to particular actions or components within a solution. These points are usually multiples of 0.50, and in some tasks, they are multiples of 0.25. This is done for finer differentiation among students' performance, since the points obtained from the NEA are used for admission into profile and professional oriented classes in secondary high schools. Fig. 1 shows the prompt for task # 22 from the NEA – 2022 [2], while table 2 outlines the corresponding scoring scheme. Such a defragmentation of points is associated with a detailed review of each student's solution. In the article [3], it is shown that this scoring is not very good practice, since a small percentage of students receive intermediate results. In addition, this method of scoring tasks is not scientifically justified. In educational measurement, the most widely accepted approaches are Classical Test Theory (CTT) and, more recently, Item Response Theory (IRT) [1].

2. MAIN RESULTS

To explore this further, the author of the report conducted an experiment with 487 students completing grade VII in 2024. In this experiment, their achievements were assessed using two different evaluation methods.

Table 1. Assessment of tasks with IE from NEA – 202 4 years.

Points	#	Difficulty	Interpretation
2	13	0.86	very easy
3	4	0.81	easy
3	10	0.81	easy
3	12	0.79	easy
2	5	0.75	easy
3	1	0.70	optimal
2	2	0.69	optimal
3	17	0.68	optimal
4	14	0.65	optimal
3	15	0.64	optimal
3	18	0.63	optimal
3	11	0.60	optimal
4	16	0.60	optimal
4	20	0.56	optimal
3	3	0.55	optimal
4	7	0.55	optimal
4	9	0.52	optimal
4	8	0.44	optimal
4	6	0.40	difficult
4	19	0.39	difficult

The first method, referred to by the author as *traditional method*, follows the scoring approach currently used in Bulgaria's National External Assessment (NEA). The maximum sum of points for one student is 100 points.

The second method, referred to *as experimental method,* is based on the following scoring scheme:

- Each MCQ task is scored with 1 point for a correct answer and 0 points in other cases.

- Each ECR task is scored with 0, 1, 2 or 3 points, which correspond to the number of "important" steps in solving it.

Thus, the maximum number of points according to the experimental method is 36 points.

Table 2. Assessment of task 22 of NEA – 2022

Description	Points
$a = 1, b = 14$ and $M = x^2 - 14x + 45 - (x-9)(x-5)$	5 points
Finding the minimum value and determining $a = 1$	1 point
Finding $b = 14$	1 point
For factoring $M = x^2 - 14x + 45$	3 points
Method I: Representing $-14x = -9x - 5x$	1 point
For appropriate grouping in pairs	1 point
For factoring out the common term	1 point
Method II: (completing the square)	0.5 points
Representing $-14x = -2.7x - 2.7x$	1 point
For representing $x^2 - 2.7x + 7^2 - 7^2 + 45$	1 point
For writing $(x-7)^2 - 4$ or $(x-7)^2 - (2)^2$	0.5 points
For factoring $(x-7-2)(x-7+2)$ or $(x-9)(x+5)$	1 point

Table 3. All tasks from NEA – 2024, sorted by difficulty

#	b-param
13	-2.09
4	-1.63
10	-1.62
12	-1.46
5	-1.18
1	-0.85
2	-0.78
17	-0.71
14	-0.57
15	-0.51
21 A)	-0.47
18	-0.46
11	-0.25
16	-0.25

#	b-param
20	-0.08
3	0.03
7	0.03
9	0.19
23 A)	0.52
8	0.61
21 B)	0.69
6	0.84
19	0.90
23 B)	1.19
22 A)	1.24
21 C)	1.65
22 B)	2.18
23 C)	2.83

The use of the experimental assessment method enables all tasks—both MCQs and ECRs—to be analyzed using Item Response Theory (IRT) on a single difficulty scale, based on the b-parameter. This coefficient is usually in the interval (-3;3). Moreover, if a task is easier, the coefficient b is closer to -3, and if it is more difficult, it is closer to 3.

Comparing tables 1 and 3, it can be established that MCQ tasks from # 1 to # 20 are arranged in the same way according to both theories – CTT and IRT. At the same time, the ECR tasks with numbers from 21 to 23 are included in Table 3. As can be seen, the tasks cover a relatively uniform difficulty interval from -2.09 to 2.83. As anticipated, the ECR tasks generally possess higher b-parameter values, reflecting their greater complexity relative to the MCQs.

To compare the scores obtained by the students in the two methods, one can approach it in different ways. One of them is by equating the scores obtained by the experimental method X ϵ [0;36] to those obtained by the traditional method Y ϵ [0;100]. This is done with the formula

$X_i^* = \frac{\sigma_Y}{\sigma_X}(X_i - \mu_X) + \mu_Y$, where

- X_i are the scores of the i-th student according to the experimental assessment;
- X_i^* are these points equated to traditional grading;
- μ_X and μ_Y are the mean values of the students' raw scores obtained from the experimental and traditional assessment, respectively;
- σ_X and σ_Y are their respective standard deviations.

This is how the formula is obtained:

$$X_i^* = 2.76(X_i - 17.63) + 49.$$

The value of the correlation coefficient is 0.99192, which means that the two assessments are identical.

The experimental evaluation method offers several key advantages:

- it enables the application of IRT for analyzing student performance;
- it allows for the comparison of results across different regions and schools;
- it facilitates more reliable comparisons between distinct populations, surpassing the traditional method used in Bulgaria, which relies primarily on average exam scores;
- it supports more accurate comparisons between different populations through so-called "anchor" tasks. This method is shown for example in [4]

3. CONCLUSIONS

In conclusion, the conventional scoring method used in the NEA can be effectively replaced by a simpler experimental approach without compromising the assessment's regulatory function. Moreover, the research on the results of these assessments is subject to analysis using various educational measurement theories, including both Classical Test Theory (CTT) and Item Response Theory (IRT). If necessary, student scores from the experimental method can be easily converted to a unified 0–100 scale by representing the raw scores as percentages, ensuring compatibility with existing reporting standards.

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FRAMING AERODYNAMIC TERMINOLOGY: A LINGUISTIC APPROACH /PRELIMINARY STUDY/

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DOI: 10.19062/2247-3173.2025.26.5

Abstract: *The aerodynamic terminological field is characterized by highly complex and specific terms which are used to describe various scientific phenomena that occur during flights. The aim of the paper is to analyze aerodynamic terminology using a frame semantics approach to study terms categorized into frames and subframes. The study reveals the linguistic behavior of aerodynamic terms within the frames. Using the corpus linguistic software Sketch Engine, we identified recurring patterns, collocations, and term frequency in a compiled corpus of books on aerodynamics. The findings reveal that aerodynamic terminology can be systematically structured into frames, which can overlap, thus demonstrating the conceptual construction of complex, technical meanings of the aerodynamic terms. The research contributes to a better understanding of aerodynamic terms as part of the aviation terminological field and is of great help to people interested in learning, teaching, and working in the field of aerodynamics.*

Keywords: *frame semantics, aerodynamics, cognitive linguistics, corpus linguistics, terminology*

1. INTRODUCTION

The dream of flying and conquering the skies has always been one of the main goals people have had. Referring to the history of aerodynamics, we can point out the names of Aristotle, who proposed that air has weight, and Archimedes, who discovered the law of floating bodies. One of the most prominent people related to the development of aerodynamics is the Italian painter, sculptor, and engineer Leonardo da Vinci, who described and designed ornithopters (machines that copied the actions of a bird's wing), the first helicopter and the first parachute. He also concluded that *'it was the movement of the wing relative to the air and the resulting reaction that produced lift necessary to fly'* [1]. The term *aerodynamics,* meaning *'science of the motion of air or other gases'* [2] dates back to 1837, and was formed from *aero- (air)* and dynamics. It was in the 20th century that the term aerodynamics was used in relation to aircraft and aviation. The beginning of the 20th century marked the first successful flight with heavier-than-air powered aircraft. Since then (1903), aviation and aerodynamics have been developing rapidly and today with the constant advancements in technology and science, we witness the emergence of new highly developed technologies. Inventions in technology have undoubtedly influenced specialized languages, including aviation language. A lot of new concepts have appeared, thus enriching and expanding the terminological field. Aerodynamics, as part of the aviation domain, is no exception. With the development of theories, and the acquisition of new knowledge about various phenomena related to flying, the terminological system of aerodynamics is constantly evolving, making it worth researching from a linguistic perspective.

Terminology used in aerodynamics can be described as highly specialized, precise, and multidisciplinary, as there are terms borrowed from Physics, Mathematics, Engineering. There are various studies on aviation language and its characteristics- Breul (2013) [3], Aziz and Rosa (2018) [4], Estival et al. (2016) [5], Kovtun (2012) [6], Katsarska (2021) [7]. Anić and Brač (2022) [8] present the process of developing the Airframe database in an article. The list of researchers who have dedicated their work to aviation language is a long one. Moreover, each of these scholars has contributed to the study of aviation language. When we began our research on aviation language, we noticed that most of the research described radiotelephony (the phraseology used between pilots and air traffic controllers) or analysed the linguistic aspects of the terminology used by aviation professionals, e.g. Fomina (2022) [9], Osadchaya (2020) [10], Katsarska (2024) [11]. What attracted our attention was that we could not find linguistic research on aerodynamic terminology. Therefore, we consider our research on aerodynamic terms innovative and unique; research that can reveal facts about a niche that has not been studied enough.

As mentioned, aerodynamics is characterized by a highly specialized scientific terminology. The concepts in this specific terminological field describe complex scientific phenomena and principles. Therefore, we asked ourselves how these concepts are structured and organized in mental representations, i.e. particularly within frames. And if they are organized in such frames, what is the common feature that links them with one another? In other words, if within a frame, there are subframes, how are these terms in the subframes related to each other? Can they exist in more than one frame? If they exist in more than one frame, does this affect their meaning?

We also thought about how these concepts behave linguistically-whether there are any recurring patterns, whether they collocate, and how often they are used in the context of aerodynamics. To find the answers to these questions, we refer to Frame Semantics and the corpus linguistic software Sketch Engine.

2. . FRAME SEMANTICS

Croft and Cruse [3] note that words denote concepts, which are units of meaning. Based on their meanings, concepts, represented by words can be compared and contrasted with each other. Words and their corresponding concepts are connected to one another. However, there are concepts that are connected to one another by a person's encyclopedic knowledge. i.e. by experience. For example, *AIRPLANE* is not merely a means of transportation. Concepts not directly related to it by hyponymy or other lexical relations, emerge from a person's knowledge: *pilot, passengers, landing, turbulence, aerodynamics.* The reason why these concepts are in a relationship lies in the fact that they are *'motivated by, founded on, and co-structured with, specific unified frameworks of knowledge, or coherent schematizations of experience, for which the general word* ***frame*** *can be used'* [12]. Fillmore also notes that a variety of terms have been proposed for these kinds of structures, e.g. frame, schema, script, cognitive model, experiential gestalt, base, and scene. However, he points out that these terms are used in various ways and some scholars distinguish among them depending on whether they are static or dynamic, '*according to the kinds of inference making they support'* [12].

Frame Semantics is a research programme in empirical semantics. It studies word meanings, describing the principles for creating new words and adding new meanings to words. Fillmore [13] refers to the notion of '*frame'*as '*the appeal, in perceiving, thinking, and communicating, to structured ways of interpreting experiences.*

Fillmore believes that to describe a language system, one has to include a description of the cognitive and interactive 'frames' that people use to interpret the world around them, create messages, thus creating cognitive models from their experiences. The concept of 'frames', also known as 'schemata' and 'scenario' is related to the idea that people have a cognitive inventory of schemata, which they use to structure and interpret their experiences. Although frames are not dependent on language, they play an essential role in language processing. According to Fillmore [13], when particular words or grammatical structures are associated with particular frames in a person's mind, these words and structures activate the frame which, in turn, allows access to the linguistic elements related to it. The term *frame* refers to a system of concepts that are related to one another in such a way that for a person to be able to understand one of these concepts, they have to know the whole structure this concept belongs to. According to Fillmore [14], words represent categories of experiences, based on a particular situation which has evoked a person's encyclopedic knowledge. He also adds that there are words that help people during the communication process by providing access to knowledge of frames and performing categorization. It means that words are more than mere meanings but they are also related to some background information. Thus, for an aviation professional, aerodynamic terms such as *lift, weight, drag* and *thrust* mean more than the basic meanings they have but are associated with principles and phenomena related to flight. It is evident that background context is of utmost importance in understanding a category. Fillmore [14] notes that a lot of framing words appear in highly specialized contexts. He also points out that '*the process of understanding a text involves retrieving or perceiving the frames evoked by the text's lexical content and assembling this kind of schematic knowledge (in some way which cannot be easily formalized) into some sort of 'envisionment' of the 'world' of the text'* [14]. In other words, to understand a text, a person uses frames evoked by the context and the schematic knowledge (the mental structure of the existing knowledge) they interpret the meaning of the text.

A word and its meaning can be related to one another in an associational way. Hearing the term *aerodynamics*, a person's mind evokes mental pictures of aircraft, airflow, or speed. Moreover, the term aerodynamics is not only related to aircraft but it may also be associated with cars, or why not with bikers or skiers who use aerodynamic principles to gain speed. Fillmore [13] notes that Frame Semantics strives for the same representation of 'word meanings, sentence meanings, text interpretation and world models'. A word can link different frames and understanding the meaning of the word requires knowledge of the scenario; the sentence that contains the word requires knowledge of the scenario, the lexical items, grammar. Fillmore [13] also argues that one aspect of a linguistic system is a person's cognitive and interactional frames are connected with language. To analyse a language, then, one has to access the frames that exist in language, pay attention to the number of frames, and study how frames are structured.

3. DATA AND SKETCH ENGINE SOFTWARE

This research is a preliminary stage of a broader linguistic study on aerodynamic terminology. Therefore, the number of terms we have extracted,109, is relatively small, however, we believe that the results will help us to lay the foundations of our study and will, undoubtedly. shed light on the research questions we have asked.

The present research mainly focuses on the terms that have the highest number of occurrences in the corpus we have compiled. We have manually extracted aerodynamic terms using the e-book *Pilot's Handbook of Aeronautical Knowledge*, published by FAA (Federal Aviation Administration), namely: Chapter 4 *Principles of Flight* and Chapter 5 *Aerodynamics of Flight* [15].

When we compiled the list, we looked up the definitions and categorized each term into its corresponding group. We used the *Dictionary of Aviation* [16], *The Encyclopedia of Aerodynamics* [17], and various websites for the definitions of the terms. Then, we studied the terms in each frame and where it was possible, we created subframes. That way, we created the following frames and subframes:

1. Aircraft Components, and subframes: Wing-Related Components, Stabilizer Components, Rotorcraft Components, Structural Components;
2. Flight Dynamics, and the following subframes: Aerodynamic Forces, Aircraft Motion and Stability, Aerodynamic Effects and Rotational Forces, Angles, Performance and Flight Limits;
3. Fluid Dynamics and the subframes Aerodynamic Flow and Aerodynamic Principles
4. Flight Performance Parameters and the subframes: Altitude-Related Parameter, Speed;
5. Flight Control and Navigation System and the subframes: Flight Control Surfaces, Pilot Control and Flight Instruments
6. Aircraft Flight Phases and Maneuvers, and the subframes: Takeoff and Landing, Aircraft Attitude and Maneuvers
7. Powerplant and the subframes: Types of Engines, Engine Components

In this paper, we will present only the first three frames and their corresponding subframes because our research is ongoing. Due to the extensive nature of the research, we discuss only the terms with the highest frequency distribution in the corpus. The other frames and subframes are being examined and the results of the study need more detailed examination and analysis. The conclusions that we have come to, are based on this particular research. We consider them preliminary findings, however, we firmly believe that they have established the foundations of our research on aerodynamic terminology.

Most of the terms belong to the Flight Dynamics and Fluid Dynamics frames, which can be explained by the fact that aerodynamics is part of physics and this includes fluid dynamics, and fluid mechanics. The Flight Dynamics frame comprises terms related to physical phenomena and principles; therefore, the prevailing number of aerodynamic terms is not surprising.

To study the terms in each frame and subframe, we decided to use the corpus linguistic software *Sketch Engine (*https://www.sketchengine.eu/*)*. Sketch Engine is web-based corpus linguistic software, which allows users to create their own corpus (corpora) by uploading text(s). A researcher can analyse the data in terms of Word Sketch (it shows a word's collocates), concordance (examples of use in context), collocation and N-grams or frequency analysis. For the purpose of this research, we uploaded the two chapters we extracted the terms from (Chapter 4 *Principles of Flight* and Chapter 5 *Aerodynamics of Flight)* and the books on aerodynamics *Introduction to the aerodynamics of flight* [1] and *Fundamentals of Aerodynamics* [18]. Creating a corpus and using the corpus linguistic software will help us analyze the terms linguistically not as extracted lexemes from texts but in a specific, specialized context.

4. PRELIMINARY FINDINGS AND DISCUSSION

Using the definitions of aerodynamic terms, we established seven frames and their corresponding subframes.

The terms in each frame, and their respective subframes, are closely related to one another as they contribute to the construction of the frame. They are dependent on each other but are also tied to a particular context.

This leads to the fact that we can observe that some terms can belong to more than one frame. The definitions given in the dictionary (i.e. their lexical meanings) do not change, however, the context they are used in, influences their meaning construction and how people perceive and understand these terms, in other words people's cognitive ability to comprehend complex, scientific concepts.

4.1. Aircraft components frame

The first frame is Aircraft Components. As the name suggests, this frame consists of terms that denote different parts of an aircraft, e.g. *aileron* (*a horizontal control surface hinged to the mainplane, which enables an aeroplane to bank or roll), fuselage* (*the central body of a plane, to which the wings and tail assembly are attached and which accommodates the crew, passengers, and cargo), rudder* (*a control surface on the fin which rotates the aircraft about its vertical axis to produce yaw)*, *wing* (*the main horizontal aerofoil or mainplane).*

Some terms that belong to the Aircraft Components frame belong to other frames as they have both structural and functional roles. For example, the term *flap* has the following definition: *a movable* ***control surface on the trailing edge of an aircraft wing****, used primarily to* ***increase lift and drag during final approach and landing***. From the definition, it is evident that the term *flap* belongs to the frames of *Aircraft Components* (as part of the wing) and *Flight Dynamics* (flaps divert the airflow). Another example of a term that can belong to different frames is *propeller (****a rotating shaft with blades*** *which,* ***together with the engine****, moves an aircraft through the air).* In this case, the term *propeller* refers to a structural component, but it is also part of the Powerplant frame, as it is connected to the engine.

If we look closely at all the terms that belong to Aircraft Components*,* we can observe that most of them belong to more than one frame. The reason for this behaviour is that as they are structural components, they are applied during flight and their meanings are influenced by the particular context, and that way they are understood as part of another frame. This, actually, confirms Fillmore's idea that concepts within frames are context-dependent. Aerodynamic terms are no exception.

To gain a better understanding of the terms in the Aircraft components frame, we established the following subframes:

i) Wing-Related Components (wing, wingtip, leading edge, wing tank, trailing edge, slat);

ii) Stabilizer Components (tail, elevator, fin);

iii) Rotorcraft Components (rotor, rotor blades, propeller)

iv) Structural Components (fuselage, landing gear, nose).

The terms that belong to this subframe are related to the aircraft's wing. These terms cannot exist independently as they enable a person to describe the structural components of the wing or the control surfaces that are part of the wing. When describing a wing, a person uses all of these terms which makes each term dependent on the others, i.e. its meaning leading to the meaning of the other concept in the subframe. Therefore, it is not surprising that *wing* has the highest frequency among these terms in our corpus- it is used 1,406 times, compared to *flap* which has 106 occurrences.

The term *wing* has an essential role in the aerodynamic terminological field. Together with the modifiers such as *delta, rectangular, straight*, it indicates different types of wings. The term w*ing* is also part of other structural concepts, which belong to the *Aircraft components frame,* such as *wing root (the part of the wing where it meets with the fuselage), wing tip (the outermost part of the wing)* or *wingspan (a measurement from the tip of one wing to the tip of the other wing).* Using N-gram analysis, we studied how the lemma *wing* is used in the aerodynamic context.

Our research shows that *wing* appears in definite noun phrases *the wing* 467 occurrences , followed by possessive constructions *of the wing* (134), and *finite wing (a wing of fixed span with wingtips)* (117). Figure 1 shows a visualization of nouns that are commonly modified by *wing* and the modifiers of *wing* in the corpus.

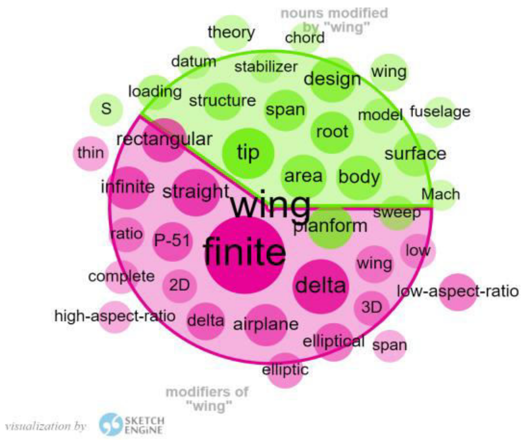

FIG. 1. Modifiers and nouns used with 'wing'

It is evident that when modified in the corpus, *wing* refers to different wing shapes and types: *delta, elliptical, finite. Finite and delta* appear to be the most frequent modifiers in the corpus while *span, structure,* and *tip* are the nouns that are modified by *wing* most frequently. The high frequency result in the corpus reveals that the term *wing* is central (core) to aerodynamic discourse and is part of compound nouns that are used in technical and aerodynamic contexts.

The second subframe of Aircraft Components is the Stabilizer Components. The terms that belong to this subframe describe structural elements that are responsible for the stability of the aircraft. The terms that belong to this subframe are: *tail (the rear part of the aircraft), fin (a fixed vertical aerofoil at the rear of a plane,* ***the vertical stabiliser****), elevator (****a movable control surface,*** *usually attached to the horizontal stabiliser of an aircraft,* ***used to produce the nose up/down motion of an aircraft*** *in level flight known as pitch), empennage (the tail assembly of an aircraft),* and *rudder (****a control surface*** *on the fin which* ***rotates the aircraft about its vertical axis to produce yaw****).* Analysing the definitions of the terms, we can observe that there are terms that can belong to more than one frame, namely: *elevator* and *rudder* are control surfaces; consequently, they can belong to the Flight Dynamics and Flight Control And Navigation frames. The term f*in* belongs to the Flight Dynamics frame because the vertical stabilizer plays a role in providing directional stability.

The term that is most frequently used in our corpus is *tail* (120 occurrences), followed by *elevator* (54 occurrences). The term *tail* denotes a structural element; therefore, it is modified by adjectives, providing information about the tail, e.g. *horizontal, vertical, wedge-shaped tail, butterfly.*

Using 2-3-grams, we observe that *tail surfaces* and *tail surface* have the highest frequency occurrences which can be explained that the term *tail* is referred to as a structural component related to aircraft stability in aerodynamic discourse. It is also used in possessive-of-constructions because of the occurrence of *tail of* (11 occurrences) and *tail of the* (7 occurrences). The analysis of the Stabilizer component frame shows that terms in this subframe can belong to multiple frames, without a change in the lexical meaning but depending on their function.

The third subframe of the Aircraft Components frame is the Rotorcraft Components. We have identified the following terms: *rotor (a device which turns about an axis or centre), rotor blades (a long thin aerofoil on a helicopter rotor),* and *propeller (a rotating shaft with blades which, together with the engine, moves an aircraft through the air).* As the name of the subframe suggests, these terms are united by a common conceptual base, the rotational motion that generates lift (rotorcraft) or thrust (propeller aircraft). We can also note that *rotor blades* is a hyponym of *rotor* as it is more specific in meaning. We have already mentioned that the term *propeller* belongs to the Powerplant frame.

Both terms *rotor and rotor blades* are not used often in the corpus we have compiled- *rotor* is used 29 times while *rotor blades* has only 5 occurrences. However, this fact does not lead to the conclusion that these terms are not important in aerodynamics. It should be noted that the corpus that we have compiled, consists of texts that are focused on basic, general aerodynamics and the texts mostly discuss airplanes. These two terms are fundamental and of utmost importance in rotorcraft aerodynamics.

The term *propeller* has 170 occurrences in the corpus. The term modifies nouns such as: *efficiency, tip, blade, forces.* The most frequently used 2-3-grams are *propeller blade* (16 occurrences), followed by *propeller and* (7 occurrences) and *propeller is* (6 occurrences). With regard to prepositional phrases, *propeller* is used in possessive structures *of propeller, propeller of* when describing components or characteristics of the propeller (*the pitch of a propeller; the length of the propeller).*

The last subframe that we have identified is that of Structural Components. This subframe consists of a few terms, however, they are worth researching as they are essential in the context of aircraft construction. These terms are: *fairing (a device to* ***improve the flow of air*** *over a surface), fuselage (the central body of a plane, to which the wings and tail assembly are attached and which accommodates the crew, passengers, and cargo), landing gear/ undercarriage (the landing gear of an aircraft), and nose (the extreme forward end of the aircraft).*In our opinion, the term *fairing* belongs to a second frame, the Flight Dynamic frame, as it also denotes a structure that reduces drag.

4.2. Flight dynamics frame

It is no surprise that the Flight Dynamic frame and the Fluid Dynamics frame include the majority of aerodynamic terms in our corpus. These two frames contain concepts closely tied to aerodynamics, its principles and various physical phenomena. Therefore, we propose that most core terminology related to aerodynamics can be found within these frames.

The Flight Dynamic frame comprises terms such as: the four fundamental aerodynamic forces: *lift (component of the total aerodynamic force acting on an aerofoil which causes an aeroplane), weight (the force with which a body is drawn towards the centre of the Earth), drag (the resistance of the air created by moving the aircraft through the air),* and *thrust (a force produced by a propeller, jet or rocket); angle of attack (the angle formed between the relative airflow and the chord line of the aerofoil), Dutch roll (a combination of rolling and yawing oscillations that occurs when the dihedral effects of an aircraft are more powerful than the directional stability).*

There are terms that belong to other frames, which again proves that there is frame overlapping in the aerodynamic terminological field and aerodynamic terms are dependent on context.

Some of the terms belonging to the Flight Dynamic frame are polysemous since they have distinct meanings in frames belonging to the domain of Aerodynamics. For example, the term *'pitch'* has the following meanings: *1. a nose up/down movement of the aircraft about its lateral;* and *2. the distance a propeller would advance in one rotation if there was no slip.*

The first meaning is related to aircraft stability while the second one refers to the Powerplant frame, i.e. these meanings describe different phenomena in aerodynamics. The term *pitch* is also used in domains that have nothing in common with aerodynamics, e.g. the music domain *(the property of a sound and especially a musical tone that is determined by the frequency of the waves producing it : highness or lowness of sound)* or in the sports domain (*an area painted with lines for playing particular sports, especially football)*.

In our opinion, the aerodynamic term *stall* is also polysemous because it can belong to two different frames. *Stall* has two meanings: *1. a loss of lift caused by the breakdown of airflow over the wing when the angle of attack passes a critical point. 2. a situation in which an engine or machine stops suddenly because an opposing force overcomes its driving power.* We can categorise the term in the frames of Flight Dynamics and Powerplant (the Engine Performance subframe). These two meanings cannot be used interchangeably, the first meaning describes the loss of lift during flight while the second one refers to engines and their performance.

These two examples demonstrate that even though the terminology in aerodynamics is highly specialized, there are cases of polysemy. It is worth noting that despite the polysemous nature of some terms, it does not create ambiguity and the terms cannot cause misunderstanding.

We have identified the following subframes:

i) Primary Aerodynamic Forces;
ii) Aircraft Motion and Stability;
iii) Aerodynamic Effects and Rotational Forces;
iv) Angles, and Performance and Flight Limits.

The first subframe Primary Aerodynamic Forces comprises the concepts that denote the four fundamental forces, namely: *lift, weight, drag,* and *thrust.* The frequency distribution results are quite interesting because the results show the dominance of two forces, namely: *lift* (1,154 occurrences) and *drag* (1,412 occurrences). The other two forces *weight* and *thrust* are used 232 and 191 times respectively. In our opinion, these figures are a result of the dynamic nature of the concepts of drag and *lift* which describe various physical phenomena while *thrust* is related to propulsion, and *weight* does not have a dynamic nature.

The highest frequency distribution of *drag* is no surprise because the term is part of collocations such as: *friction drag (drag caused by the friction of a fluid against the surface of an object that is moving through it); wave drag (it is caused by the formation of shock waves around the aircraft in supersonic flight or around some surfaces of the aircraft whilst in transonic flight); parasite (profile) drag (a type of aerodynamic drag that acts on any object when the object is moving through a fluid); interference drag (drag that is generated by the mixing of airflow streamlines between airframe components such as the wing and the fuselage, the engine pylon and the wing); total drag.* Nouns that are modified by *drag* are: *coefficient, force, friction.*

Figure 2 shows the modifiers of *'drag'* and the nouns modified by *'drag'*. The representation can serve as an example of the concept of *'drag'* as a core concept in the aerodynamic terminological field, a term that comprises a number of collocations which denote different types of drag, as well as it describes various dynamic physical phenomena. From Fig. 2, it is evident that *coefficient* is frequently used with *drag*. The 2-3-grams results show that *drag coefficient* has 208 occurrences in our corpus. We believe that it is due to the fact that *drag coefficient* is often used in formulae and calculations. Interestingly, the term *lift coefficient* is used only 149 times.

We are not experts in aerodynamics to explain if there is a clear reason for this difference, however, we are inclined to propose that this difference in frequency distribution is based on the technical contexts of the books that compile our corpus.

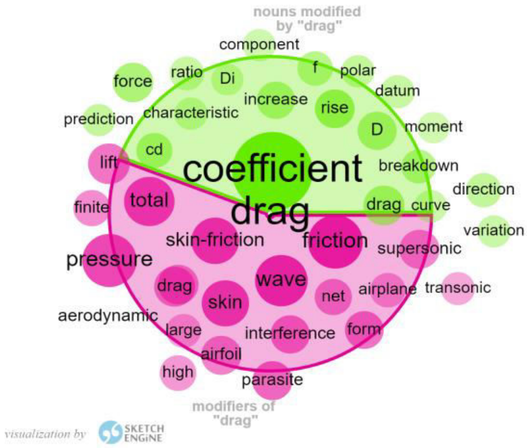

FIG. 2. Modifiers and nouns used with drag

The second subframe is *Aircraft motion and stability.* This subframe contains concepts such as: *pitch, roll (1. a rotation about the longitudinal axis of the aircraft, created by movement of the ailerons; 2. a flight maneuver with 360° rotation about the longitudinal axis of the aircraft), yaw (rotation of the aircraft around its vertical axis),* or *bank (to rotate or roll around its longitudinal axis to a particular angle).*

The term *bank* has the highest result of frequency distribution in the corpus: 87 occurrences, followed by *pitch* (79) and *yaw* (68). In the Aerodynamics corpus, *bank* is part of the collocation *bank angle*, meaning *'angle at which an aircraft is tilted sideways during a turn'*. *Angle of bank* is also used in the corpus- it has 21 occurrences. The degree symbol ° has an MI (Mutual Information) of 9.56, and LogDice of 8.99, which means that it has a strong connection with *bank.* However, it has only 3 occurrences; therefore, we can conclude that *bank* is not often used with a degree value, but is used in descriptions of aircraft motion.

The term *bank* also appears in the corpus as a verb (21 occurrences). The concordance analysis shows that the verb *'to bank'* is sometimes used in passive structures (*The aircraft* ***is banked*** *too much.; the aircraft* ***must be banked*** *approximately..),* and the KWIC (Keyword in Context) results show that '*it'* is a pronominal subject of *to bank*: *If* ***it*** *is not banked, there is no force available to cause;* and *'... the aircraft attempts to turn whenever* ***it*** *is banked.* This result supports our conclusion that the term *'bank'* is used to describe motion.

The verb t*o bank* is defined as: *(of an aircraft) to rotate or roll around its longitudinal axis to a particular angl*e. It is evident from the definition that the verb represents a characteristic motion related to the aircraft. Therefore, we decided to compare this meaning with the meanings the verb *to bank* has in other domains.

Do these meanings share some commonalities or are they completely distinct? To find the answer to this question, we used the online dictionary Merriam-Webster (https://www.merriam-webster.com/). Some of the examples given on the website are: i) *bank a fishpond (to build a raised border);ii) they banked the campfire (to restrict the flow of air to (a fire)); iii) torpedo planes… darting in to attack, then banking off (to incline laterally), and iv) skiers banking around the turn (to follow a curve or incline).*

Using these examples, we can propose that the following meanings of the verb *to bank* tend to be close to one another rather than completely distinct: they are related by control and motion (two terms closely tied to aviation).

The fact that the verb *to bank* has meanings which, on the one hand, have something in common but, on the other hand, they are distinct leads to the proposition that this verb is an example of polysemy.

The third subframe of the Flight Dynamic frame is Aerodynamic effects and Rotational forces. In our opinion, this subframe contains the following concepts: *P-factor (asymmetric blade effect and asymmetric disc effect), keel effect (pendulum stability), torque (a moment of forces causing rotation),* and *moment (the tendency to cause rotation about a point or an axis).* The term that has the highest frequency distribution across the corpus is *moment* with 330 occurrences, compared to *torque* with 20, and *keel effect*-only 3. The term *P-factor* appears too infrequently in the corpus and cannot be computed.

The highest frequency distribution of *moment* leads to the proposition that we can consider it as a key term in aerodynamics. Modifiers of *moment* are: *roll(ing), pitching, negative, positive, aerodynamic. Pitching* has the highest MI (12.25) and LogDice (10.93), followed by *rolling* with MI (11.71) and LogDice (10.21). These results strongly suggest that *pitching moment* and *rolling moment* are collocations related to the highly specific domain of aerodynamics. The 2-3-gram results show that *'and moment'* is the most frequently used (47 times) which suggests that *moment* is used in descriptions: (*where the lift, drag, and moment.., and moment coefficient data, and moment coefficients are defined as..).* The term *moment* has 37 occurrences which can mean that the term is used in specific aerodynamic context, related to forces and motion.

The next subframe is Angles. This frame comprises concepts such as: *bank angle (angle at which an aircraft is tilted sideways during a turn), climb angle (the angle between a horizontal plane representing the Earth's surface, and the actual flight path followed by the aircraft during its ascent.), pitch angle (the angle between the chord of the propeller and the plane of rotation of the propeller),* or *angle of attack (the angle formed between the relative airflow and the chord line of the aerofoil).* There are two structural patterns in this subframe: the majority of terms in our list follow the pattern *X angle,* and two terms (*angle of incidence* and *angle of attack)* follow the pattern *angle of X,* where X stands for the concept in question. Considering that *angle* forms patterns, we decided to check how frequently this concept is used in aerodynamics. The frequency distribution of *angle* in the corpus is quite impressive- it has 985 occurrences. Therefore, we can propose that *angle* is a fundamental concept in the aerodynamic context, and it has a central role in the aerodynamic terminological field. We can find modifiers such as *deflection, small, geometric, effective, stall, sideslip, bank, conical shock wave,* the list is long. The 2-3-grams results show that *angle of* has 489 occurrences while *the angle* and *an angle* have 159 and 60 occurrences, respectively. Consequently, we can suggest that the pattern *angle of X* is predominant in the corpus compared to *X angle.* This statement can seem contradictory to our statement that in our data we have terms that follow the pattern *X angle* while only two terms have the pattern of *angle of X.* However, when we studied the frequency distribution of terms with the pattern *X angle*, we found that it is less frequent compared to the pattern *angle of X: bank angle*- 21 occurrences, *blade angle*- 20 occurrences and *angle of attack*- 413 occurrences.

Based on the results discussed above, we propose that *angle* is a core concept in the aerodynamic terminological field, and with the high number of collocations, it holds a central place in the domain of aviation terminology.

The last subframe of the Flight Dynamics frame is Performance and flight limits. Concepts that belong to this subframe are: *airspeed (the speed of the aircraft relative to the air around it), (flight) envelope (the set of limitations within which a technological system, especially an aircraft, can perform safely and effectively), endurance (the length of time an aircraft can stay in the air without refuelling), Mach number (a number that expresses the ratio of the speed of an object to the speed of sound).* The term that has the highest frequency distribution in the corpus is *Mach number* (544 occurrences), followed by *airspeed* with 158 occurrences. Given the high frequency of these two terms, we can suggest that they can be referred to as key terms in aerodynamics. Examples of the modifiers of *Mach number* are *critical, high, low, subsonic, supersonic, hypersonic*; we can note that they describe the properties of the *Mach number.* The verbs that are used with *Mach number* show that it can be *calculated, measured, increased* or *reduced.*

According to the 2-3-gram results *critical* is the most commonly associated modifier of *Mach number* with a LogDice of 11.39, which means that we can accept *critical Mach number* as a specific and key aerodynamic term. The MI of *critical Mach number* is also the highest- 8.86, which confirms that it is a common and fixed collocation in this specific discourse.

4.3. Fluid dynamics frame

The frame Fluid Dynamics comprises a group of concepts such as *airflow (1. the movement of air over the aircraft as it travels through the atmosphere 2. a current of air flowing through or past an object or body), airstream (the flow of air caused by the movement of the aircraft through the air), Kutta condition (the relationship between the*

smooth airflow circulation around the wing and the resulting lift it produces) , or *eddy (a current of air moving in the opposite direction to the main current, especially in a circular motion).* The terms that belong to this frame are related to the movement of the airflow around the aircraft and the Aerodynamic flow subframe includes concepts such as *airflow, airstream, downstream (in the direction of flow, or further along the line of flow), streamline (a path traced out by a massless particle as it moves with the flow), eddy (a current of air moving in the opposite direction to the main current, especially in a circular motion).*

The highest frequency distribution in our corpus has *streamline* (476 occurrences), followed by *downstream* (138) and *airflow* (104). *Streamline* can be modified by *parallel, horizontal,* or *circular.* The collocation *streamline pattern* has the highest MI (10.68) and LogDice (11.74), indicating that it is a key collocation in aerodynamic discourse. The 2-3-gram results show that most frequently *streamline* is used with determiners (indefinite and definite articles) and we can suggest that it is typically used in descriptions as it is used in *along the streamline* (38 times). Also, it can be used in possessive-of-constructions (*a streamline of the flow)* and is part of the prepositional phrase pattern *X of a streamline, (the concept of a streamline)*, where X stands for a noun (in our case *concept, definition, equation).* The verb *to be* most frequently follows *streamline,* when used as a subject, *'are'* is used more frequently than *'is'*, 41 and 31 occurrences, respectively.

The second subframe consists of concepts that refer to principles in aerodynamics; therefore, the subframe is labelled Aerodynamic Principles, related to airflow and forces.

Concepts that belong to this subframe are: *Kutta condition (the relationship between the smooth airflow circulation around the wing and the resulting lift it produces), Bernoulli's principle (an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy)* and *Reynolds number (the dimensionless coefficient related to the ratio of inertia force to the kinematic viscosity force).*

The term *Reynolds number* has the highest frequency distribution of all- with 168 occurrences in the corpus, which indicates that it is an important concept within the corpus. It is commonly used in prepositional phrases (*of a low Reynolds number, the value of the Reynolds number, associated with the very low Reynolds number)*. Modifiers of *Reynolds number* are*: critical, high, low*. It is also used as *Re* (175 occurrences), which shows that the abbreviation is also commonly used in aerodynamic discourse, especially in formulas and equations; therefore, we can conclude that *Re* is mostly used in mathematical contexts, Verbs used with *Reynolds number* are: *associate, achieve, determine, define, calculate (define a critical Reynolds number; calculate the Reynolds number)*. The most commonly used collocation in the corpus is *critical Reynolds number* with an MI of 9.10 and LogDice of 11.08. It is followed by *low Reynolds number* (MI-5.97, LogDice- 8.18) and *high Reynolds number* (MI-5.13, LogDice-7,68). *Critical Reynolds number* is *used to define the transition from laminar to turbulent flow for a particular system as the fluid flow rate increases,* which suggests that this collocation is mostly used in the corpus to describe the transition between laminar and turbulent flow.

CONCLUSIONS

Our study is likely the first attempt to systematically structure aerodynamic terminology, using Frame Semantics and Corpus Linguistics software. It is a necessity that connects linguistics and the aviation scientific terminological field. We do not claim that the presented preliminary findings are definitive as the research is still ongoing. To achieve more accurate and insightful results, further analysis will be carried out using an expanded corpus and data.

Analysing the presented data, we can infer that aerodynamic terminology can be systematically structured in conceptual frames. Most of the terms are not polysemous, however, they are strongly dependent on a particular context. These terms can belong to more than one frame, which does not affect their primary meanings. It is a well-known fact that polysemy is avoided in aviation language as it can lead to confusion and misunderstanding. While researching aerodynamic terminology, however, we have found that even though language of aerodynamics is highly scientific and technically specialised, there are terms that can be polysemous. It should be noted that these cases are not numerous and if there is a polysemous term, it does not lead to confusion and aviation professionals will easily recognise the correct meaning.

We believe that our preliminary findings contribute to the development of the linguistic study on aviation language and they will be of help to educators, translators, aviation professionals and linguists.

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IMPLEMENTATION OF PROJECT MANAGEMENT IN THE MILITARY ORGANIZATION

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DOI: 10.19062/2247-3173.2025.26.6

Abstract: *The military potential of any state is determined primarily by its economic capacity, by the endowment of military structures with modern combat equipment and technology, as well as by the level of training of the combat forces. It can also be stated that the economic, financial, social, diplomatic and political dimensions as components of national security are achievable only by ensuring efficient management, integrated both at the organizational and national levels. Currently, most states are marked by permanent transformations, unpredictability, rapid changes and challenges in all areas, management thus becoming an essential tool for the efficient organization and implementation of diverse and complex projects. I believe that an adequate and applicable management model for the military organization is project management, which can be considered an essential component in the successful strategies of units and large units.*

Keywords: *national security, military organization, management, project, performance.*

1. INTRODUCTION

As a result of the increasing complexity of human activities, the development of technology, especially in the era of artificial intelligence, there is a strong need for organizations to adapt to new challenges, to the demands of society and consumers, which are increasingly diversified.

Although the term project has been used since the 15th century, its definition was limited at that time, as introduced by Filippo Bruneleschi, to architectural projects or other activities specific to the construction field. A project is defined as any individual or collective activity, which may include research or design and which is carefully planned to ultimately achieve the desired result.

In the contemporary era, projects are part of our lives, being found in all fields and we are surrounded by them everywhere.

It can be said that the project is one of the most used words in the economic vocabulary in general, but also in most segments of activity, including the military organization. This is happening because we are facing a real explosion of projects at the global economy level. This trend is visible even more significantly at the level of the European Union.

Joseph Weiss and Robert Wysocki consider that the project can be defined as an activity or a collection of complex and sequential activities, which represent a unique set of events, with well-defined start and end dates (finite project), with limited resources and budgets and involving several people (usually with different functions or roles) whose actions are oriented towards a common goal, having as a final result a product or service [1].

Management has a significant impact on our existence, given that everything is located under its incidence in different aspects of our lives, as we constantly come into contact with various organizations, or even carry out activities within them. Organizations are under the control of one or more people who are in charge of orienting and guiding them through the decisions that the responsible ones make.

Project management is the application of knowledge, skills, tools, and techniques to carry out the activities and operations of a project in order to meet its requirements. Specifically, project management aims to transform ideas and concepts into reality. Whether it is developing a new technology, setting up a laboratory, or organizing an event, the project management process involves identifying objectives, developing a detailed plan, assigning resources, and carefully monitoring progress. Project management is based on a series of key principles, practices, and concepts, including the clear definition of tasks and responsibilities, effective communication between team members, risk management, and adaptability to the inevitable changes that may occur during the project.

I believe that the success of a manager's activity is closely linked to the way in which they foresee and plan the use of resources, the way in which they organize the work of the team and coordinates it during the project, personally getting involved, while checking progress at the same time.

2. GENERAL NOTIONS ON PROJECT MANAGEMENT

2.1. Project management fundamentals

The concept of project management appeared in the early 1950s as a specialized branch of management, thus creating a discipline targeted to the organization and verification of complex activities specific to the branches of the economy, especially heavy industry.

Although some specialists consider it a new field, its existence and practical approach date back thousands of years. The oldest projects are considered the Egyptian pyramids due to the prior planning of the project and the supervisors that the pharaoh sent to play the role of project management.

Among the most important factors regarding the emergence and development of project management, the following are worth mentioning: the competition between the economies of nations for supremacy in the military field and the pressure that customers put on their projects to be ready as quickly as possible in order to recover their investments. Moreover, the National Aeronautics and Space Administration (NASA) was influential in the emergence of this branch of management, as a result of the initiation and development of its space programs.

The experience and knowledge accumulated over the years, as well as the development of computer science, favoured in the 1990s an explosion of knowledge in the field of project management, as well as the emergence of new methodologies such as PRINCE (Great Britain, 1990), RUP (Relational Unified Process) or XP (eXtreme Programming- Kent Beck, 1996).

Starting with the 2000s, an attempt was made to develop a final and mature model of the project management concept.

For theoretical knowledge of the project management concept, but also for its application, it is essential to define the term *project*. It originates in Latin from the word "*projectum*" as a derivative of the verb "*proicere*" which could be translated as "*to throw forward*". We can see that the verb is composed of the prefix "*pro*", to indicate an activity that precedes the action and the action "*iacere*" (to propel).

In this sense, several approaches have been outlined to define this concept.

Mihaly Görög and Nigel Smith consider that the project represents any type of activity with a fixed duration, with certain constraints in relation to costs and with the aim of obtaining a finite result [2].

In our opinion, the project represents an accumulation of activities with a unique character, focused on clear, distinct objectives, with well-specified goals, without a routine character, representing a way of moving from the idea stage to the actual action, going through various phases of this process, using human, material, informational, and financial resources.

Any project is defined by its characteristics, and must be approached as a unitary whole. Even if the project will involve a series of contributions from several people, the notion of whole is applicable.

The project will also be defined by its features, which are correlated with the functions of project management.

The main specific features of any project, regardless of the field, are the following:

- the project objective – a project has a fixed set of objectives, and when they have been achieved, the project can be considered completed;
- the lifespan – a project has a limited lifespan, the end being usually specified in the set of objectives that must be met;
- a singular entity – the project is unique and is normally entrusted to a single centre of responsibility, while there can be several participants in the respective project;
- teamwork – the project is a unitary ensemble that needs teamwork, the contributions of the participants being closely linked and in a relationship of interdependence;
- life cycle – the project is defined by a life cycle going through stages such as development, maturity, and aging;
- uniqueness – no project is the same, they will differ by locations, infrastructure, resources, or microstructures;
- change – the project is characterized by many changes throughout its life, actions, interventions, phases, and resources;
- successive nature – the project components are gradually completed, as the time resource is consumed;
- custom-made – the project is always created at the request of a legal or natural person who has the quality of customer;
- the degree of innovation and complexity –the project will depend on a lot of defining characteristics: its element of novelty, the scale of the project, social repercussions, uncertainty in achieving the project objective, etc. A project will be complex regardless of whether one or more of its characteristics are less complex, as long as others have a higher degree of complexity.

During its development, the project goes through several stages, the total of which makes up the project life cycle. The life cycle must be viewed in its entirety, from all perspectives, and it is necessary to take into account a variety of aspects, such as the necessary resources, the time available, the technological quality, the benefits, etc.

The specific stages that any project goes through are the following:

-the conception phase;
-the definition phase;
-the planning and organization phase;
-the implementation phase;
-the product delivery and project evaluation phase;
-the product operation and maintenance phase.

Normally, these phases should be completed in order, but this happens quite rarely in reality. Oftentimes, not only do the successive phases overlap with the previous ones, but a complete overlap of all phases can also occur. We can observe that some of these phases contain elements specific to management, such as its functions, planning, organization, decision, etc.

In the last ten years, experts in the field have been analyzing and evaluating how the project integrates into the organization, how the organization behaves, how it adapts to the permanent development of projects, while also aiming to increase the capacity to develop more and more projects. An organization in which project management is applied represents the organization of the future, which has the ability to operate dynamically and efficiently and which is much more difficult to imitate by other competing organizations.

Thus, we can see that the role of projects within the organization is defined in two distinct areas: the operational area and the strategic area. The role of the project is visible both at a strategic level because it can be subordinated to the organization's strategies, but also at a tactical level because it must represent ways to solve problems.

This role results from the following aspects:

-it initiates change;

-it ensures development;

-it allows the achievement of the proposed objectives;

-it maintains internal competitiveness;

-it creates competitive advantages;

-it streamlines the organization's activity.

Project management is based on the understanding and effective application of the principles and techniques in the respective field. The following aspects are relevant in this context:

-project planning is an essential process in project management and involves the development of detailed documents regarding the courses of action necessary to achieve the established objectives;

-project control consists of carrying out the process of monitoring, evaluating, and adjusting the progress and performance of the project, respectively monitoring progress, comparing it with the initial plan, identifying deviations and problems, taking corrective measures, and reassessing the plan, if necessary;

-communication is a key concept of project management, being essential for the success of the project and consists of applying the following algorithm: identifying stakeholders, defining communication channels, establishing communication objectives, creating a communication plan, active listening, adaptability, feedback and evaluation;

-risk management is a fundamental concept of project management and involves identifying, evaluating and managing the potential risks that may affect the success of the project;

-quality management represents the concept of ensuring that the products or services delivered within the project meet or exceed established standards and expectations, an aspect that is materialized by establishing quality standards, quality planning, quality assurance, quality control and continuous improvement.

By analyzing project management in an organizational context, we discover that it has brought added value, ensured the transition from an inferior to a superior situation or from a negative to a positive one, and that the project itself represents a change.

Such examples of projects that have completely changed the way of working within organizations are: the transition from typewriters to computer systems, from physical archives to electronic ones, from landline to mobile telephony, from mail to e-mail, from radio to satellite communications, and so on.

By implementing project management in the military organization, creativity and involvement of subordinates in the act of execution and creation, design and verification are achieved, thus creating the premises for maintaining internal competitiveness.

Employees can be stimulated to work both in teams and individually, being pushed towards initiative by the project manager who must know how to organize their subordinates into teams, to coordinate them, to communicate the objectives to them, and to ensure that communication in the created microgroups is optimal.

Therefore, project management is not just a simple method of coordinating activities, but represents a strategic framework aimed at optimizing the use of resources in a synergistic way, so that the organization achieves superior performance and remains competitive in its specific environment. Against this background, knowing these concepts, it is necessary to identify the ways in which this type of management can result in increasing and at the same time ensuring the performance of any organization.

Iit is worth mentioning the fact that not all projects can have the same level of performance, since a lot of aspects depend on the quality of the leader in charge of project development, more precisely the project manager. They must analyze the five basic factors that represent the foundation of any project, namely time, costs, quality, purpose and last but not least risks (Fig. 1).

FIG. 1 Fundamental factors in a project

2.2. Increasing project management performance through the use of artificial intelligence

The implementation of artificial intelligence (AI) in project management has been a constant topic of interest for researchers and practitioners alike in recent years. Its potential advantages regarding project management include increased efficiency, improved decision-making, as well as better management of operational risks. In this context, artificial intelligence brings with it a series of significant transformations, revolutionizing the way such initiatives are planned, implemented and monitored.

Joined shows one way of using AI in a competitive organizational environment in companies on several continents (Fig. 2), [3].

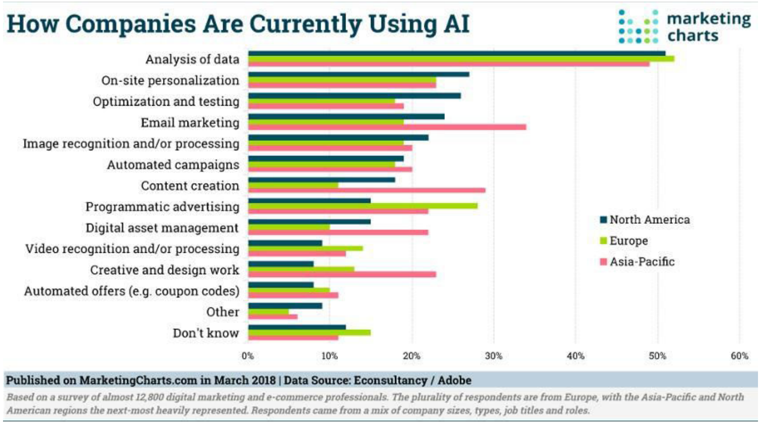

FIG. 2 Comparison of current uses of AI (source: *Project Management.com*)

AI can be used to automate routine tasks such as data entry, scheduling, and reporting, which can free up time for more strategic and complex aspects of the project. In addition, AI can help identify patterns and trends in data that may not be immediately apparent to humans, which can inform decision-making and improve the quality of project outcomes. Implementing AI may also require the development of new skills, such as data analysis and programming, to effectively manage and use AI technologies. According to a study conducted by PwC Romania and the International Project Management Association in 2020, over half (52%) of project management professionals anticipate integrating a Digital Assistant and adopting artificial intelligence in the next five years. Within project management, the roles with the greatest potential to be taken over by AI in the next five years are the Project Manager Assistant (52%) and the Project Manager Advisor (44%).

The integration of artificial intelligence into this process has brought considerable benefits through operational efficiency, informed decision-making, innovation, and adaptability to changes in the project environment. The significant contribution of artificial intelligence in project management is also manifested in facilitating intelligent decision-making, an essential aspect for the success of a project implementation [4].

Advanced data analytics is a powerful tool in the hands of project managers, offering them critical information needed to substantiate key decisions. AI systems are able to process the huge volume of data generated by projects, identifying patterns, trends or risks that might go unnoticed in a typical human analysis. By anticipating risks, artificial intelligence helps to outline a solid action plan, designed to minimize the impact of potential problems. Informed decisions, guided by real-time data analysis, not only optimize the path of a project, but also significantly reduce the risk of failure due to uninspired decisions.

Thus, the use of artificial intelligence in decision-making not only brings immediate benefits, but also consolidates and sustains long-term success in project management. Another key aspect of the importance of artificial intelligence is stimulating innovation in project management.

By analyzing data and identifying unexpected patterns, AI can suggest new approaches and strategies for project management. This not only optimizes existing processes, but also encourages and facilitates innovation in addressing problems and developing innovative solutions. Also, adaptability to change is an essential feature brought by AI to project management.

AI systems can analyze available information in real time and dynamically adjust plans and strategies according to changes in the environment.

This adaptability ensures flexibility in project management, and helps reduce the risk associated with inevitable changes.

With all these advantages, it is important to emphasize that the implementation of AI in project management must take into account ethical and social aspects.

Additionally, AI systems process and store a large amount of data, some of which is sensitive and confidential. Thus, there are security risks and possible threats to data confidentiality, requiring additional measures to protect information from possible cyber attacks. Implementing AI systems and training staff to use them can also involve some significant costs, especially for smaller organizations.

3. MANAGEMENT OF THE DESIGN OF AN "INDOOR" FIRING RANGE

The issue of national security is the attribute of public institutions, dedicated ministries, including the Ministry of National Defence, their role is to focus on the integrated management of risks, threats and vulnerabilities existing at national, regional, and European levels in the military field [5].

Romania's defence capability represents an accumulation of elements, namely economic, military, social and diplomatic. At the same time, the combat capabilities of military structures are directly determined by the level of equipment and technical endowment, the level of operationalization and training of combat and support forces.

In order to argue that project management is a high-performance model applicable to the military organization, respectively the military structures within the Defence, Public Order and National Security System, I will present a design variant of an "Indoor" Shooting Range.

I believe that this project represents an innovative and efficient solution intended for light weapons training of military personnel, the range will ensure the training and modernization of the training structure [6].

The management of this project requires a meticulous and well-structured approach, an application of general and technical knowledge which should take into account the following aspects:

- detailed planning: the construction of the range involves numerous stages, from identifying suitable land to designing and building the infrastructure required for shooting activities. A detailed plan, covering each stage of the project, is essential to ensure that deadlines and budget are met;
- regulations and permits: all necessary permits and approvals must be obtained from local authorities and other competent entities from the design stage, this will lead to compliance with environmental, urban planning, and safety regulations;
- resource management: ensuring the availability of the necessary resources, such as budget, construction materials, equipment and skilled labour. Efficient management of these resources can help avoid delays and reduce additional costs;
- supervision and quality: closely monitoring the progress of the work and ensuring that quality standards are met are critical aspects of project management in the construction of a shooting range. It is important that each stage of construction is supervised and verified to ensure that the final result meets the established standards and requirements;
- communication and coordination: effective communication between all those involved in the project, including the execution team, clients or beneficiaries, as well as other stakeholders, is essential to avoid misunderstandings and to maintain alignment on the project objectives and progress;

- risk management: identifying, analyzing and managing potential risks, such as adverse weather conditions, delays in supplies or changes in project requirements, are essential to ensure that the project runs smoothly and is delivered on time and within budget.

The design and construction of the range presents a number of specific characteristics and challenges that require a rigorous and well-planned approach.

The specific characteristics of such a range are the following:

- the size and the configuration: covered ranges are designed to occupy a smaller area than surface ranges, they must ensure adequate distances for various types of weapons. The safety zone must be well defined to prevent accidents, involving appropriate barriers and protective measures;
- construction materials: the materials used in the construction of the range must be impact-resistant. Walls and barriers are usually made of reinforced concrete, and bullet absorption systems, such as sand or recycled rubber, are essential to reduce the risk of ricochets and ensure the safety of users;
- ventilation systems: an effective ventilation system is necessary to eliminate fumes and lead particles resulting from shooting activities, especially in the case of indoor ranges;
- lighting system: lighting is essential for the operation of the range, the installation of an adaptive lighting system will allow shooters to train in various scenarios, simulating real operating conditions;
-safety and access control: the implementation of strict safety measures, such as security gates and video surveillance systems, is vital. Access control must be well managed to ensure that only authorized personnel have access to the range, thus reducing the risk of unauthorized incidents;
-training infrastructure: to maximize the efficiency of training, the range must be equipped with moving targets and automatic systems for evaluating the shooters' performances. Also, theoretical training facilities and post-shooting analysis are essential for the development of marksmanship.

The overall objectives of the project include creating a safe shooting environment, ensuring compliance with relevant standards and regulations, and achieving cost-effectiveness. It is also imperative that the range meets the requirements imposed by military and civilian regulations to ensure the legality and safety of operations.

The specific objectives consist of determining the optimal capacity of the range, including the number of firing lines and the space required for training. The implementation of modern technologies for monitoring and evaluating shooters' performance is also a key objective.

The design team should include architects, civil engineers, safety engineers, and ballistics specialists. The execution staff will include builders, skilled workers, electricians, and plumbers. It is essential to recruit external consultants with expertise in specific areas, such as ballistics safety and acoustic engineering.

Specific training, such as site safety training and the use of specialized equipment, is essential for the success of the project. It is also beneficial to organize workshops and continuing education sessions to improve the team's skills and ensure compliance with safety and quality standards.

Construction materials, such as concrete, steel, and wood, are essential for the construction of the polygon infrastructure. It is important to select high-quality materials to ensure the durability and safety of the construction.

Supplier selection should be based on quality, price, and delivery terms, and contract negotiation and signing ensure on-time deliveries and compliance with technical specifications. It is important to implement a quality management system that includes quality control procedures, internal and external audits, and rigorous documentation of processes and results.

Budget planning involves allocating funds by stages and categories of expenditure. Sources of funding can include funds allocated from the military budget, government grants, and public-private partnerships. It is essential to develop a detailed financial plan that includes financial projections, cash flow, and profitability analyses**.**

CONCLUSIONS

In the context of a world characterized by rapid changes, the growth or decrease of the economic potential of states, project and program management becomes an essential component in the success strategies of the military organization. Its importance is evident both in the social and military environment, where the efficiency of project management has a direct impact on the achievement of specific objectives.

I believe that at the level of military structures, the application of project management can contribute not only to increasing operational efficiency, but also to strengthening the country's defence capabilities.

By presenting a project variant, I aimed not only to offer a theoretical perspective on management, but also to present how it can be applied and adapted in the specific context of the construction of an "indoor" shooting range, namely the efficient management of complex military projects. I believe that its implementation within military structures will bring multiple benefits, both in the short and long term. Thus, a local range will allow for the conduct of intense and regular training, adapted to the specific needs of units and large units, which will contribute to the significant improvement of the operational training and skills of the military.

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ASPECTS OF HAMMING ENCRYPTION USING RASPBERRY PI PICO

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DOI: 10.19062/2247-3173.2025.26.7

Abstract: *In this article I will try to address the encrypted form of transmission using Hamming encoding on a Raspberyy Pi Pico W platform. I chose to test on a PiPico platform because it offers computing power comparable to that of a microcomputer and allows easy programming in Python.*

Keywords: *Pi Pico, Hamming, bits*

1. INTRODUCTION

Hamming encryption is an error detection and correction technique that uses hamming codes to detect and correct data transmission errors. The Raspberry PI Pico, a microcontroller based on the ARM CORTEX-M0+, is ideal for implementing this type of encryption, having the necessary resources to process and manipulate the data. This microcontroller allows the implementation of subsystems that can make it possible to extend an encryption system for several types of encoding, Fig. 1

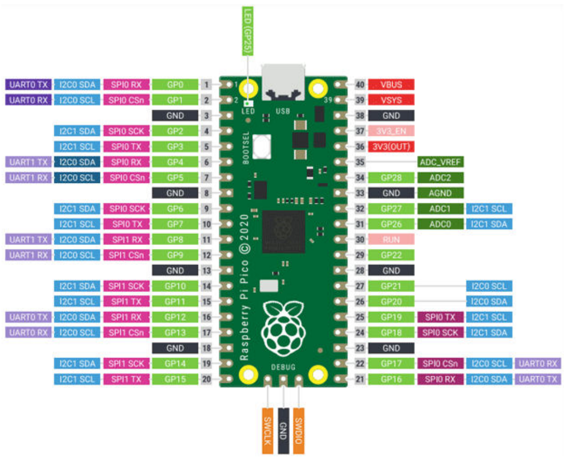

FIG.1 Raspberry Pi Pico Structure

Hamming code is an error-correcting code that adds parity bits to a sequence of data to enable errors to be identified and corrected during data transmission. A hamming code of length 7 (hamming (7,4)) adds 3 bits of parity to a 4-bit message to create a 7-bit sequence, allowing a single bit of error to be detected and corrected.

2. IMPLEMENTING HAMMING ENCRYPTION ON THE RASPBERRY PI PICO

Hamming code uses parity bits to protect data and make it resistant to errors. The 7-bit Hamming code for a 4-bit message has 3 parity bits that are placed on the positions that are powers of 2 (1, 2, 4). The data positions are placed in the other locations.

Example for Hamming code (7,4):

1. Positions 1, 2, and 4 are parity bits.
2. Positions 3, 5, 6, and 7 are data bits.

Encryption process:

- The parity bits are calculated so that the total parity of each set of bits is 0 (even parity).
- After the parity bits are added, the final 7-bit sequence is transmitted.

In Fig. 2 I will present a Hamming encryption system with LCD to be able to visualize the result

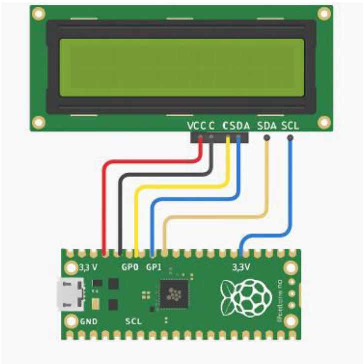

FIG. 2 Schema PICO LCD

I did the programming in Python and is based on the following example, Fig.3:

- Post: 1011
- Parity bits: p1, p2, p4

The values for the parity bits are determined so that each parity bit guarantees an even sum of the bits.

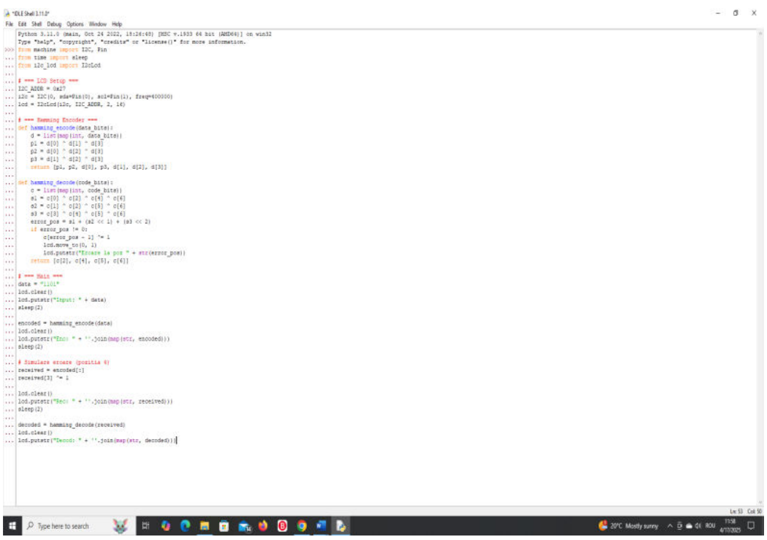

FIG.3 Example of Hamming encoding (7,4)

In order to be able to use the encoding results (e.g. in a radio data transmission system) we can use an SD card save, in which case the data can be kept for a longer period. A model is given in Fig.4 and the code in Fig.3.

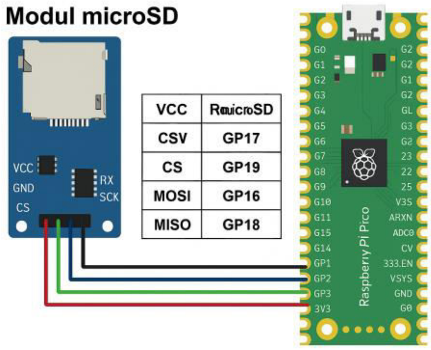

FIG.4 Conectare SD Card la Pi Pico

The connection of the Pi Pico through a radio transmission system can be done using a transmitter and a receiver that can transmit the data in encrypted format. Experimentally we used two HC-12 radio systems, the connection reference is in Fig. 5 and the module is in Fig.6.

HC-12 pin	Pico tx	Pico rx
VCC	3.3v	3.3v
Gnd	Gnd	Gnd
Tx	GP1	GP1
Rx	gp0	gp0

FIG.5 Connection reference

FIG. 6 System Radio HC-12

The corresponding codes for the respective receptive transmission are in Figures 7 and 8 respectively. Same Hammming code was used(7,4)

Hamming_encode function: receives 4 bits of data and calculates the parity bits to form a 7-bit Hamming message.

Hamming_decode function: receives a 7-bit message and checks for errors. If there are errors, it corrects them and returns the original data.

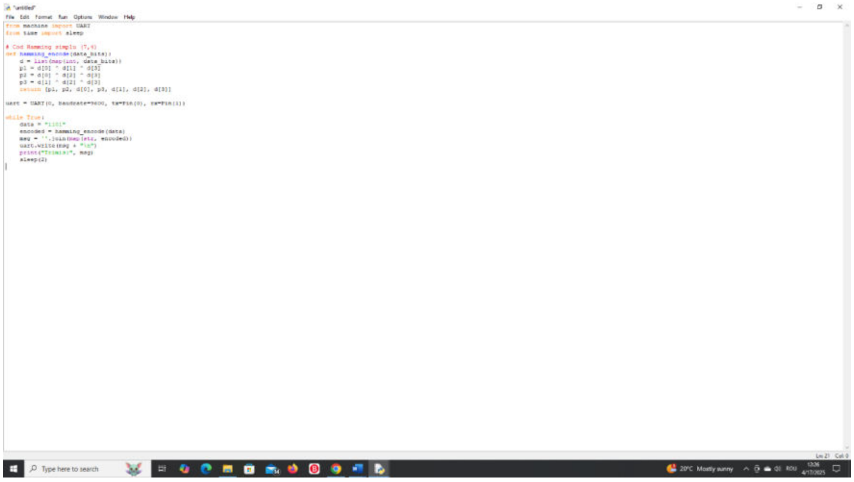

FIG.7 Emission code

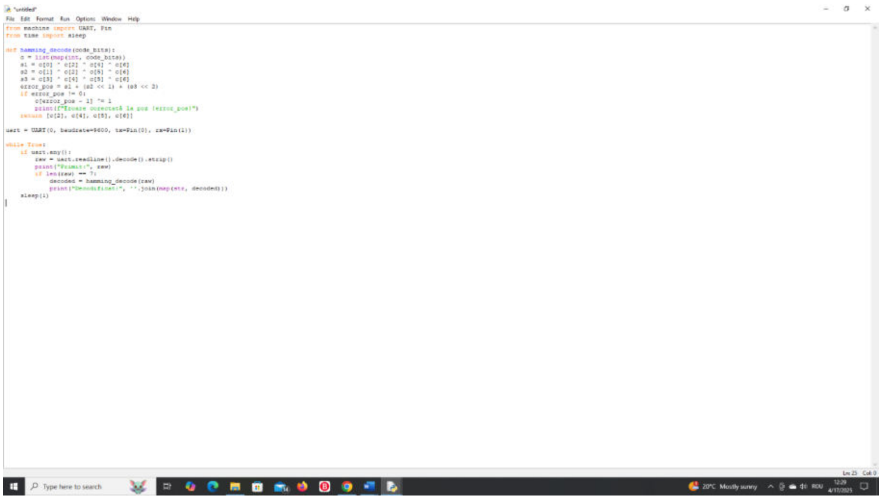

FIG.8 Reception Code

3. CONCLUSION

The use of Hamming coding in radio transmission systems is very efficient if such microcontrollers are used, which allow a wide range of applications in Python and can bring an advantage in the case of electronic warfare applications or in amateur radio applications within the emergency networks of Romania. Hamming encryption on the Raspberry Pi Pico is an effective way to protect data and learn about error correction. The implementation can be extended to support more complex applications, such as wireless transmissions or secure data storage.

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A STUDY ON METHODS TO APPLY THE ENERGY CONSERVATION THEOREM IN THE INVESTIGATION OF TRAFFIC ACCIDENTS USING DETAILED BREAKDOWN OF ENERGIES

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DOI: 10.19062/2247-3173.2025.26.8

Abstract: *The road accidents are still part of our daily lives in an unwanted way and, in order to resolve the various resulting disputes, they need to be investigated in detail. If the investigation methods based on testimonials or/and visual observation are accessible even to amateurs, they also reveal a lot of subjectivity. The most reliable, professional and "cold" method of analyzing a traffic accident remains the scientific one based on the mathematical apparatus and studies specific to the field of accidentology science. We are going to present a possibility to apply the energy conservation theorem in the case of an road accident where we will attempt to thoroughly detail all the energies resulted from the impact.*

Keywords: *traffic accident, impact energy, detailed breakdown*

1. INTRODUCTION

Regardless of the progress made by current technology and driver education, with direct positive implications on the human-vehicle-environment system, road accidents will remain a major problem as long as hazard, technical imperfections and human lability are not completely eliminated. Even after the complete automation of transportation, if this ever happens, there will certainly still be traffic incidents because no program or technical achievement is perfect.

Consequently, accidentology, as a science, will never disappear and, moreover, it will have to keep up with the evolution of technology. And specialists will need to continuously improve themselves in the art of scientific investigation of traffic events. The intelligent accident analysis systems/programs have already been created (such as PC-Crash and others), but even these, regardless of how efficient they are, depend on the algorithms initially introduced, as well as on the concrete data relating to each individual event. Thus, specialists will have to perfect new and new scientific methods of technical analysis of accidents because these are the safest, the most professional and "cold" (devoid of feelings and subjectivity) methods of analyzing an accident because they are based on the standard mathematical-physical apparatus, as well as studies specific to the field of accidentology

Of course, traditional methods, based on observation, such as verifying the correspondence of damages and their complementarities according to the forensic principle of the shape, or analysis of the situation according to testimonial statements continues to play an important role, especially in the legal field, that is why the investigator is forced to consider them in parallel with the technical-scientific one, which is his main working tool.

In the technical-scientific investigations of the technical expertise resulted from accidents with impacts between two technical systems, the most used methods are the theorem of conservation of energies and the momentum conservation theorem. In this paper, in the case study presented as an example, a detailed developing of the energy method will be used, applying in this sense the energy conservation theorem in the new vision of thermodynamics according to [1]. Thus, it results that the total energy possessed by both cars before the collision (kinetic energies) should be found in the total energy output from the impact in the forms of kinetic energies, deformation energies, fracture energies, bending moments, shearing work, rotation/pivoting moments as a result of the eccentric impact, frictions, rotational kinetics, slewing etc.

2. CASE STUDY – PART ONE - ANALYSIS OF THE TRAFFIC ACCIDENT THROUGH THE METHODS OF TESTIMONIAL STATEMENTS AND VERIFICATION OF THE CORRESPONDENCE OF THE DAMAGES AND THEIR COMPLEMENTARITY ACCORDING TO THE FORENSIC PRINCIPLE OF THE SHAPE

The tactical situation to be analyzed (resulting from the official documents studied, the statements of those involved and the expert's on-site reconnaissance):

- one-way road, part of a boulevard with a central pedestrian area without slopes, in alignment, traffic flows on two lanes, lane 2 being shared with the tramway, lane 1 partially blocked by the rear of the bodies of larger vehicles legally parked obliquely at an angle of approximately 30-45 degrees to the longitudinal axis of the road near the right sidewalk;
- visible longitudinal road marking with a dashed line between the traffic lanes and specific parking marking obliquely on the right side of the street near sidewalk;
- asphalt road in very good condition, without bumps, possibly a longitudinal stress area for drivers on the lane 2 due to the presence of the tramway which makes many drivers prefer a driving position, illegal but considered more secure, between the traffic lanes in order to avoid some possible conflicts with the common carriageway with the tramway (to the left) and with the cars that are trying to leave the parking lot (to the right);
- there is a pedestrian sidewalk on both sides of the road;
- curbstones delimitation of the roadway plus oblique parking place;
- traffic regulated by signs;
- according to the statements, two cars arrived at the point of tension simultaneously and crossed paths;
- the two cars were a BMW 645Ci, it was traveling in the normal way of travel (Fig. 1-b) and the Alfa Romeo was intending to go back in reverse of the oblique parking lot without being guided (Fig. 1-a).

Based on the testimonial statements and the investigation of the damages suffered by both cars involved, the general scheme and evolution of the accident presented in Table 1 resulted [7, 10].


(a)

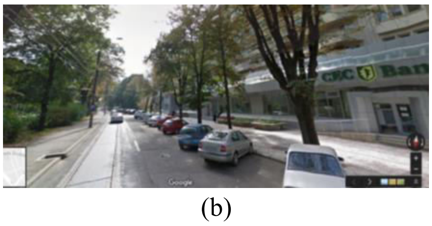
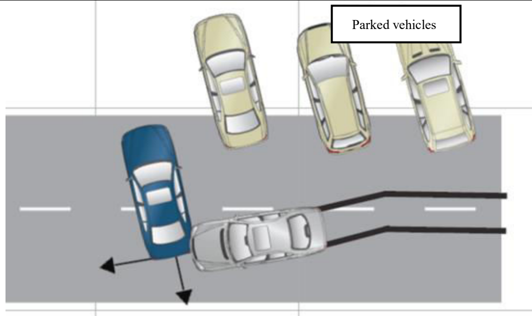
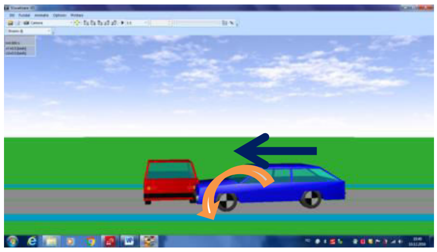
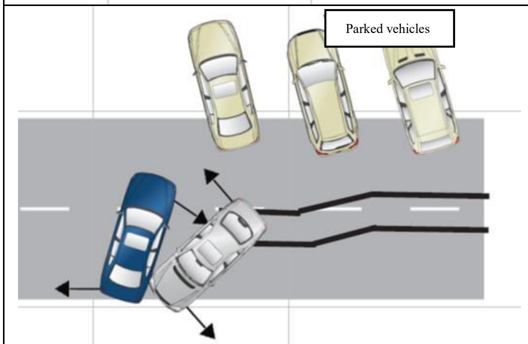
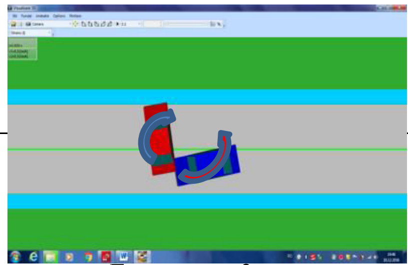
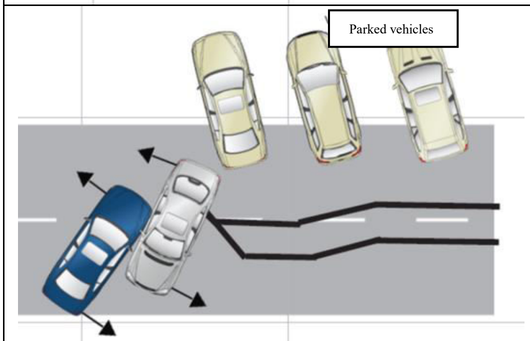

(b)

FIG. 1 Accident area – *Alfa Romeo/AR* driver's perspective (a) and *BMW* driver's perspective; (b) *Google Earth Pro* processing -

Table 1. The evolution of cars during the event

	Event stage 1 – The maximum engagement 
	Event stage 2 – The reaction of the cars following the primary impact, the separation after the first impact, the impact of the BMW with the curbstone and the trajectory followed towards the second impact between the cars 
	Event stage 3 – The second impact between the cars and the final position

3. CASE STUDY – PART TWO - TRAFFIC ACCIDENT ANALYSIS USING THE ENERGY METHOD (PHYSICAL MATHEMATICAL CALCULATION OF THE POSSIBILITY OF DAMAGES TO THE TWO CARS USING THE ENERGY CONSERVATION METHOD)

Applying the energy conservation theorem, the new vision according to [1], it results that the total energy possessed by both cars before the collision (kinetic energies) should be found in the total energy output from the impact in the forms of kinetic energies, deformation energies, fracture energies, bending moments, shearing work, rotation/pivoting moments as a result of the eccentric impact, frictions, rotational kinetics, slewing etc.

In other words:

$$\sum E_{input} = \sum E_{output} \tag{1}$$

It can be written as follows:

$$\sum E_{input} = E_{kineticBMW} + E_{kineticAR} \tag{2}$$

and also:

$$\sum E_{output} = \sum [E_{damages\ production} + (E_{pivoting} + E_{heat} + E_{noise})] \quad (2)$$

where, it must be taken into account that the damage to the BMW's bumper/front reinforcement consumed most of the energy.

A. Impact speed calculation for Alfa Romeo car

The distance traveled by the Alfa Romeo car from the moment of starting to the moment of impact - *d* is *4.2 meters*. The maximum possible acceleration (*a*) achievable by the type of vehicle in question, Alfa Romeo, is adopted to be *2.5 m/s²*. It follows that the maximum possible speed that the Alfa Romeo car could have had before the impact could have been:

$$v_{impact\ AR} = \sqrt{v_0^2 + 2ad} = \sqrt{0 + 2 * 2{,}5 * 4{,}2} \approx 4{,}5 m/sec \approx 16 km/h \quad (3)$$

It follows that the Alfa Romeo car could have collided with a maximum speed of *16 km/h.*

Taking into account the way to approach such maneuvers (see [2]), a speed of *8 km/h (2.22 m/sec)* will be adopted as the impact speed of the Alfa Romeo car.

B. Calculation of the energy required to deform the BMW front bumper reinforcement

The front bumper reinforcement, or, in other words, the bumper/protective bar, includes a supporting structure and a curved beam reinforcement (Fig. 3.1).

The total deformation energy of the bumper bar is composed of the energy required for bending under the $F_î$ effect (see Fig. 2) and the energy required for fracturing the welding bridges.

Within the bumper bar there are two types of welding seams:

- points-welding;
- fillet welding by material addition.

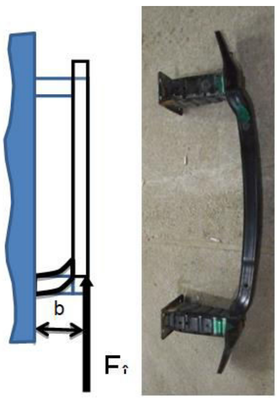


FIG. 2 BMW front reinforcement deformation energy calculation diagram

According to Fig. 2.6, the deformation under the statically applied force $F_î$ is:

$$\sigma_{st} = \frac{F_î * b}{E * A} \rightarrow F_î = \frac{\sigma_{st} * G * A}{b} = \frac{0{,}17 * 8{,}1 * 10^5 * 1 * 10^{-3}}{0{,}51} = 270 * 10^3\ N \quad (4)$$

$$E_{initial\ deformation} = M_î = F_î * b = 270 * 10^3 * 0{,}51 = 137{,}7 * 10^3\ Nm = 137{,}7 * 10^3 J \quad (5)$$

where:
- F_i – the force that produced the bending;
- b – brațul forței;
- A – the area of the bent section; it is approximated by the bending of the length of the sheet metal section from which the shock-absorbing (fixing) element of the reinforcement is formed; $A = l * g = 0{,}41 * 0{,}003 = 0{,}001 m^2$
- G – modulus of elasticity in shear for carbon-steel.

Because there are two reinforcements that support the bumper and usually only 80% of the energy is absorbed:

$$E_{deformation} = 0{,}8 * \frac{E_{initial\ deformation}}{2} = 55{,}08 * 10^3 J \tag{6}$$

Calculation of the energy required to fracture weld bridges for additional welding areas, fillet welding:

The formula for calculating the load supported by the seam welding is:

$$P = 2 * 0{,}7 * s * l * \sigma_{as} \tag{7}$$

where:
- P – the load that can be supported by the welding seam (in our case the value of the minimum energy required to fracture the welding seam);
- s – the thickness of the plate to be welded;
- l – length of the broken welding seam (the approximate length was identified on the photographs);
- σ_{as} – strength of welding load.

So:

$$E_{fracture1} = P = 2 * 0{,}7 * 0{,}004 * 0{,}26 * 1050 * 10^4 = 15288 J \tag{8}$$

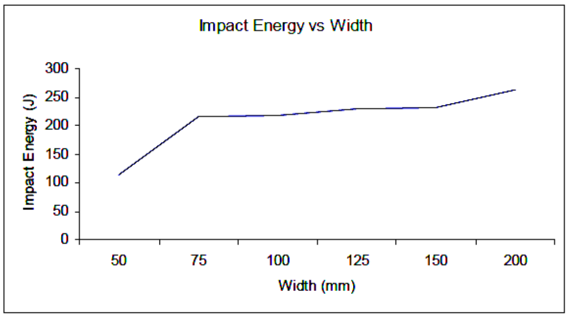


FIG. 3. The energy required to fracture point-welding bridges

Calculation of the energy required to fracture welding bridges for the points-welding areas will be made according to the tests presented in [3], the energy required to fracture point-welding bridges depending on the welding diameter is as shown in Fig. 3.

For a point-welding diameter of 5 mm, it results that an energy of approximately 120 J is required to fracture it. If we consider a number of 6 fractured welding points, the energy consumed for this is:

$$E_{fracture2} = 6 * 135 = 810 J \tag{9}$$

The total energy for fracturing and deforming the bumper bar (front bumper reinforcement) is:

$$E_{bumper\ bar\ deformation} = E_{deformation} + E_{fracture1} + E_{fracture2} = \mathbf{71178\,J \approx 71kJ} \tag{10}$$

C. Calculation of the total energy as a result of the damages suffered by both cars

By extrapolating the calculation of the energy required to deform the BMW bumper onto the other damages to both cars, in which the most important are the deformations suffered by the Alfa Romeo car, mainly the deformation of the chassis, it is adopted:

$$E_{bumper\ bar\ deformation} = E_{deformation} + E_{fracture1} + E_{fracture2} = \mathbf{71178\,J \approx 71kJ} \tag{11}$$

$$\begin{aligned}\sum E_{output} = \sum&[E_{damages\ production} + (E_{pivoting} + E_{heat} + E_{noise})] \\ &= E_{bumper\ bar\ deformation\ BMW} + E_{other\ damages\ AR+BMW} + E_{pivoting\ BMW+AR} \\ &+ E_{heat\ BMW+AR} + E_{noise} = 71kJ + 90kJ = 161kJ\end{aligned} \tag{12}$$

D. Calculating the impact speed for BMW car

The calculation of the impact speed for BMW car will be done using the deformation model used in the CRASH3 program [11]. Thus:

$$E_{col} = \frac{1}{2} m v_{BMW}^2 (1 - \varepsilon^2) = E_A (1 - \varepsilon^2) \tag{13}$$

where:

- E_{col} – the energy consumed in the collision;
- v_{BMW} - impact speed for BMW car;
- ε – collision coefficient;
- E_A – the kinetic energy of the BMW car held before impact.

The energy consumed in a collision is the sum of the energy of the deformation of the bumper and the kinetic energy of rotation/pivoting of the car as a result of the impact:

$$\begin{aligned}E_{col} = E_{bumper\ bar\ deformation\ BMW} &+ E_{kinetic\ of\ rotation\ BMW} + E_{other\ damages\ BMW} + E_{pivoting\ BMW} \\ &+ E_{heat\ BMW} + E_{noise\ BMW} = \mathbf{79kJ + 5kJ = 84kJ}\end{aligned} \tag{14}$$

The rotational kinetic energy of the car as a result of the impact is:

$$E_{kinetic\ of\ rotation} = \frac{m_{BMW} * v_{BMW}^2 * r^2}{2} = \frac{1895 * 7^2 * 4{,}5^2}{2} = 982J \tag{15}$$

Thus, the speed at impact of the BMW can be calculated:

$$v_{impactBMW} = \sqrt{\frac{2E_{col}}{m(1-\varepsilon^2)}} = \sqrt{\frac{2*(84kJ)}{1895kg(1-0{,}8^2)}} = \mathbf{15{,}69\ m/sec \approx 56{,}49km/h} \tag{16}$$

where:

- *ε = 0.8* is adopted because the first impact is considered more elastic due to the special construction of the bumper bar of the BMW car;
- BMW mass = 1815 kg (according to technical data) + 80 kg (driver's mass) = 1895 kg.

E. Determining the moment of time and the place of possible perception of the danger of an accident by the driver of the BMW car

Taking into account the largeness of the deformations of both cars involved, it is unlikely that the driver of the Alfa Romeo car actually took any evasive action before the impact.

The moment of perception of the dangerous situation by the BMW driver, due to the narrow width of the street (approximately 5 m) is considered to be the moment when he was certain that the Alfa Romeo is about to cross his direction of travel.

From that moment on, the Alfa Romeo car will travel a distance of approximately 4.2 m, with a uniformly accelerated speed that is considered to have reached a value of 8 km/h at the moment of impact. It will be considered uniformly accelerated rectilinear motion. Thus, the time (until impact) necessary to pass the *4.2 m* at a speed of *8 km/h* is:

$$t_{impact\ AR} = \frac{v_{impact\ AR}}{a_{AR}} = \frac{2{,}22}{2{,}5} = 0{,}88\ sec \tag{17}$$

The beginning of the avoidance action by the BMW driver occurs after the space traveled during his reaction time, $t_{reaction}$, which, for such situations, has been statistically shown to be *1-1.5 sec*. It follows that the BMW car driver had no time left to brake before the impact.

Thus, the conclusion is that the effective braking of the BMW driver occurred after the impact, simultaneously with the steering action to avoid it. Taking into account the calculation of the impact speed of the BMW car (*56.49 km/h*), as well as the inherent losses in the speed of moving in the longitudinal direction of the road as a result of the sudden evasive turn to the left, the speed of the BMW car when the danger was detected is estimated to be *60-65 km/h*.

Returning to the beginning of the demonstration…

The total energy that the two cars had when they collided is the sum of the kinetic energies of both cars.

$$\sum E_{input} = E_{kinetic\ BMW} + E_{kinetic\ AR} = \frac{m_{BMW} * v_{BMW}^2}{2} + \frac{m_{AR} * v_{AR}^2}{2} = \frac{1895 * 15{,}69^2}{2} + \frac{1280 * 2{,}22^2}{2} = 233{,}25kJ + 3{,}15kJ \approx 236{,}4kJ \tag{18}$$

As it can be observed:

$$\sum \boldsymbol{E}_{output} \approx \sum \boldsymbol{E}_{input} \tag{19}$$

because the difference $\mathbf{236{,}4kJ - 161kJ = 75{,}4kJ}$ is explainable by the terms that were not taken into account, namely: $E_{body\ shape\ deformation}$, $E_{rotational\ kinetic\ AR}$, $E_{other\ damages\ AR}$, $E_{pivoting\ AR}$, $E_{heat\ AR}$, $E_{noise\ AR}$, $E_{avoid\ steering\ BMW}$, $E_{braking\ BMW}$, $E_{tire\ lateral\ friction\ (AR+BMW)}$, $E_{lost/neglected\ at\ secondary\ impact}$ and $E_{calculation\ errors,\ tolerances,\ approximations}$.

The resulting conclusion after running the calculations: the energy balance confirms that the impact could have occurred under the conditions described in the testimonial statements and official documents.

CONCLUSIONS

As it can be easily seen, this analysis of a traffic accident case included two clearly delimited parts: the first one which was presented very briefly in point 2 of the paper is based on testimonial statements and other documents from the judicial file, as well as on the observation and in-depth analysis of the deformations of the vehicles (their bodyworks, wheels etc.) involved in the event. The other, presented in point 3 of the paper, aims to verify the scenario presented in point 2 and it is based exclusively on a physical-mathematical apparatus specific to the field of accidentology. More precisely, the principle of conservation of energy was used, the collision between two vehicles being more complex than a simple elastoplastic impact between two material bodies.

The originality of the research consists in detailing breakdown of the forms of energy resulting from the impact because in terms of the input energies they were clear and they were of the type of kinetic energies of two bodies in motion. And it is sufficient to recall the example of calculating the energy required to damage the bumper bar of the BMW car, which was identified as consisting of the energy required to bend it and the energy required to break the welding bridges.

The resulting energies of the impact were extremely complex. On the one hand, some have been calculated, but a lot of other components, listed in detail at the end of point 3, have remained uncalculated, the space of the present article not being enough. On the other hand, within the official judicial technical expertise, because of the space and time crisis these energies, which in our case have not been calculated, are statistically approximated based on the results of crash tests.

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ENHANCING FLOOD RESPONSE IN ROMANIA: THE ROLE OF AI AND INTEGRATED ALARM SYSTEMS

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DOI: 10.19062/2247-3173.2025.26.9

Abstract: *Introducing combined alarm systems for Romania flood zones is critical for constructing a disaster response as well as for people's safety. Communication, evacuation and flood relief involve advanced technology. Image processing also facilitates assessment of flood impact on roads, bridges and other infrastructures. By using AI in algorithms across large datasets organizations can upgrade their operations and decision-making in real-time. The concerns of rehabilitation can therefore be helped by AI to assess the floods in the infrastructures and hasten its rehabilitation process. Moreover, the AI generated models can actualize flood scenarios hence enabling the authorities improve their preparation for different levels of floods. It aids in identifying the data and off-loading it which makes flood control more effective and intelligent. These smart sensors with the help of AI may assist communities in getting the first warning and preventing the situations. The use of actual data as the basis of simulations and real-time data gathering may enhance existing evacuation plans so that authorities can better organize those routes and make faster decisions with better information. These integrated solutions might help to improve the existing technical infrastructures aimed at the prevention and management of floods in Romania by improving preparation and assessment of flood hazards and disasters. The implementation of real-time gathered data alongside actual data from simulations can improve current evacuation strategies by helping authorities better manage evacuation paths and respond through more informed choices.*

Keywords: *Flood Risk Management, Integrated Alarm Systems, Artificial Intelligence, Remote Sensing, Flood Forecasting, Disaster Preparedness, Real-Time Data Processing, Infrastructure Rehabilitation.*

1. INTRODUCTION

The more frequent and severe occurrence of floods and other natural catastrophes has been largely linked to climate change, which represents an eminent threat to both the developing and the developed countries. In Romania flood risks have emerged as a real problem, often the impacts resulting to damage property and several fatalities [1]. These natural events most especially floods require efficient early warning system and efficient means of managing the impending disasters. Although natural phenomena are unavoidable measures must be put in place to curb the effect of disasters to save lives and property. Current research shows that warning systems are critical particularly in the forecasting phase as this would enable authorities to make early interferences/allocations [2]. In the disaster, efficient action reduces the first loss and, after the tragedy, the restoration process and support for the victims are significant. Like other countries, Romania wants to improve its flood risk management capacities now.

IEMS founded in 1993 helped the countries to navigate the storms of emergency management and provided how to respond to the disaster based on common procedures [39]. Failure to which the target of the millennium development Goals 2015 may not be achieve, thanks to information and communication technology that facilitate communication between the authorities and the affected region thus reducing on further damages. The proposed systematic review will concern itself especially with the state-of-art technologies employed in Romania for flood risk management with reference to integrated alarm systems. The review shall use approaches such as image processing and artificial intelligence and integrated approaches of data capture and analysis. It will compare/contrasting these technologies based on their efficiency and areas in which they can be implemented/useful to identify the extent to which they can be useful to the authorities.

2. LITERATURE REVIEW

The literature review of the current disaster management field revealed that there is a significant research void especially in the application of new technologies to tackle flooding disasters. The proposed direction should remain oriented on identifying effective methods of the early alerting system, based on algorithms, frameworks, or even sensor networks to inform the process of floods adequately. Disaster risk reduction is one of the United Nation's proposed sustainable development goals for the year 2030, and Romania also seeks to enhance its structures for the same reason [3]. Combining the human resource, modern technology, and sound planning can optimize floods prevention by authorities and minimize the effect of floods on the economy. The incorporation of innovative disaster management solutions, such as machine learning, artificial intelligence (AI), and information and communication technologies (ICT), can streamline flood risk management across all stages: planning: before an occurrence of the disaster, during the occurrence and after the occurrence [4]. These technologies when put in the context of integrated alarm systems, result into a faster and accurate decision making thus improving on anticipatory mechanisms [40]. However, the local authorities, scientific communities and other stakeholders who are involved in this line of business may come up with better systems that can cope with the actual management of floods risks in their areas of operation.

For instance, like Japan or China, Romania has been looking for specific configurations of emergency management solutions to decrease flood effects. An example from the Japanese approach to multi-level emergency management and risk planning and Chinese application of computational intelligence in disaster response can give lessons for flood management in Romania. Both systems incorporate the use of high-end computational applications for data analysis, weather forecasting and operational decision making on a real-time basis that will enhance the response of the systems in accelerated flood events [5]. Accurate management of flood requires big data analytics and real-time algorithms to support the management information systems decisions. All these systems involve use of computational intelligence to undertake data analysis, fitting models, and finding floods risks and produce displays for the decision makers. AI technologies developed over the years for accurate prediction of weather conditions and mapping of flood risks, has brought a significant change in controlling floods [6]. On the same note, drones and satellites provide means of capturing up-to-date information where disasters have occurred, or where the paths for evacuations have not been affected.

Several practical directions related to the integrated alarm systems for flood management in Romania can be used for improvement: the usage of the remote sensors, drones, and analysis based on artificial intelligence technologies [41].

These technologies can be used to forecast the occurrence of floods, estimate the extent of the problem, and design an efficient evacuation path that would help cope with floods in the shortest possible time [7]. Incorporation of emergent solutions is critical within the construction of sustainable flood mitigation frameworks for reactions to disasters as well as for preventing more similar damage in the future.

3. MATERIALS AND METHODS

The objective of this systematic review is dual: examining the state of developments in combined alarm systems for flood risk zones in Romania and evaluating how these alarm systems improve the nation's flood mitigation and early warning systems. The review process was conducted in two phases: articles in entry and review. For this purpose, articles were searched in Scopus, Google Scholar, Science Direct, Elsevier, Springer to select recent and interdisciplinary articles on flood alarm systems. The next process that entailed was to develop a set of specific questionnaires which could be used across these avenues. Starting with the primary goal of searching these databases till the fag end to find out as many articles relating to integrated alarm systems for flood risk management in Romania as possible.

By using three types of words for searching it would be possible to find resources giving different perspectives of the subject. The first set of keywords that were used for article selection were: ‘‘flood alarm systems’’; ‘‘flood risk monitoring’’; ‘‘early flood detection’’) as well as ‘‘integrated alarm systems.’’ The second category focused on searching the articles with technologies such as “remote sensing,” “sensor networks”, “IoT based flood monitoring”, and “real time data for flood alarm systems.” The third category dealt almost exclusively with cross-disciplinary approaches, employing such terms as ‘disaster management,’ ‘emergency response systems’ and ‘flood warning infrastructure.’ Number of articles retrieved from each keyword category is presented in Fig.1 below;

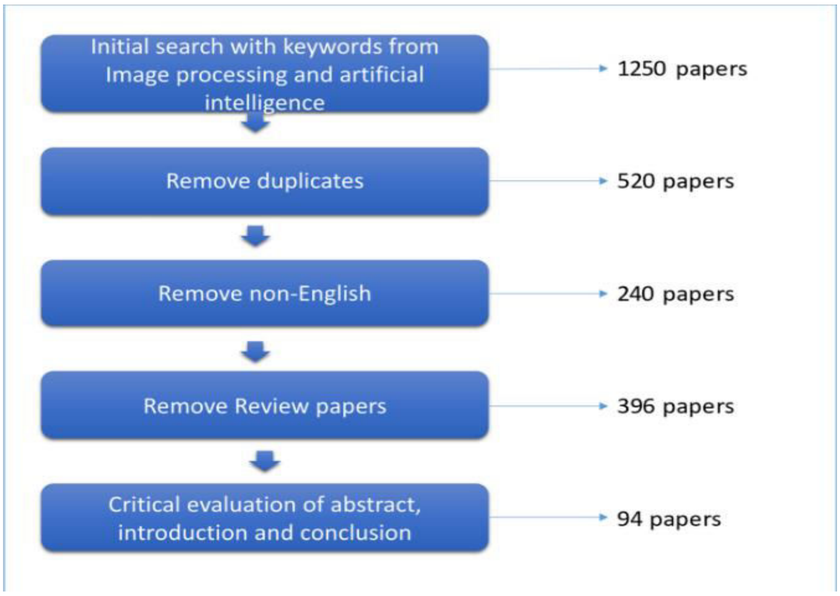

FIG. 1 The detailed screening process of the latest articles for flood management (Munawar et al., 2021)

After the initial phase of article retrieval, the selected articles underwent a screening process to refine the selection criteria. Four specific assessment criteria were defined to evaluate the articles:

1. No Duplicates
2. Time Interval: 2010–2021
3. Document Type: research article, abstract, book chapter
4. Language: English only

By applying these filters only, the beautiful research articles in just the English language published in the last couple of years which is also very rare and unique is acquired only. Using the above criteria the first phase of the study yielded 1250 articles out of which only 94 contained all the four elements. As a result, 94 articles have been screened for this systematic review. Figure 1 illustrates the distribution of articles into bailors including image processing, artificial intelligence, integrated approaches for flood risk. Thus, screen salvage excluded about 502 duplicate citations, 240 non-Eng articles, and 396 review papers. Consequently, 94 papers were filtered for the review. As is depicted in Fig. 2, the number of articles published in each category at year-wise is as follows. It was found to have a more significant concentration on image processing and artificial intelligence technique experimentations in the past decade as compared to integrated approaches to flood risk management. On the other hand, significantly fewer articles explored implementation of these technologies in post-disaster situations, and even fewer explored multi-method applications to floods. The search was expanded to further encompass reports, magazine articles and web pages from scholarly sources for this review. Only the articles published after December 31, 2009, were considered with the exclusion of early pervasive papers introducing the foundational technologies associated with the explored technologies.

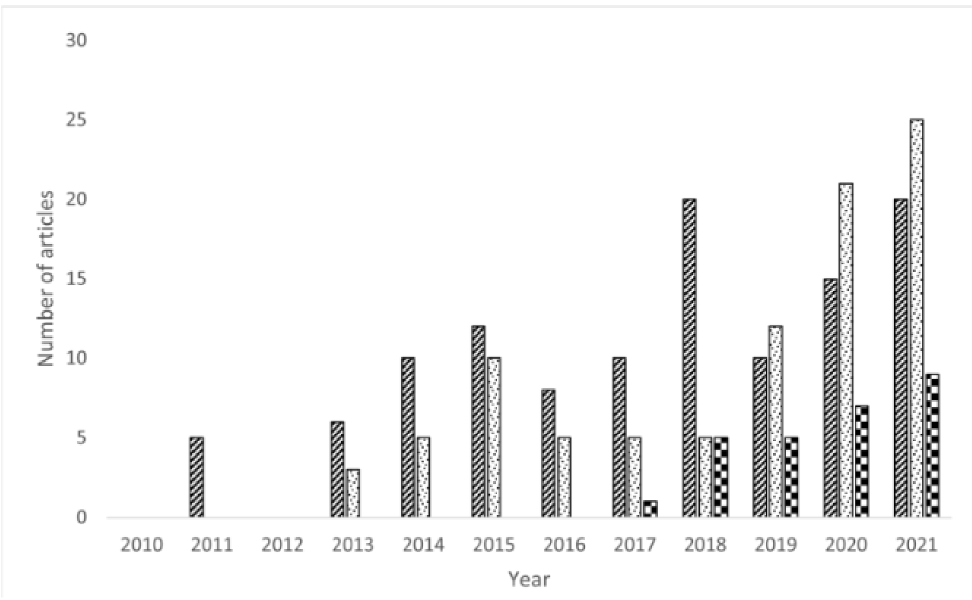

FIG. 2 Yearly distribution of the papers published in the selected domains (Al-Rawas et al., 2024)

4. RESULTS

Image Processing for Flood Detection

Edge Detection

Preprocessing techniques especially edge detection methods have been widely used in assessment of floodwater levels in Romania.

These techniques encompass several procedures comprised of Region of Interest (ROI) selection, image pre-processing, edge detection toward estimation of water surface. The primary steps in this process include:

Region of Interest (ROI): This is used to zoom onto portions of the image in which the flood water levels are to be calculated; it minimizes distortion of other segments of the image which are not of interest. The feature of the algorithm is the isolation of the area flooded making it easier and more accurate to filter out noise [7]. The ROI technique is advantageous because the scope is limited to factors applicable to the flood situation.

Image Pre-processing: Lighting and contrast improvements the image to improve the recognition and accuracy of the image. When the brightness and contrast bar is moved to the middle, then the water levels stand out clearly so that the edges become easier to identify [8]. This is very important in flood detection since one need clear edge along which to gauge the water level.

Edge Detection: After this, the point of interest concentrates on edge detection for the demarcation of boundary of water surface. These algorithms isolate a water region with the image, and the water level computed using the coordinates of the edge pixel. If the edge has a higher height measurement, the coordinates of the edge are changed, and a flooding alert may be activated [9]. Correct tuning of the system enables prediction of the flood levels which in turn is useful especially in the provision of early warning systems in Romania.

Landmark Detection: Additional analysis requires identifying important signposts, including bridges, roads, and structures that will help to figure out if the area is flooded or not. The identification of such features is paramount in formulating strategies for evacuation, flood effects' evaluation, and as a confirmation of a disaster's occurrence [10][42]. Some of the recent developments are Edge detection used on multispectral aerial images for proper disaster management.

Integrated Flood Alarm System (IFAS)

The IFAS or Integrated Flood Alarm System is a flood warning system that consists of an apparatus for real pictures that enable the monitoring of the water levels. In Romania, examples of flood sensors are used to capture video feeds around the rivers and the resultant videos are converted into still images for flood detection. The system improves on these images to make them contrasty and sharp as these will help during flood monitoring [11]. The IFAS predicts water surfaces from the adjacent structures by means of point-based, edge-based, region-based, as well as point, edge, and region hybrid algorithms. Nevertheless, smoke, storms, and reflections are considered among the environmental factors that may delete segments or distort flood computation [43]. To counteract this, the system incorporates flood-risk classifiers that assist in adjusting the flood prediction thus enhancing the capability of the system to provide accurate flood warnings for Romania [12]. The system works in two primary modules: image analyses and risk identification. The first module refines and further categorizes the images, and the second one raises an alarm as soon as the level of flooding is identified. This offers real-time flood mapping which is handy and very valuable especially to the rescue squads and helpful in disaster response in flooded areas in Romania.

Post-Disaster Assessment Using UAVs

Post-earthquake UAVs with camera have been broadly adopted as an essential tool for rapid assessment in Romania. AUVs are used for the aerial photography with an imagery that is influential in assessment of flooded regions. With this technology one is in a position to undertake a very fast assessment the damage caused, be it structures, vegetation and extent of flood water. Further, aerial imagery acquired by UAV also helps assess the quantity of water and effects on the floodplain [13].

Multispectral cameras and RGB imagery help in assessing the actual volume of damages done to crops and part of the infrastructural supports [44]. Besides, the collected information contributes to the preparation of the recovery activities and then directs the government's actions to the right place. Assessments using UAVs are essential in Romania after floods because they provide Recovery programs and decisions with the needed information promptly [14]. By implementation of these integrated technologies, Romania can be enabled with better access to detect flood risks and therefore, have better prepared management strategies.

Artificial Intelligence (AI) for Post-Disaster Flood Management in Romania

The AI techniques have been found to be quite valuable in flood management in Romania both in the pre and post disaster situation. The use of AI in predicting and managing floods would provide both systematic view of flood hazards, improved identification of floods, and quick post-flood crisis recovery. Contemporary research has identified and discussed several AI methods that make a crucial contribution to flood risks reduction and, therefore, flood damages minimization in Romania [15]. Alphabets have been designed as well as deployed several AI-related tools to assist with the venation of flood-related problems especially in the post-flood phase. These tools harness information from AI to identify, locate and visualize flood occurrences [45]. For example, the QCRI tool initially designed for disaster informatics in Qatar has also proved effective at identifying disaster information in real-time. It processes Twitter and textual data from several input data sources and develops immediate recovery plans [16]. However, this tool was not specifically developed for the flood management in Romania but after observing its features in similar disastrous prone areas demonstrates that, this tool has a capability of easy flood disaster response operations.

The Concern tool which is integrated into the process of managing flood disasters is another example of large regions that have introduced integration with artificial intelligence at the next level. It provides a live image of the flood situations during an emergency and helps the emergency management organizations to identify the situation and respond to the needy as and when required [17]. This tool is also fitted with a planning component that identifies areas vulnerable to disasters and guides the evacuation of people thus minimizing on the actual human loses. In Romania for an instance, tools like Concern could be of uttermost importance in pointing out areas that are susceptible to floods in addition to other related information like evacuation drills all in preparation for as well as making sure that any likable rescue operations are launched on time [18][46]. An essential and another related tool that is used for AI-based post-disaster rehabilitation is BlueLine Grid. Created in the United States, this communication tool is used by relief workers and disaster emergency responders. It works more as a movable communication hub where different rescue teams, security squads and local administrative bodies are networked in a single interface [19]. Such a system may well play an important role in the context of Romania identified as having high susceptibility to flood phenomenon, in that it enhances information exchange in the course of flood response and recovery.

AI-Based Flood Prediction Models

Apart from response post-disaster, current AI models are also applied in flood forecasting and prediction.

Google partnered with several agencies to maintain a close watch on Google Maps and Google Search in using AI for flood forecasting and subsequent prevention. In Romania, such system could use information concerning rainfall, historical floods, and other climate indicators to provide precise flood prognosis [20].

Machine Intelligent Flood Prediction Models will be of great benefits to Romania flood management strategies since authorities will be in a better position to manage any floods particularly since they will receive warning. Random Forest method and Decision Trees (DT) are among the outstanding tools utilized in flood prediction systems nowadays. These models are dependent on the influx of data flowing from various outlets; weather data among them to forecast future flood occurrences from past floods [47]. Some of the flood-related reconstructions contain patterns that can be learned by artificial intelligence to predict such floods in the future [21]. In Romania the incorporation of these models into current flood forecasting systems could have impacts of raising the capacity of Romania of coping with floods.

Flood Susceptibility Mapping Using AI

Studies have also recently centered on the creation of flood susceptibility maps through the use of the AI. Method such as the Bagging Logistic Model Tree (LMT) which is an amalgamation of ensemble method and machine learning to generate detailed flood susceptibility map. When the above analytical approach is applied to regions such as the Haraz region in Northern Iran this Gis based approach yielded a 95.5% overall accuracy [22]. As in Romania, the similar mapping tools supported by the AI, can be employed for the same purposes, forming the base for more precise evaluations and better planning of the actions to minimize the impact of the floods [23]. These AI models help in improving flood risk assessment and in preparing for disaster, since these models consider various flood-conditioning factors.

Integration of Statistical Methods and AI for Improved Performance

In another effort to make flood predictions even more precise, theorists have complemented statistical assessment with forecasts generated by machine learning algorithms. For instance, to predict floods, researchers integrate the Frequency Ratio (FR) and the Support Vector Machine (SVM) for spatial modelling. This approach makes it easier to determine correlation between different conditioning factors and flood occurrences [24]. In Romania, the use of statistical techniques in conjunction with AI models could help enhance flood forecasting and guarantee that threat of floods is detected with a very high level of precision in regions that are not frequently monitored or those which have complicated terrain. Also, disaster predictions have also incorporated Artificial Neural Networks (ANN), which have had significant improvements in flood disaster management [25][48]. In this research, SAE and BPNN are used to forecast floods based on input data, including rainfall trends and past flood data. Through analyzing specific floods situations, ANN models can be used for flood behavior anticipation, thus the Romanian authorities can more effectively confront flood hazards.

5. DISCUSSION

Technological Advances in Flood Management

Currently, alarms in areas prone to flooding in Romania could highly benefit from new technologies such as image processing, machine learning, and UAVs. It has been revealed that these technologies have played the roles in diverse DM systems; nonetheless, they could be integrated with existing systems for flood monitoring for the improvement of flood preparedness, response, and rehabilitation.

Advanced image processing strategies, which have been adopted over conventional image analysis methods, include three-dimensional geodetic data for improved measurements of slope and flood fluctuations.

Given the fact that photogrammetric, LIDAR, and UAV are useful methods for obtaining accurate and high-resolution GIS data for the assessment of existing conditions as well as flood impact simulations, they remain critical technologies in flood management frameworks [26]. These technologies help in collection of large data in short span of time, using which predictions about the areas that are most prone to floods can be made and better strategies to deal with floods can also be prepared. But, as of now, there are some challenges connected with their usage. Lighting conditions during flood occurrences, level of contrast, pollution of environment, and other atmospheric interferences have impact on the quality of pictures obtained [49]. These interferences make it hard to achieve precise results, therefore affecting the efficiency of image processing methods [27]. To address these issues, several correction techniques; radiometric and geometric corrections must be done. Still, such discrepancies appear rather often, as well as when images from different time and space are processed with the help of certain pre-define variants. This inconsistency underlying the significance of developing improved machine learning to improve accuracy and dependency of image processing performance.

Integration of AI and Machine Learning

AI and machine learning can intensively enhance flood management. A progress of machine learning models on large data resources can contribute to the improvement of the monitoring systems' ability to make accurate predictions. These models can recognize patterns and outliers in the typical flood areas and assist with the best strategies for evacuation as well as decision-making procedures to best allocate their resources [28]. For instance, control centers can utilize UAVs to gather information during a flood event, if these UAVs are accompanied by machine learning models or not. Additionally, if data from the camera was automatically fed into an analyzer using artificial intelligence, then the problems with inconsistent picture quality would not affect the flood response reliability. Supplementing the AI classification with image processing tools will improve the classification between flood and no flood areas by utilizing slightly complicated elements such as edges and deep learning [50]. This method helps to determine areas affected and to increase the rate of decision-making and thus develop an effective and timely response. It is shown [29] that with the use of machine learning techniques, flood related images can be efficiently processed by AI models useful for post disaster management hence reducing time and increase accuracy of impacts of floods. This integration, however, is heavily dependent on the existence of big data for training, which is sometimes a bottleneck. To resolve this problem, one able to utilize Generative Adversarial Networks (GANs) for generating realistic severities from little datasets for increasing the realism of the training data [30]. These synthetic datasets can be to enhance areas of artificial intelligence with managing the aspects of floods, thereby yielding improved predictive faculties.

Use of UAVs for Flood Monitoring

Unmanned Aerial Vehicles UAVs central to the contemporary flood management systems provide valuable, adaptable and cheap means to register actual imagery in the disaster zones. Combined, UAVs in formation can cover significantly large areas with speed, and efficiency as a swarm in a very short time allowing for faster capture of geospatial data [31]. The use of advanced sensors and cams in UAVs enables the acquisition of high-definition images that can be used to determine areas affected by floods as well as the barriers to disasters response.

Authorities can use UAVs in certain areas and keep track of the flood advancement while responding in the real time, including changes of the evacuation routs and emergencies etc. [32].

Current research has established that incorporating machine learning into UAV's is effective particularly when faced with dynamic floods, because it will process the images faster and accurately than fixed methods. The planning of UAV paths, as postulated by [51], increases efficiency through increased utilization of limited resources. UAVs can in addition be used to develop flood maps and check on the viability of aerial drops to affected regions. Nevertheless, such factors as restricted battery power and the need for high-intensity communication networks still persist.

The Role of Social Media and Cloud Computing

IT items that can be utilized as applicable to the flood management are social media and cloud computing which have vital role in sharing real-time information and actual situation. Many people use the internet especially the applications in their smart phones for update from the authorities as they get data concerning the current flood situation [33]. Another advantage of using artificial intelligence is that through posts, images and videos from the public, the algorithms will help the authorities determine where to focus on first. Further, through cloud computing, information can also be stored and shared across many agencies, and hence there are improved interactions as well as decision-making [34]. This communication can be supported by more frequently utilizing the AI-based techniques for real-time disaster identification and analysis. According to a recent study, data processing task can be managed externally on cloud base platform to make the whole system more responsive and scalable in the event of disaster occurrence.

Improving Flood Response with Cutting-Edge Technologies

Such measures should be employed to improve the existing manage flood system in Romania: Cloud computing, image processing, and AI technologies. These integrated systems can offer constant situational establishment and help the authorities to evaluate the levels of flood and dispatch resources [35]. Appropriate artificial intelligence algorithms can be employed for the most effective routing in emergencies to fasten the rescue operations and prioritize areas where they are needed most. In addition, integrating these technologies with sensor networks including infrared sensors for capturing human motion enables early warning and best evacuation practices [36]. In informing and planning efficiently in case of a flood, it is possible for AI to work with data from sensors in real-time to determine the flow of the floods and identify the viability of the possible routes for evacuation. Emergency preparation can be made regarding floods, and the right evacuation plan can help prevent the loss of lives and property.

6. CONCLUSIONS

Flood has always remained a natural disaster-prone area in Romania and to protect the safety of the community integrated alarm systems has been the main core. Hence, communication, evacuation, and even flood relief are said to be aided by use of this technology. Comparative studies between these technologies are necessary to find the limitations of the existing system and determine whether the two technologies can be integrated. Since flood catastrophes are as a rule characterized by excessive flow rate and hence time-sensitive these devices can help save lives and this is especially true with the third world or underprivileged communities. Due to development in the procedures of mapping, it became possible to generalize the instruments that indicate the risks of floods, as well as to develop the procedures of evacuation. In real-time processing it is also very simple for the officials to identify the safe evacuation areas that are likely to be affected before flood disaster strikes. Image processing can also affect inwards the quantity of the flood impact on roads, bridges and structures.

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ENERGY INDEPENDENCE: AN ESSENTIAL PILLAR FOR CRITICAL INFRASTRUCTURE RESILIENCE

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DOI: 10.19062/2247-3173.2025.26.10

Abstract: *In the contemporary geopolitical landscape, characterised by instabilities, climate change, and mounting cyber threats, the pursuit of energy independence has transcended the realm of mere political aspirations, becoming a matter of strategic imperative. Recent events in Spain and Portugal, where a substantial blackout impacted critical infrastructure and communications, underscore the vulnerabilities of centralized and interdependent energy networks. This incident has led to a resurgence of interest in the necessity for local, sustainable, and secure energy solutions, particularly in regard to critical infrastructure. Such infrastructure may include hospitals, data centres, communication networks, public transport, and defence systems. The solutions are varied, but must be chosen in relation to the available and potential resources and infrastructure, and especially the level of importance of the objectives to be protected.*

Keywords: *energy independence, critical infrastructures, resilience, energy reserves, VUCA.*

1. INTRODUCTION: EUROPE'S GEOPOLITICAL AND ENERGY CONTEXT

In the contemporary geopolitical landscape, characterized by increased volatility, strategic uncertainty and the constant emergence of new hybrid and cyber threats, along with the challenges exacerbated by climate change, the concept of **energy security** has advanced on the agenda of global strategic priorities. The pronounced dependence on external energy sources has been recognized as a major systemic vulnerability, with the potential to generate economic dysfunctions and compromise the functional integrity of national critical infrastructures [1].

The European Union, a leading player in the global security and economic architecture, has faced increasing pressure in recent years to strike an optimal balance between **energy needs** and **strategic autonomy**. Recent statistical data acutely underline this challenge: in 2022, the European Union's energy dependency ratio (Figure 1) reached a level of 62.5%, indicating a considerable vulnerability to international market fluctuations and geopolitical events with a major impact. Although there was a slight decrease to 58.3% in 2023 [2], this persistent dependence constitutes a substantial risk factor for the internal and external stability of the community bloc. The need to reduce exposure to external shocks has spurred a fundamental reassessment of energy strategies, reinforcing the concept of **energy independence** as a central pillar of state sovereignty and resilience.

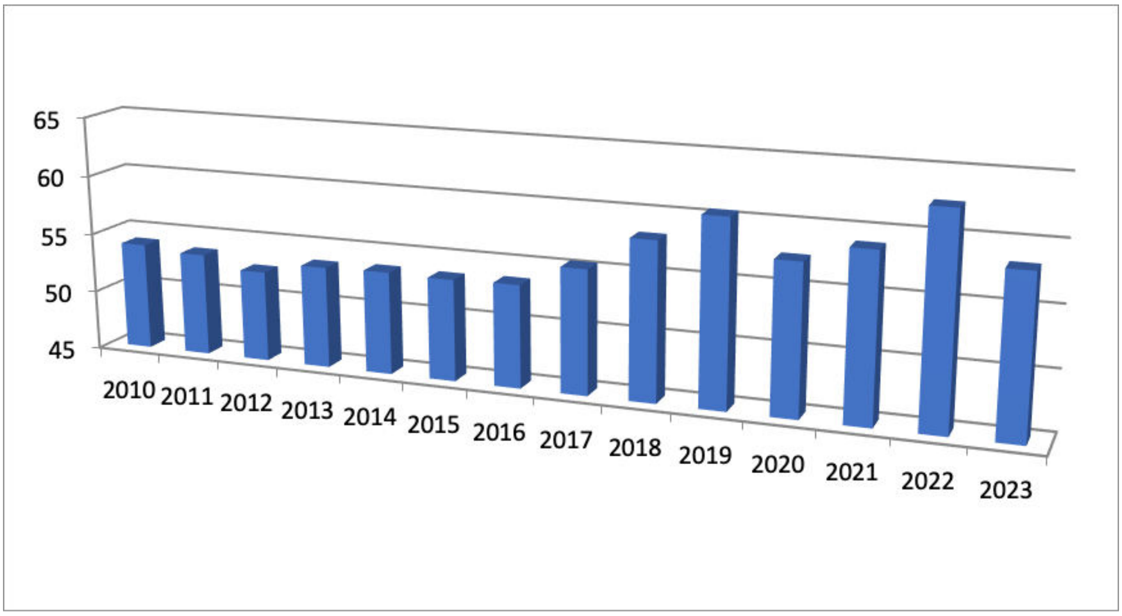

FIG.1 Evolution of the European Union's energy dependence (%)

At the same time as efforts to reduce dependence on imports, the European Union has taken a firm strategic direction towards **the energy transition**, aiming at a deep decarbonisation of its energy mix. The target of 42.5% of renewables in gross final energy consumption by 2030, up from 24.5% in 2023 [3], reflects a substantial ambition to combat climate change and build a sustainable energy system.

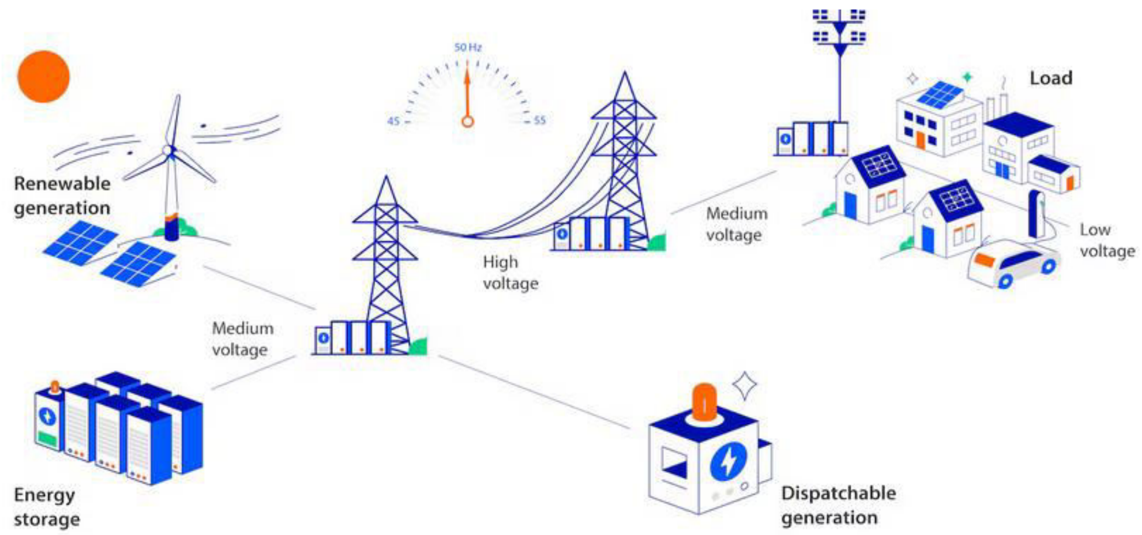

FIG.2 Components of the energy system *(Source: RaboResearch 2025)*

This structural transformation, while necessary for environmental protection and long-term sustainability, presents inherent challenges. The large-scale integration of renewable energy sources, characterized by **intermittency** and **variability** [4], requires prompt adaptation and significant modernization of existing energy infrastructure (Fig. 2), including the deployment of advanced storage and grid management solutions [5].

In this dynamic context, the concept of **resilience** acquires a particular importance. It is not enough just to ensure a continuous energy supply; It is necessary for energy systems to demonstrate the ability to absorb shocks, adapt to fluctuating operational conditions and quickly restore their functionality after major disturbances [6].

This requirement becomes even more stringent in the case **of critical infrastructure**, whose relevant components – including hospitals, communication networks, transport systems and, in particular, **defence and radar systems** – depend to a large extent on a reliable and uninterrupted power supply. Any malfunction in the energy supply of these infrastructures can lead to serious consequences, with widespread reverberations on national security, economic stability and societal well-being. This article aims to carry out an in-depth analysis of the intersection between energy independence and critical infrastructure resilience, with a particular focus on identifying vulnerabilities and proposing applicable solutions, integrating a relevant perspective for defence and radar systems.

2. CASE STUDY: POWER OUTAGES IN SPAIN AND PORTUGAL (APRIL 28, 2025)

Major incidents affecting energy infrastructure serve as alerts, highlighting the fragility of centralised and interdependent systems. One such event occurred on **April 28, 2025**, when a massive power outage simultaneously paralyzed Spain and Portugal, cutting off electricity supplies for millions of citizens [7], [8]. At 12:33 CET, the Spanish energy system experienced a steep loss of generation capacity. According to initial reports, around 15 GW were lost in Spain, equivalent to about 60% of national demand, in just a few seconds [9]. This rapid decrease in generation capacity illustrated the inherent vulnerability of modern grids to sudden disruptions.

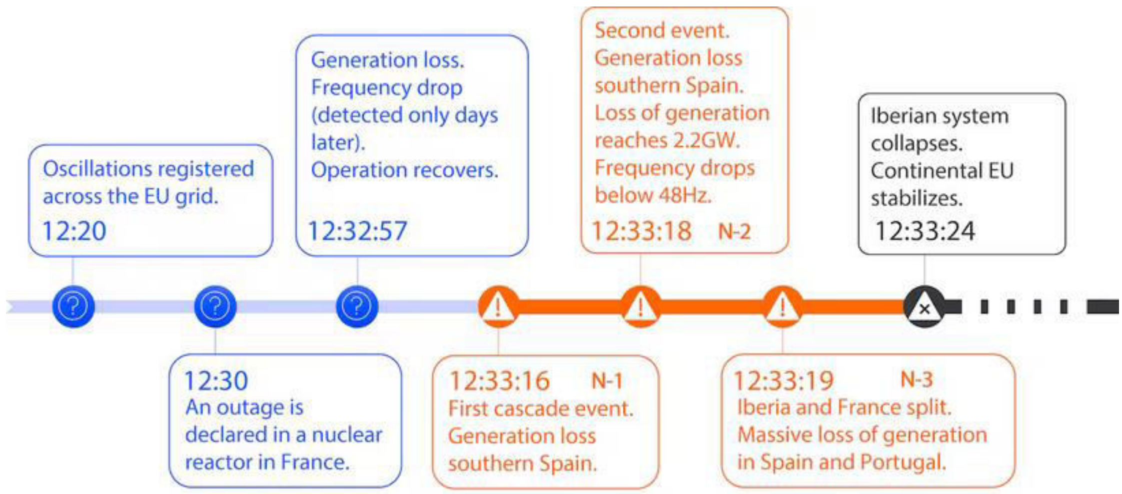

FIG.3 Timeline of events at the power outage in Spain *(Source: RaboResearch 2025)*

Preliminary investigations, carried out by entities such as ENTSO-E [10], indicate that the incident was triggered by a series of disconnections of generation units, in particular in south-west Spain. A major factor contributing to this instability was the lack **of mechanical inertia** specific to traditional rotary generators (such as those in thermal or nuclear power plants), inertia that contributes to the stability of the grid frequency in the event of rapid fluctuations. Photovoltaic and wind systems, due to their electronic nature, do not offer the same inertia, which can amplify grid instability in stressful situations.

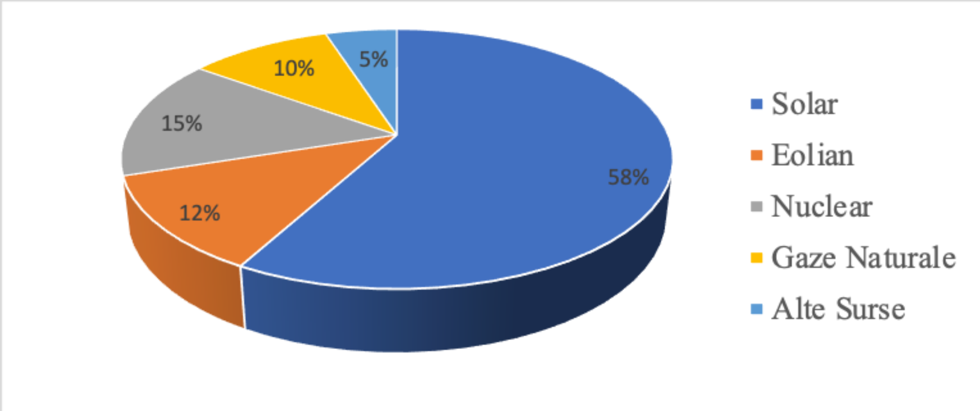

FIG.4 The energy mix of the Iberian Peninsula at the time of the power outage (April 28, 2025)

For example, at the time of the incident, the Iberian system had a very high share of renewable generation, with solar energy accounting for almost 60% of the energy mix (Figure 3) and wind power for about 12% [11][12]. This technological gap highlights a major challenge of the energy transition: ensuring grid stability as the share of intermittent renewables increases exponentially.

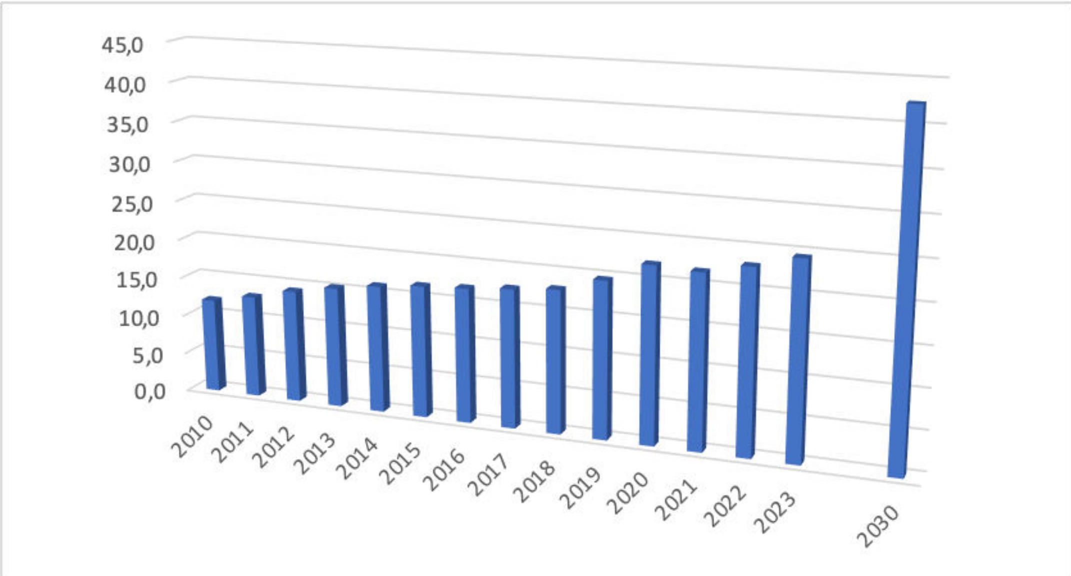

FIG.5 Share of renewables in EU gross final energy consumption (%)

The impact of this power outage (Table 1) on **critical infrastructure** was considerable. Airports were forced to suspend operations, hospitals switched to emergency generators, public transport networks and communications were significantly disrupted, and ATMs and electronic payment systems became inoperable [13][14]. This incident clearly demonstrates the degree of interdependence of modern societies on a continuous and stable power supply. In the specific context of defence systems, such a disruption could substantially affect the air and maritime surveillance capability, the functionality of command and control systems, as well as the operationality of military units that depend on the civilian network for supply. It underlines the need to develop autonomous and resilient energy solutions for these infrastructures [15].

Table 1: Impact of the power outage of April 28, 2025

Critical Infrastructure Sector	Observed Impact
Airports	Suspended operations; Rerouted/delayed air traffic
Hospitals	Switching to emergency generators; Potential risk for patients dependent on appliances
Public Transport Networks	Total stop (metro, trams); Extensive roadblocks
Communications	Significant disruptions to voice and data networks; difficulties in calling emergency services
Financial Systems	Inoperable ATMs; blocked electronic transactions; impact on trade
Defense Systems (Radar)	Risk of loss of surveillance and detection capability; Compromise of C2 (Command and Control) functionality

3. VULNERABILITIES OF CRITICAL INFRASTRUCTURE IN THE CONTEXT OF THE ENERGY TRANSITION

Critical infrastructure is the set of systems and assets, physical or virtual, whose malfunction or destruction would have a debilitating impact on the security, economy, public health or safety of citizens. This includes sectors such as health (hospitals, clinics), transport (airports, ports, railways), communications (data and voice networks), financial systems and, obviously, the **energy sector** itself, alongside **defence systems** such as radar and surveillance [16]. The continued functioning of these sectors is a key element for social cohesion and the state's ability to react in crisis situations.

The massive integration of **renewables**, although a necessary step towards sustainability, introduces new **risks and vulnerabilities** in the stability of energy grids. The intermittent nature of solar and wind energy, dependent on weather conditions, imposes complex grid balancing requirements. Without adequate **energy storage** measures and advanced **grid stabilization** solutions, rapid fluctuations in production can generate frequency and voltage instabilities, culminating in the risk of cascading disconnections. The incident in Spain is illustrative of this: at the time of the power outage, Spain generated a significant proportion of its electricity from solar (53%) and wind (11%) sources, along with nuclear and gas (15%) [9]. Reliance on low-inertia sources can amplify the speed and severity of a network collapse in the absence of robust response systems.

For **radar systems**, which are important components of defense infrastructure, these vulnerabilities are amplified. A radar system, whether dedicated to aerial, sea or ground surveillance, requires a **continuous, stable and high-quality power supply**. Outages, even of short duration, can lead to loss of detection and tracking capability, equipment reset, or even irreparable damage. This would seriously compromise the reaction capacity of the armed forces, from early warning to the guidance of defense systems. The exclusive dependence on the national grid, even in the presence of conventional backup generators, exposes radar systems to multiple risks: physical attacks on transmission lines, cyber attacks on the SCADA control systems of the civil network, or even extensive technical failures, as exemplified in the case of Spain. Therefore, energy autonomy and resilience become not only options, but strategic requirements for maintaining the operational capacity of defense systems.

4. STRATEGIES FOR STRENGTHENING ENERGY INDEPENDENCE AND CRITICAL INFRASTRUCTURE RESILIENCE

Ensuring **the energy independence** and **resilience** of critical infrastructure requires a multifactorial approach, which combines technological innovation with strategic planning and the implementation of appropriate public policies. A central element in this strategy is **the development of microgrids and energy storage systems**. Microgrids are localised energy systems capable of operating independently of the national grid (island mode) in the event of disruptions, ensuring continuity of supply for critical consumers. The integration **of** high-capacity batteries (such as Li-Ion or flow), alongside other storage solutions (thermal, mechanical or hydrogen-based), is useful to compensate for the intermittency of renewable sources and provide immediate backup power [5]. For radar stations, the development of hybrid microgrids (solar-wind-batteries, with diesel/gas backup) would ensure increased energy autonomy, reducing dependence on the centralized grid and, implicitly, the associated vulnerabilities.

Diversification of energy sources is another basic strategy. Reducing dependence on imports and a single type of fuel is achieved by increasing domestic energy production from multiple sources. This includes not only accelerating the deployment of renewable energies (solar, wind, small hydro, geothermal, biomass) [17], but also maintaining a balanced energy mix, which also includes basic capacities (nuclear, natural gas) capable of ensuring long-term stability. For defense infrastructure, especially for isolated or mobile units, the use of compact and easy-to-deploy renewable energy solutions (e.g. portable solar panels, small wind turbines) becomes a relevant aspect for reducing the logistical footprint and vulnerabilities related to fuel transport.

Investments in the modernisation and digitalisation of critical infrastructure are significant to enable smart and efficient management of energy resources. The implementation **of Smart Grids**, capable of monitoring and controlling energy flows in real time, optimizes distribution, minimizes losses and allows a better integration of distributed sources [18]. For radar systems, the modernization of the local energy infrastructure by integrating advanced monitoring and automated control technologies can prevent malfunctions and allow a rapid reaction in case of emergency.

Last but not least, **the cybersecurity** of the energy infrastructure of critical systems is an important aspect. As energy systems become more digitalised and interconnected, the risk of cyberattacks increases. The protection of industrial control systems (ICS) and SCADA that manage energy flows, including those of the microgrids that feed radar systems, is necessary to prevent sabotage, information gathering or disruption of operations [19][20]. An integrated approach, combining physical and cyber security, is needed to ensure the full resilience of critical infrastructure.

RECOMMENDATIONS AND CONCLUSIONS

Ensuring **energy independence** and strengthening **the resilience of critical infrastructure** are significant strategic objectives in the current global geopolitical and energy context. The case study of the power outage in Spain and Portugal on 28 April 2025 served as an illustration of the inherent vulnerabilities of centralised energy systems and the considerable impact on relevant sectors, including the potential impact on defence systems. The accelerated integration of renewable energy sources, while necessary to achieve decarbonisation goals, requires the adoption of robust technological and strategic solutions to manage intermittency and ensure grid stability.

Based on the analysis carried out, we formulate the following **key recommendations**:

- **Integrated Public Policies:** It is advisable to develop and implement coherent public policies that balance energy transition ambitions with security and resilience objectives. They must stimulate investment in energy storage technologies, the development of microgrids and the modernisation of existing infrastructure, with dedicated financing mechanisms for critical and military infrastructure.
- **Priority Investments in Microgrids and Storage:** Governments and entities responsible for critical infrastructure should prioritize investments in autonomous microgrids and advanced energy storage systems. They enable independent operation in crisis situations, ensuring the continuity of relevant services, including for defence and radar systems, which require exceptional reliability of supply.
- **Real Diversification of the Energy Mix:** Beyond the adoption of renewable energies, national strategies must aim at a broad diversification of supply sources and generation technologies, reducing excessive dependence on any single source or vulnerable import routes.
- **Strengthening Cybersecurity:** As energy infrastructure becomes increasingly digitized, investments in the cybersecurity of the control systems (ICS/SCADA) associated with it are necessary to prevent attacks that could compromise the power supply of critical infrastructure.
- **International and Regional Collaboration:** Cooperation between EU Member States and beyond is useful for developing interconnected, resilient and interoperable energy networks, as well as for sharing best practices and threat intelligence.
- **Education and Strategic Awareness:** An information campaign is needed for the general public and decision-makers on the strategic importance of energy independence and critical infrastructure resilience, in order to ensure the necessary support for the implementation of appropriate measures.

Therefore, energy independence is no longer just an economic option, but a strategic requirement of national and European security. By adopting an integrated approach, combining technological innovation with visionary public policies and a deep understanding of specific vulnerabilities, especially in areas such as defence and radar systems, an energy infrastructure can be built capable of sustaining the resilience of our societies in the face of present and future challenges.

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OPTICAL RECEIVER FOR SIGNALS TRANSMITTED ON FREQUENCY-MODULATED LASER CARRIERS

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DOI: 10.19062/2247-3173.2025.26.11

Abstract: *The development of wireless optical communication systems, along with the increasing application of laser technologies in space systems, has led to a growing interest in unguided optical communication, including within military domains. This paper presents the design and simulation of an optical receiver capable of demodulating unguided laser signals and reconstructing the original transmitted data. The first part of the paper outlines the architecture and key components of the optical receiver, intended for signals transmitted via an optical carrier modulated in frequency or position. Design principles, component selection, and system-level considerations are discussed in detail. In the second part, the receiver's performance is evaluated through time-domain SPICE simulations. The results confirm the correct operation of the proposed circuits and provide a basis for optimizing the receiver's performance within a wireless optical communication system. The associated optical transmitter, employing a frequency-modulated laser source, was described in a previous study and complements the system presented herein.[8].*

Keywords: *optical receiver, laser carrier, wireless optical communication system*

1. INTRODUCTION

The proposed wireless optical communication system consists of two main subsystems: a laser transmitter [8], employing frequency or position-modulated (FM or PM) subcarriers, and an optical receiver that demodulates the unguided laser signal and reconstructs the original audio signal.

A fundamental requirement for such a system is that it offers advantages over traditional radio frequency (RF) or microwave communication systems, both in terms of performance and cost-efficiency. Free-space optical (FSO) communication [1, 2, 4] has emerged in response to the growing demand for higher data transmission rates and enhanced security. Optical links are particularly relevant in scenarios involving satellites, deep-space probes, ground stations, unmanned aerial vehicles (UAVs), high-altitude platforms, aircraft, and other communication nodes. These links are applicable in both military and civilian domains.

Free-space optical communication represents a significant step forward in the evolution of network connectivity, offering superior bandwidth, broader spectrum availability, and improved data security, thus making it a strong complement – or even an alternative to RF – based systems.

However, optical communication systems based on laser carriers are subject to various noise sources, including the quantum nature of light, shot noise in photodetectors, and disturbances introduced by the transmission medium.

In atmospheric propagation, the most significant impairments are signal fluctuation (scintillation) and attenuation of optical power.

The structure of a laser communication system is closely related to the optical demodulation technique employed. The main demodulation methods involve detecting variations in intensity, amplitude, phase, polarization, or frequency of the optical carrier. These can be implemented through direct detection, homodyne detection, frequency conversion techniques, or parameter-conversion demodulation methods.

Depending on the intended application, wireless optical communication systems can be implemented at various scales: short-range indoor systems (10–30 m), outdoor terrestrial systems (1–20 km), and long-range deep-space systems exceeding 10610^6106 km [3, 4, 6, 7].

2. PRINCIPLE OF OPERATION

The optical receiver is responsible for converting the incident optical signal into an electrical signal and for extracting and amplifying the information modulated onto the optical carrier [2, 3]. The photodetector performs the initial photoelectric conversion, generating a current proportional to the incident optical power, which is subsequently amplified and converted into a voltage signal.

Laser pulse detection is achieved using a photodiode matched to the emission wavelength of the laser diode (LSRD650-A5) [8]. For this purpose, the BPW20RW photodiode was selected, due to its high relative spectral sensitivity at the specific wavelength emitted by the laser source.

The optical signal, modulated at 100 kHz, is detected by the photodiode and converted into an electrical signal, which is then fed into a band-pass amplifier. This amplifier is designed to pass signals within the 70–130 kHz range, centered around the 100 kHz carrier frequency, corresponding to the sinusoidal modulating signal band of 20 Hz to 16 kHz.

The amplified signal is then buffered by a voltage follower (CI1), implemented with an operational amplifier, to provide impedance matching. This ensures the subsequent discrimination circuit is driven by a near-ideal voltage source.

The discrimination stage uses a monostable multivibrator (CI2) that generates fixed-duration output pulses corresponding to the incoming signal transitions. These pulses are then processed by a low-pass filter (CI3), implemented using an active filter (FTJ) with a cutoff frequency of approximately 16 kHz, suitable for audio signal recovery.

To correct for frequency-dependent gain introduced by the audio amplification stage in the transmitter [8], the system incorporates an integration circuit (CI4) that introduces a frequency attenuation slope of –20 dB/decade. The resulting audio signal is then amplified using a dedicated audio power amplifier (CI5), with a variable gain factor ranging from 20 to 200, effectively restoring the original analog signal from the frequency-modulated input.

For systems transmitting analog signals via pulse-modulated laser carriers, signal reconstruction is performed by low-pass filtering the sampled signal [3, 5]. The reconstruction filter (FTJ) is designed with a cutoff frequency equal to the highest frequency component of the original signal. A higher sampling rate facilitates easier filtering, as the spectral replicas of the original signal x(t)x(t)x(t) remain well separated. Conversely, a lower sampling rate increases the risk of aliasing, leading to signal distortion.

The wiring diagram of the low-pass filter is shown in Fig. 1, where (Fig. 2): $Z_3 = \frac{1}{sC_8}$; $Z_5 = \frac{1}{sC_{10}}$; $Z_8 = \frac{1}{sC_7}$; $Z_1 = R_{11}$; $Z_2 = R_{10}$; $Z_4 = R_{12}$; $Z_6 = R_9$; $Z_7 = R_8$; $s = j\omega$.

The transfer function of the low-pass filter is of the type:

$$\frac{V_2}{V_1} = H_{TJ}(s) = \frac{a_0}{b_s s^3 + b_2 s^2 + b_1 s + b_0} \tag{1}$$

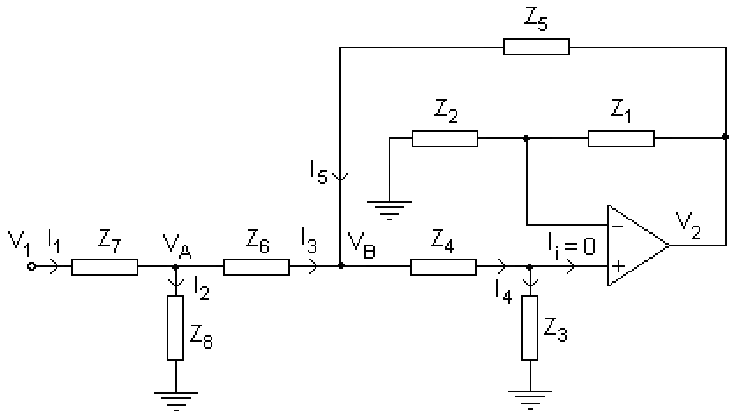

FIG. 1 Low-Pass Filter Wiring Diagram (FTJ)

The equations underlying the determination of the transfer function of FTJ are the following (Kirchhoff's theorems apply):

$$V_+ = V_- = V_2 \frac{Z_2}{Z_1 + Z_2}\ ;\ \mathrm{I}_4 = \frac{\mathrm{V}_+}{\mathrm{Z}_3} = \mathrm{V}_2 \frac{\mathrm{Z}_2}{\mathrm{Z}_3(\mathrm{Z}_1 + \mathrm{Z}_2)}\ ;\ V_B = I_4 Z_4 + V_+ = V_2 \frac{Z_2}{Z_1 + Z_2}\left(1 + \frac{Z_4}{Z_3}\right)$$

$$I_5 = \frac{V_2 - V_B}{Z_5}\ ;\ I_3 = \frac{V_A - V_B}{Z_6} = I_4 - I_5 \tag{2}$$

Equations (2) show the following relationship between the input and output voltages of JTF:

$$V_1 = V_2 \left\{ \left(1 + \frac{Z_7}{Z_8} + \frac{Z_7}{Z_6}\right)\left[\frac{Z_2 Z_6}{Z_3(Z_1 + Z_2)} - \frac{Z_6}{Z_5} + \frac{Z_2}{Z_1 + Z_2}\left(1 + \frac{Z_4}{Z_3}\right)\left(1 + \frac{Z_6}{Z_5}\right)\right] - \frac{Z_7}{Z_5}\frac{Z_2}{Z_1 + Z_2}\left(1 + \frac{Z_4}{Z_3}\right)\right\} \tag{3}$$

The following expression results for the HTJ transfer function:

$$H_{TJ} = \frac{V_2}{V_1} = \frac{a_0}{\left(1 + \frac{Z_7}{Z_8} + \frac{Z_7}{Z_6}\right)\left[\frac{Z_6}{Z_3} - \frac{Z_6(Z_1 + Z_2)}{Z_5 Z_2} + \left(1 + \frac{Z_4}{Z_3}\right)\left(1 + \frac{Z_6}{Z_5}\right)\right] - \frac{Z_7}{Z_5}\left(1 + \frac{Z_4}{Z_3}\right)} \tag{4}$$

where: $a_0 = \frac{Z_1 + Z_2}{Z_2}$.

In relation (4) the eight impedances are substituted.

Taking into account the expression of the transfer function (1), for $a_0 = 2$ and $b_0 = 1$ and choosing arbitrarily $Z_1 = R_{11} = 100k\Omega$, we also get $R_{10} = R_{11} = 100k\Omega$ $R_8 << R_9$. It is considered $R_8 = 1k\Omega$, respectively, $R_9 = 10k\Omega$.

The coefficients in relation (1) will have the simplified expressions:

$$b_1 = R_8(C_7 - C_{10}) + R_9(C_8 + C_{10}) + R_{12}C_8,\ b_2 = R_8R_9C_7(C_8 - C_0) + R_{12}C_8(R_9C_{10} + R_8C_7)$$

$$b_3 = R_8R_9R_{12}C_7C_8C_{10} \tag{5}$$

The cutting frequency, $f_t = \omega_t / 2\pi$, of the filter is calculated from the relation (1), noting that at the frequency $s = j\omega = 0$, the ratio $\frac{V_2}{V_1}$ has the value $\frac{V_{20}}{V_1} = a_0 = 1 + \frac{R_{11}}{R_{10}} = 2$, and for any frequency $j\omega$ we obtain:

$$\frac{V_2}{V_{20}} = \frac{1}{b_3(j\omega)^3 + b_2(j\omega)^2 + b_1(j\omega) + 1} = \frac{1}{j\omega_t(b_1 - \omega_t^2 b_3) + 1 - \omega_t^2 b_2} \tag{6}$$

In order to obtain an attenuation of *3dB*, the following condition is met:

$$\frac{V_2}{V_{20}} = \frac{1}{\sqrt{\omega_t^2(b_1 - \omega_t^2 b_3)^2 + \left(1 - \omega_t^2 b_2\right)^2}} = \frac{1}{\sqrt{2}} \tag{7}$$

resulting in the relationship:

$$\omega_t^2(b_1 - \omega_t^2 b_3)^2 + (1 - \omega_t^2 b_2)^2 = 2 \tag{8}$$

Note that for a cut-off frequency $f_t = 16kHz$, the equation is satisfied if: $b_1 \approx 2 \cdot 10^{-5}$, $b_2 \approx 2 \cdot 10^{-10}$, respectively, $b_3 \approx 10^{-15}$. In equations (5), considering $C_{27} = 10nF$, it follows that they are satisfied for $C_8 = C_{10} = 1nF$ and $R_{12} = 10k\Omega$.

For a sinusoidal signal of constant amplitude and variable frequency, the integrating chirp provides at the output a signal with the same frequency, with amplitude dependent on frequency and circuit elements and out of phase with a phase dependent on the frequency of the signal.

The integration circuit introduces a frequency attenuation of *20dB/dec* to restore the sinusoidal signal from the line amplifier input in the electrical diagram of the laser transmitter [8] (the integrator will thus compensate for the frequency amplification achieved by the audio signal amplification circuit).

For $\underline{Z}_1 = R_{13}$ and $\underline{Z}_2 = R_{14}$ in derivation with *C13* (Fig. 2), respectively:

$$\underline{Z}_2 = \frac{R_{14}}{1 + j\omega R_{14}C_{13}} \tag{9}$$

Results:

$$A(j\omega) = -\frac{\underline{Z}_2}{\underline{Z}_1} = -\frac{R_{14}}{R_{13}(1 + j\omega R_{14}C_{13})} \tag{10}$$

Logarithm the relation (10) yields:

$$|A|_{dB} = 20\lg\frac{R_{14}}{R_{13}} - 20\lg\sqrt{1+\omega^2\tau_2^2} \tag{11}$$

where $\tau_2 = R_{14}C_{13}$. It is chosen $C_{13} = 10nF$. For an attenuation of *20dB/dec*, starting from the frequency of *20Hz*, it results:

$$f_{2i} \cong \frac{1}{2\pi\tau_2} = \frac{1}{2\pi R_{14}C_{13}} = 20Hz \quad \Rightarrow \quad R_{14} \cong 820k\Omega \tag{12}$$

3. SPICE ANALYSIS OF OPTICAL RECEIVER

The SPICE analysis scheme of the optical receiver is shown in Fig. 2.

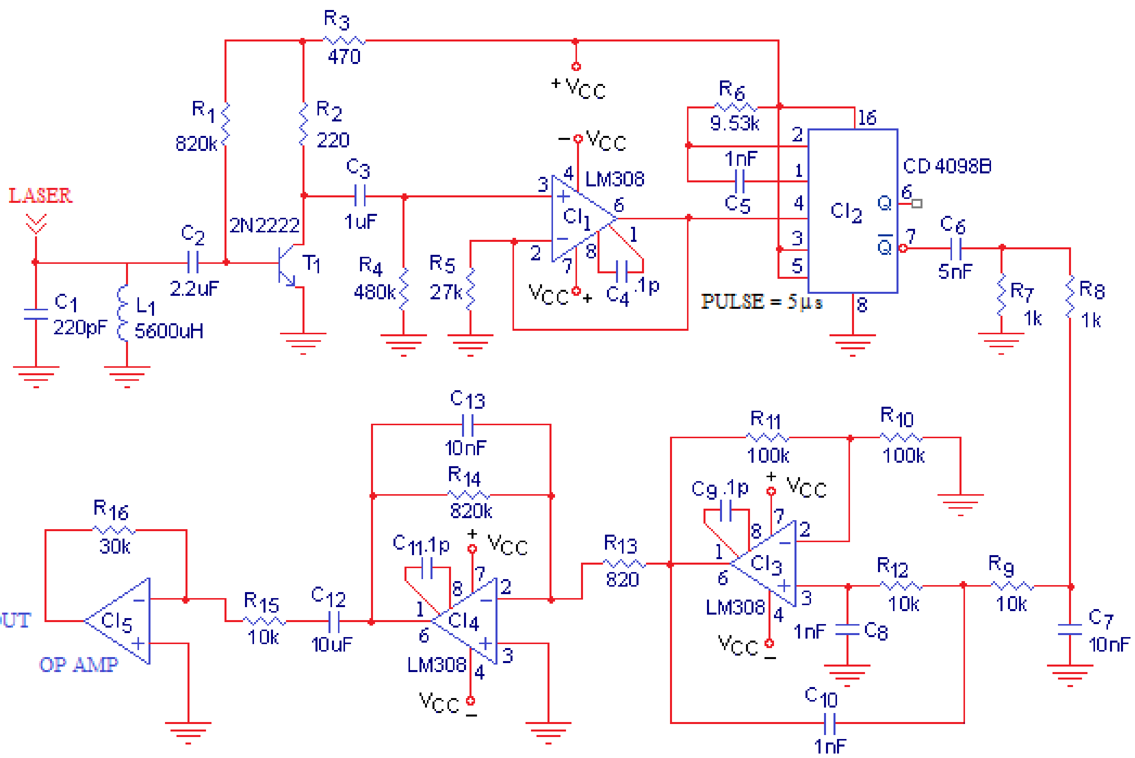

FIG. 2 Optical Receiver SPICE Analysis Scheme

From the analysis carried out, it is observed that the cut-off frequency of the filter passes down is *16kHz*, and the integrator circuit (CI14) achieves an attenuation of the input signal by *20dB/dec*, in the frequency band *20Hz... 16kHz*. Figures 3...6 show the waveforms for: the signal at the optical receiver input (blue), the signal from the band boost output (red), the signal from the $\overline{Q}$ monostable output (green) and for the signal from the audio amplifier output (yellow), for an input signal $V_{AMPL} = 200mV$, at frequencies of *16kHz*, *10kHz*, *5kHz* and *2 kHz*.

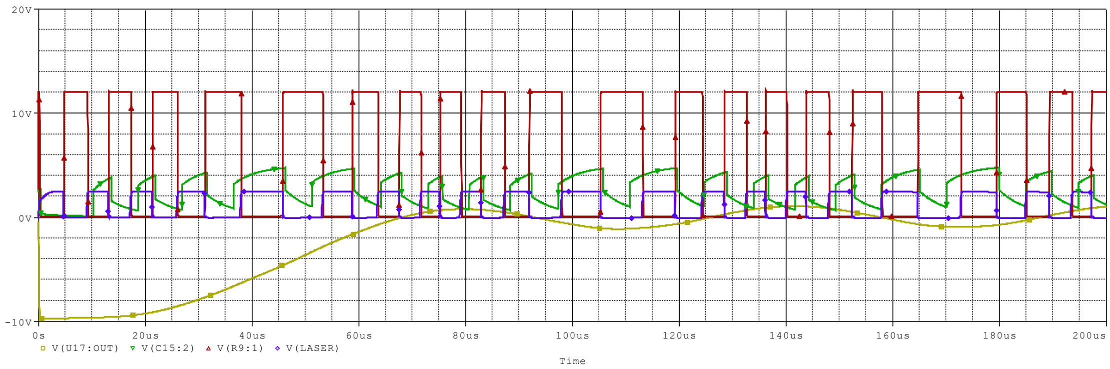

FIG. 3 Waveforms for $V_{AMPL} = 200mV$, $f = 16kHz$

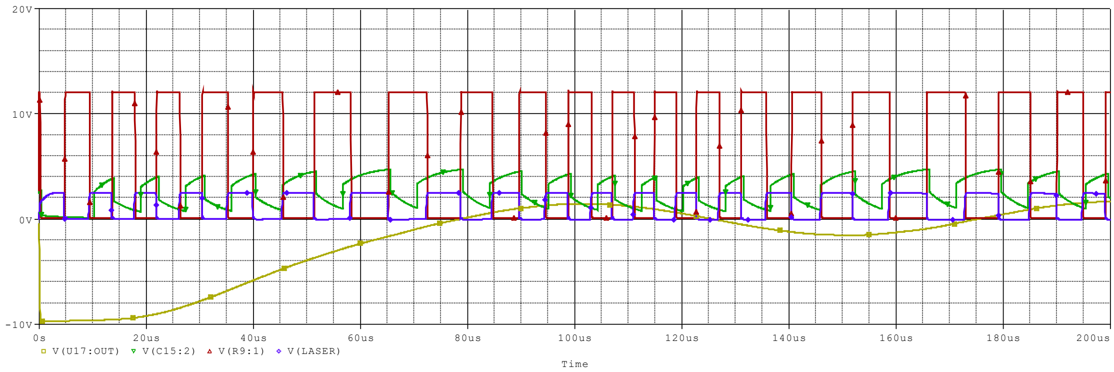

FIG. 4 Waveforms for $V_{AMPL} = 200mV$, $f = 10kHz$

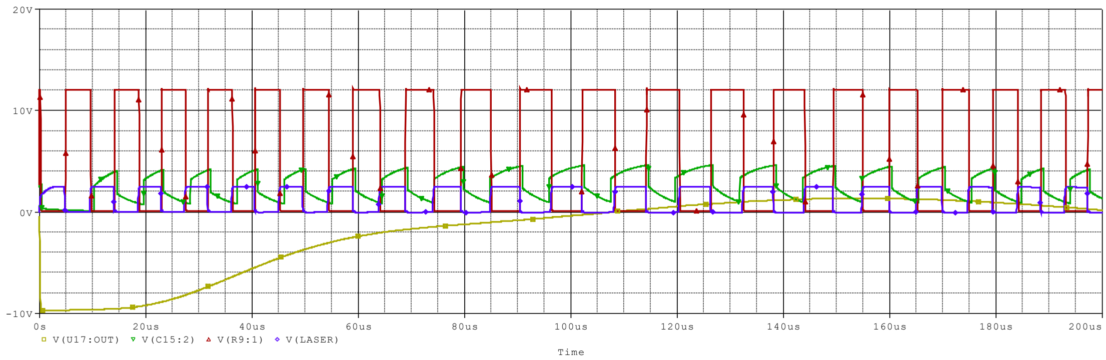

FIG. 5 Waveforms for $V_{AMPL} = 200mV$, $f = 5kHz$

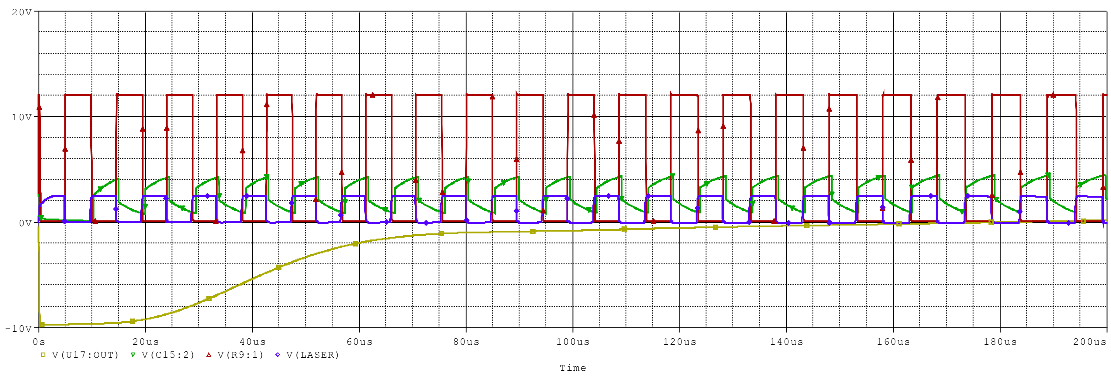

FIG. 6 Waveforms for $V_{AMPL} = 200mV$, $f = 2kHz$

It is observed that the signal from the output $\overline{Q}$ of the monostable has a fixed duration of $5\mu s$, the monostable being controlled on each positive front of the signal from the output of the band amplifier. The frequency of the signal obtained at the output of the monostable is variable (*70kHz... 130kHz*), depending on the frequency of the audio signal from the line amplifier input (*VAMPL).*

Figure 7 shows the comparative signals from the FTJ output (CI3) (green) and the output of the frequency attenuation circuit (CI4) (red), for a frequency of *10kHz* and an audio signal amplitude of *200mV*. Figure 8 shows the comparison of the input audio signal ($VAMPL = 200mV$) (blue) with the frequency of *10kHz* and the signal from the output of the audio amplifier (CI5) (red). It is observed that the output signal follows the input signal, having the same frequency.

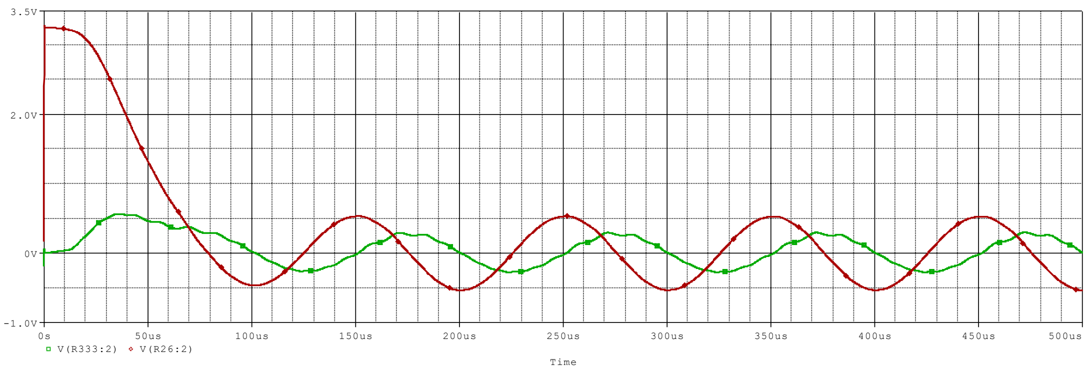

FIG. 7 The signals at the output CI3 (FTJ) and CI4 (integrator) for $V_{AMPL} = 200mV$, $f = 10kHz$

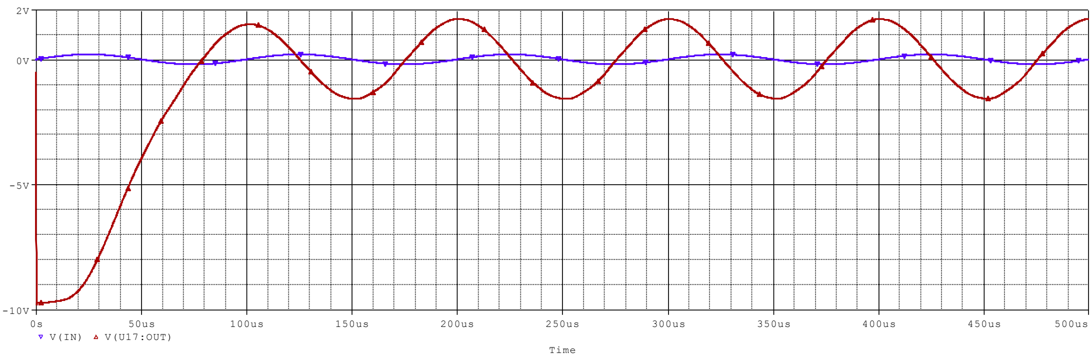

FIG. 8 The audio signal from the input of the laser transmitter [8] and the audio signal from the output optical receiver, for $f = 10kHz$

Figures 9 and 10 show the signals from the line amplifier output (blue) and the audio amplifier output (red), for $f = 16kHz$ and $f = 5\ kHz$.

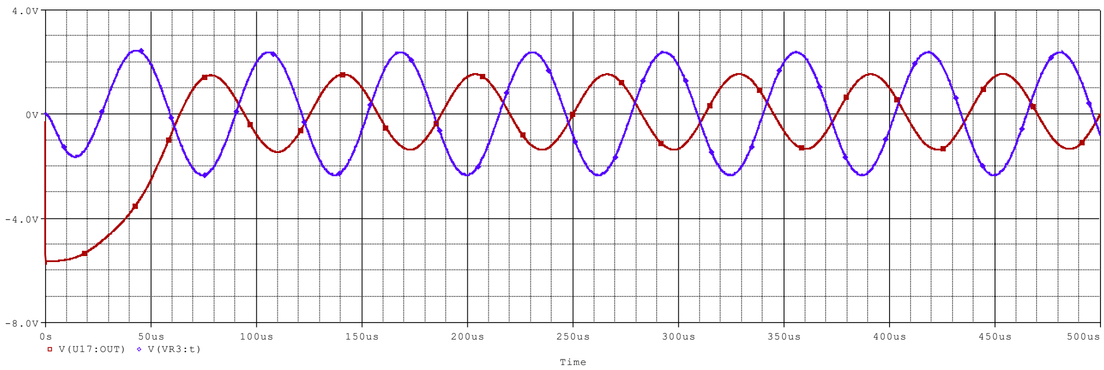

FIG. 9 Output signals – line amplifier and audio amplifier, for $f = 16kHz$

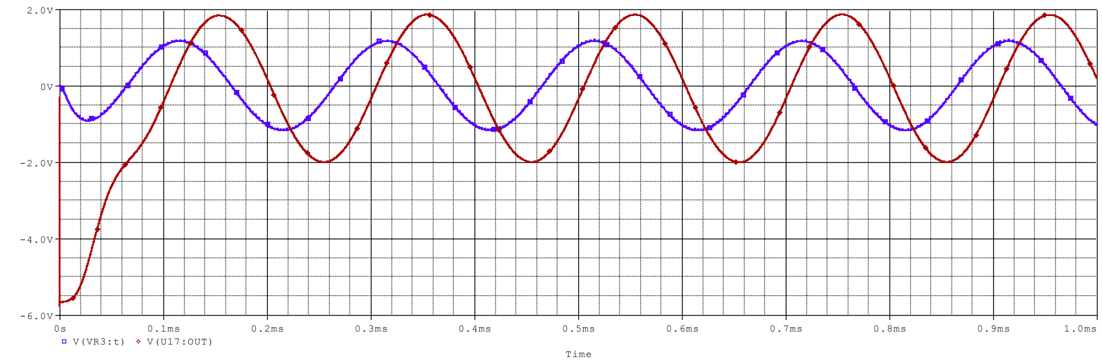

FIG. 10 Output signals – line amplifier and audio amplifier, for $f = 5kHz$

Figure 11 shows the signals from the line amplifier output (red) and the audio amplifier output (blue) simultaneously, for two frequencies of the audio signal, $f_1 = 2kHz$ and respectively $f_2 = 20kHz$.

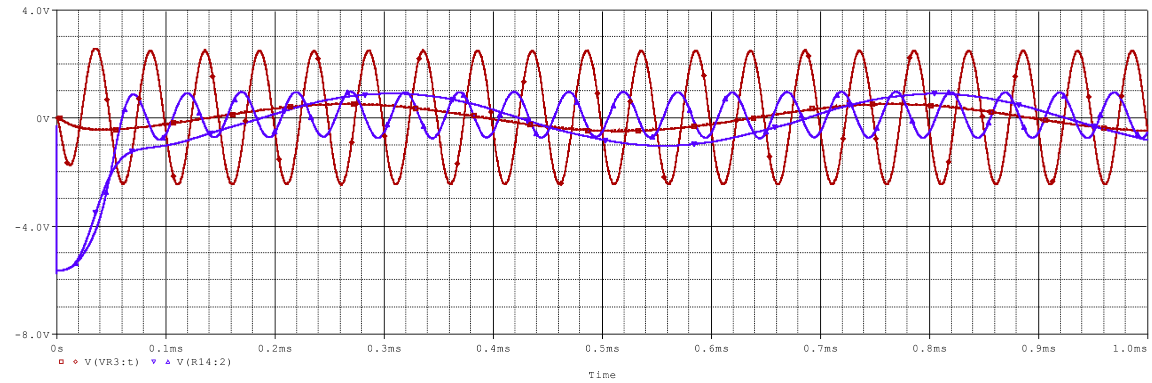

FIG. 11 Output signals – line amplifier and audio amplifier (optical receiver)

CONCLUSIONS

The frequency-modulated (FM) signal is demodulated using direct detection via a low-pass filter, with a cutoff frequency equal to the maximum frequency of the modulating audio signal. Since the information is conveyed through variations in frequency, the demodulation process involves converting these variations into a signal of constant amplitude. The filter effectively suppresses high-frequency components, allowing the recovery of the original baseband signal.

A key advantage of frequency modulation lies in its inherent noise immunity. As long as the amplitude of the received signal exceeds that of the noise, the detection process—based on amplitude limiting—suppresses amplitude-related noise, thereby improving the signal-to-noise ratio. The limiter ensures that the amplitude of the detected signal remains constant, further enhancing robustness against interference.

SPICE simulations confirm that the signal at the output of the audio amplifier (in the optical receiver) closely matches the frequency content of the original audio signal applied to the input of the laser transmitter [8]. The results indicate a short transient response, with the system stabilizing within a duration below $300\mu s$.

A slight time delay $35\mu s$ is observed between the input and output audio signals, which is attributed to the cumulative time constants of the analog processing circuits within both the transmitter and receiver subsystems.

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DESIGN AND EXPERIMENTAL EVALUATION OF AN ION WING PROTOTYPE

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DOI: 10.19062/2247-3173.2025.26.12

Abstract: *Ion propulsion, traditionally utilized for adjusting satellite and space station trajectories, also holds considerable promise for aeronautical applications. This paper explores the viability of an ionic wing designed to ionize atmospheric air using a grid-based system thus eliminating the necessity for external gases such as xenon. The proposed wing features a rectangular configuration equipped with multiple grids, enabling selective application of electrical voltage to facilitate controlled tilting and directed flight maneuvers. Preliminary propulsion calculations are presented, linking voltage requirements to achievable speeds and the resulting thrust. These findings contribute to developing an aircraft model capable of self-propulsion without reliance on fossil fuels, highlighting the potential to replace conventional kerosene-based propulsion with simpler, more cost-effective, and environmentally sustainable alternatives.*

Keywords: *Aerospace, ionic wind, ionic wing, ionic interferences*

1. INTRODUCTION

The ionic wing represents a complex propulsion system composed of multiple grid-based subsystems. Its conceptual development is grounded in both theoretical and experimental contributions of Jack Wilson (ASRC Aerospace Corporation, Cleveland, Ohio), as well as Hugh D. Perkins and William K. Thompson (Glenn Research Center, Cleveland, Ohio). The present design iteration incorporates significant optimizations that reflect a reevaluation of the classical ionic propulsion model. [1,2,3,4]

These enhancements primarily involve a reconfiguration of the emitter–collector arrangement. In the traditional setup, the ionic propulsion mechanism utilizes an electrode emitter and an electrode collector. However, in the current study, the collector has been replaced with an anodic element, transforming the system into an anode–cathode configuration. This redesign allows for the ionization process to occur over a distance that is directly proportional to the applied electric potential, thereby enabling more efficient thrust generation. [1,3]

In parallel, the Hall-effect thruster system—specifically, the low-cathode flow fraction configuration developed by Scott J. Hall, Benjamin A. Jorns, and Alec D. Gallimore—has been studied. The analytical framework of this propulsion model supports the development of the grid-type structural architecture for the ionic wing and facilitates the estimation of its power output under defined operational conditions. [1,3]

2. POWER SUPPLY SYSTEM

Li-ion 18650 Rechargeable Cell

The 18650 lithium-ion cell is a highly prevalent energy storage component, frequently utilized in applications ranging from DIY electronics and portable power banks to electric mobility systems. The designation "18650" corresponds to the cell's standardized physical dimensions: 18 mm in diameter and 65 mm in length.

The key electrical characteristics of this cell type include:

- Nominal voltage: 3.7 V
- Maximum charging voltage: 4.2 V
- Minimum discharge voltage: 2.5 V
- Capacity range: 1200 mAh to 3500 mAh
- Discharge current: 1C to 30C, contingent upon the specific model

Among the advantages of the 18650-cell architecture, we find:

- High energy density, enabling compact power systems
- Rechargeability, which enhances cost-efficiency over extended usage periods
- Broad applicability across various technological domains
- However, these benefits are accompanied by notable limitations, such as:

Disadvantages:

- The necessity for protective circuitry to prevent overcharging and deep discharge, which can degrade cell performance
- Sensitivity to high temperatures, which may compromise operational safety
- Risk of catastrophic failure (e.g., thermal runaway or explosion) in cases of mechanical damage or short-circuiting

In order to estimate the discharge time of the battery, the following formula is used:

$$T = \frac{C}{I} \tag{1}$$

Where:

- T is the discharge time (in hours)
- C is the battery capacity (in Ah)
- I is the current draw (in A)

For a battery with a capacity of 2500 mAh (equivalent to 2.5 Ah) and a current consumption of 0.5 A the estimated discharged time is:

$$T = \frac{2.5}{0.5} = 5\ hours$$

This means the battery can theoretically sustain the 0.5 A load for 5 continuous hours under ideal conditions.

FIG.1 Li-ion 18650 Rechargeable Cell

FIG. 2 High-voltage generator module (1000 kV output, 3–6 V input), used in ionic propulsion experiments.

FIG. 3 Alligator clips (crocodile clamps) used for temporary electrical connections in the test circuit.

3. THE IONIC WING (GRID-BASED SYSTEM)

The initial design concept is based on a rectangular wing geometry, specifically configured to house an internal grid-type subsystem. The wing is intended to have dimensions of approximately 24–25 cm in length and 18–20 cm in width, and will be modeled using 3D CAD software. Physical fabrication will subsequently employ materials such as cardboard or lightweight composites, in combination with adhesives and modular joining elements to facilitate assembly.

The grid system itself is composed of several smaller independent grid units rather than a single centralized propulsion unit. This modular architecture enables greater directional control by adjusting the electric potential of individual grid elements, allowing localized thrust vectoring. While this approach introduces added complexity in terms of voltage regulation and distribution, it offers a significant performance advantage in terms of control authority over the wing's orientation and flight path.

First Iteration of Grid System Design (3x3 Configuration)

3D CAD Model Development

For the initial prototype, a unit composed of a 3×3 grid configuration was proposed. The base structural component of the grid was modeled using 3D CAD software with the following dimensions:

- Length: 119 mm
- Width: 40 mm
- Each unit features three slots, each with a width of 1 mm and length of 15 mm, as illustrated in Fig. 4.

These slots are designed to house the high-voltage electrode elements necessary for ionic generation, while maintaining a modular layout that facilitates experimentation with various grid configurations.

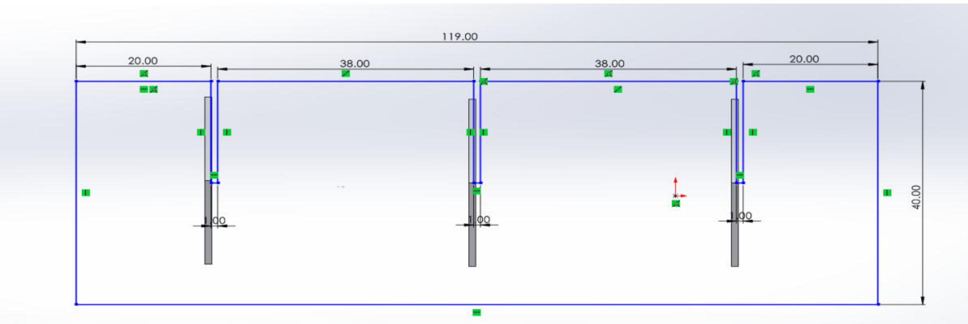

FIG.4 Lateral view grid configuration

Using the Boss-Extrude feature, the component was given a thickness of 1 mm, as illustrated in Fig. 5.

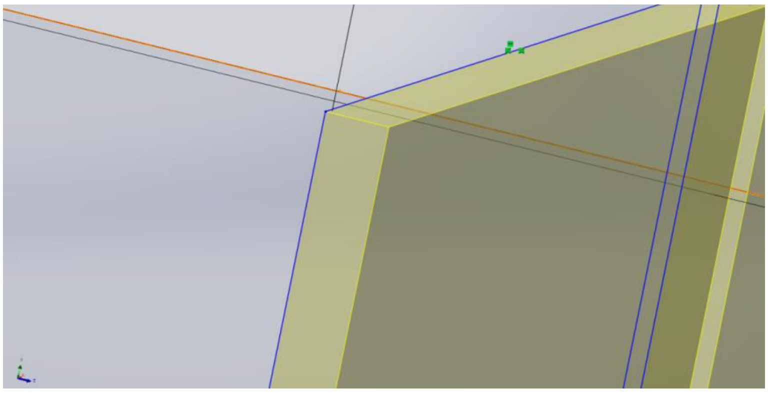

FIG.5 Grid rib width

For the second component, the following dimensions were selected:

- A width of 30 mm
- A base length of 119 mm
- A top surface length of 99 mm

All parts will be replicated three times and assemble together, as shown in Fig. 6.

Additionally, three slots were created, each with a thickness of 1 mm and a length of 15 mm, to accommodate the insertion of grid elements Fig. 7.

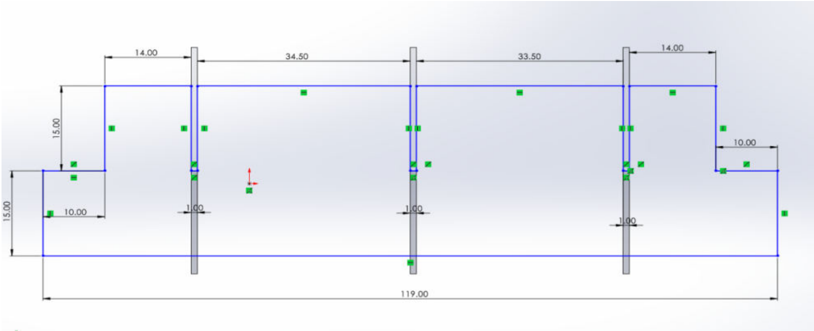

FIG.6 Lateral view of the grid assembly

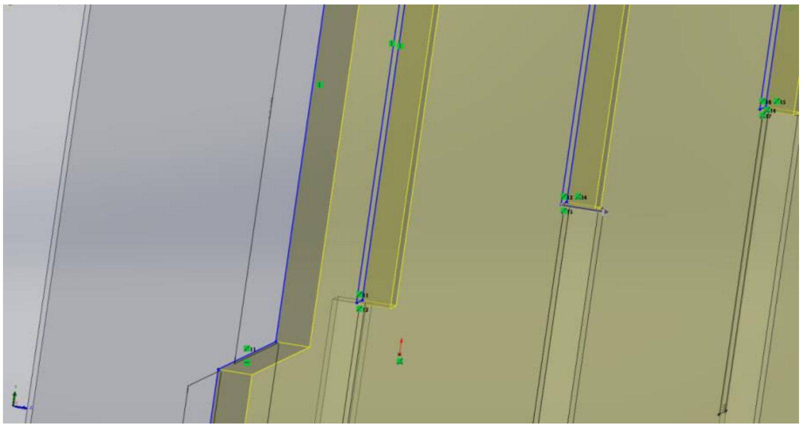

FIG.7 Grid slots designed for assembly

In the next stage, all the designed components were integrated into an assembly environment, where the final 3×3 grid system was mounted together, as illustrated in Fig. 8.

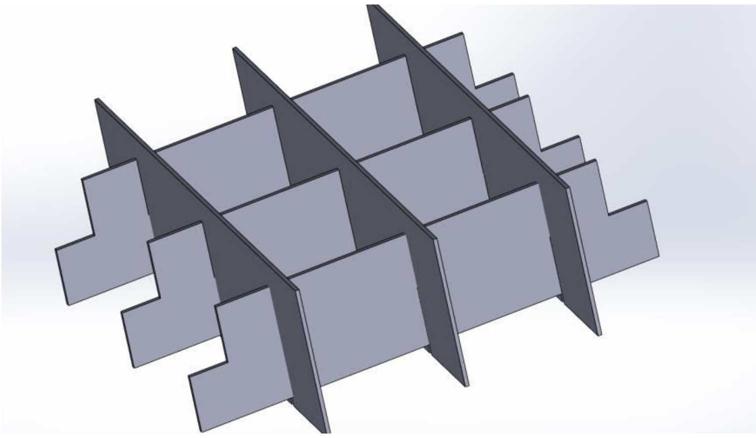

FIG.8 Base structure of the grid unit for the ionic wing

4. PHYSICAL CONSTRUCTION OF THE 3×3 GRID SYSTEM PROTOYPE

The ribs were fabricated from 280 g/m² cardboard sheets with an approximate thickness of 1 mm, as shown in Fig. 9. The dimensions were directly extracted from the CAD assembly. The fabrication process involved tracing the outlines using a 0.8 mm marker, ensuring alignment with a ruler, and manually cutting the components with scissors.

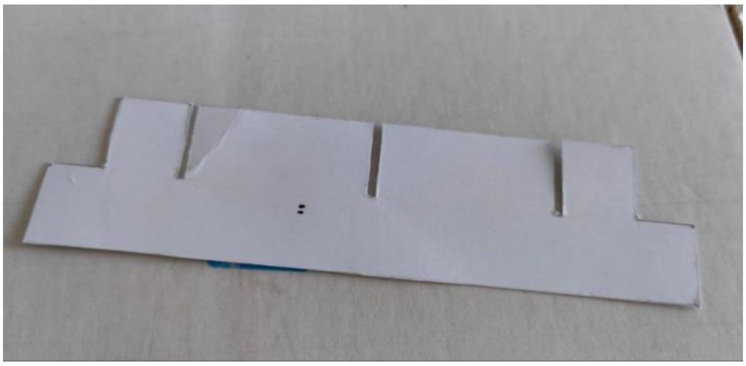

FIG.9 Grid rib

Once all the ribs were fabricated, aluminum foil was cut using the pre-marked template piece, as illustrated in Fig. 10. The cutting process was carefully executed to maintain a consistent gap of approximately 0.8–0.9 mm, a parameter considered critical for achieving optimal air ionization within the grid system.

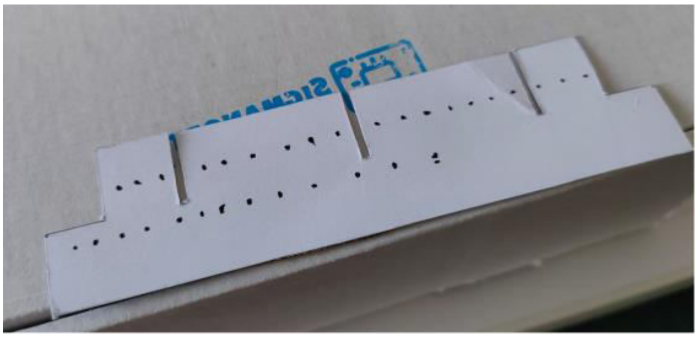

FIG.10 Grid rib with wire holes

Following the cutting of the aluminum foil according to the template markings, polyvinyl acetate (PVA) adhesive was applied to securely bond the foil to the surface of the component, as illustrated in Fig. 11 and Fig. 12.

FIG.11 Grid gluing proces

Upon completion of the previous steps, the component is fully assembled, as illustrated in Fig. 13.

FIG.12 Attaching the aluminum foil to the grid rib

FIG.13 Grid ribs with aluminum foil attached

After covering the components with aluminum foil within the defined limits—ensuring a spacing of 0.8–0.9 cm between the two extremities—the elements were assembled to form the final product, representing Iteration 1 of the grid-type system, as illustrated in Fig. 14.

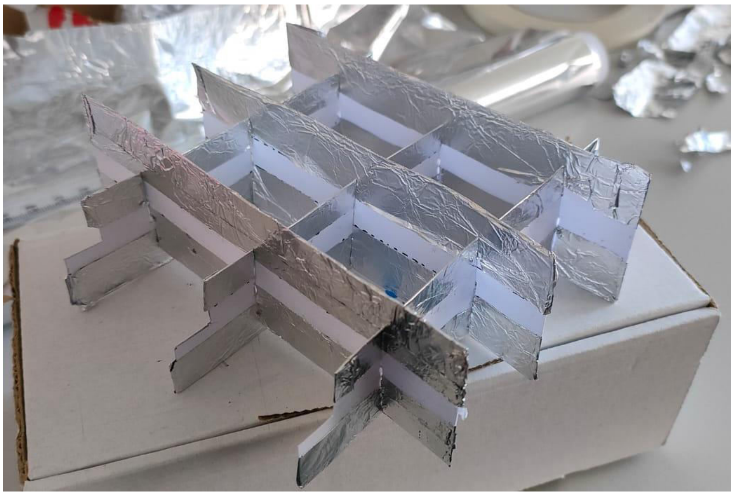

FIG.14 Final assembly of ionic wing module

5. DEVELOPMENT OF THE GRID SYSTEM – SECOND ITERATION (6×6 CONFIGURATION)

3D Modeling

To increase the number of active ionization zones while maintaining optimal spacing that prevents electrical arcing, a 6×6 grid configuration was selected. This design enables the creation of smaller and more numerous square/rectangular cells, improving overall ionization control.

The following dimensions were established for the base component, which was replicated six times to complete the structure:

- Length: 119 mm;
- Width: 40 mm;

As shown, each unit includes six slots, each with a width of 1 mm and a length of 15 mm, spaced at 16.14 mm intervals.

The construction process followed the same steps used in the previous (3×3) iteration up to the point of physical manufacturing. The goal of this iteration is to develop a more structurally refined model with enhanced air ionization potential, thanks to the increased number of active electrodes and improved spatial distribution.

6. PHYSICAL FABRICATION OF THE 6×6 GRID SYSTEM

Due to the reduced dimensions and increased complexity of the 6×6 configuration, the decision was made to fabricate the component using 3D printing technology. The printing material selected was PLA (Polylactic Acid), with the following printer settings:

- Extruder Temperature: 230 °C;
- Build Plate Temperature: 60 °C

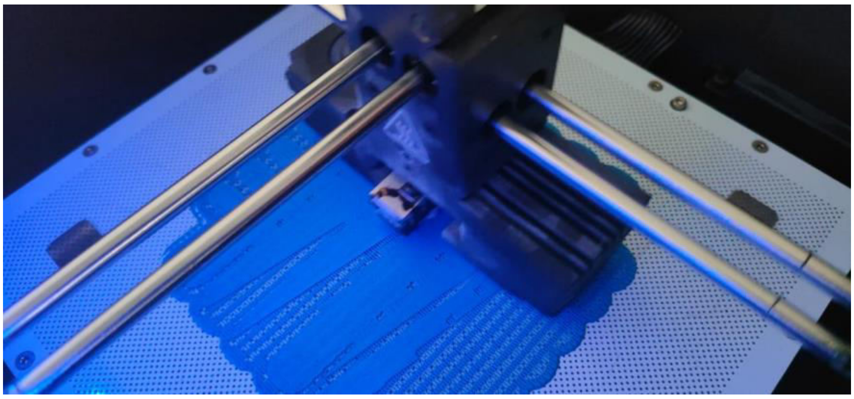

FIG.15 Printing the new grid unit

The component was processed on a 3D printer with a total print time of 13 hours and 30 minutes, as shown in Fig. 15 and Fig. 16.

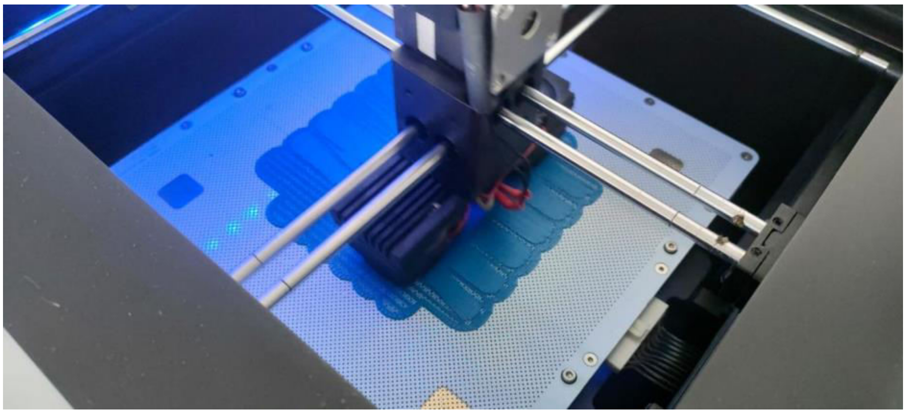

FIG.16 Intermediary steps on printing the new grid unit

The component was completed following the pre-set 3D printing program with a total duration of 13 hours and 45 minutes, as illustrated in Fig. 16 and Fig. 17.

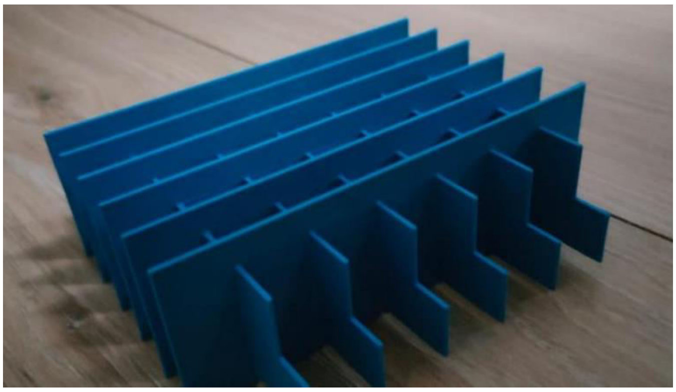

FIG.17 The new printed grid unit

7. FINAL SURFACE TREATMEANT AND OPTIMIZATION STRATEGY

With the grid model completed, two surface treatment approaches are considered to ensure proper conductivity and maintain the critical 0.8–0.9 cm ionization gap. The first option involves applying a conductive paint, while the second involves placing copper adhesive tape along the designated paths.

Should further optimization be required, a revised structural approach is proposed: perforating the grid structure and, based on experimentally determined optimal spacing, routing copper wire along both the top and bottom surfaces. This would result in a revised electrical network configuration, different from the initial iteration, potentially improving performance and efficiency.

CONCLUSION

Based on multiple experimental iterations, the system demonstrated structural adaptability under consistent voltage conditions. A key observation is that electrical concentration points significantly influence the effectiveness of air ionization. Additionally, it became evident that alongside geometric optimization, the integration of a parallel-distributed internal grid system enhances the overall thrust generation capability.

Furthermore, future iterations will incorporate a voltage regulation system, which is expected to provide a broader range of performance data. Varying the input voltage will be essential in exploring the optimal distribution and directional control potential of the ionic wing.

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DESIGN OPTIMIZATION USING FEM FOR A CARGO FLOOR STRUT

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DOI: 10.19062/2247-3173.2025.26.13

Abstract: *This paper presents an applied study for topological optimization, a modern engineering design technique that aims to optimally distribute the material in a given area, in order to obtain a structure that is as light and mechanically efficient. The first part of the paper analyzes the general concepts of topological optimization, such as the basic principles, common constraints and objective criteria used in engineering applications. The case study focuses on an aircraft cargo floor strut, a structural element frequently encountered in aeronautical applications. The optimization was performed using the OptiStruct solver developed by Altair Engineering, which offers advanced structural analysis and optimization capabilities. The pre-processing and boundary condition definition steps were performed in HyperMesh, while the analysis of the results and visualization of the optimal material distribution were performed with HyperView. The obtained results demonstrate a reduction in the mass of the component, while maintaining structural performance within the specified limits, thus validating the efficiency of the method used in the optimized design process.*

Keywords: *topology, strut, optimization, finite element method, stress*

1. INTRODUCTION

In recent years, the aerospace industry has witnessed a transformation in the design and manufacturing methods of structural components. The main goals related to weight reduction, efficiency and improved structural performance have led to the adoption of advanced design optimization techniques, especially in the conceptual phase of product development. Among these methods, topology optimization has emerged as an essential tool in modern engineering [1].

The topological optimization is a computational method that aims to determine the optimal distribution of material in a given area, in order to meet objectives such as maximum stiffness, minimum mass or a certain safety factor [2]. Unlike traditional shape optimization methods, which operate on a predetermined geometry, topology optimization does not assume a fixed initial shape, but allows for the achievement of innovative and efficient configurations, often impossible to imagine by classical means [3]. This approach is increasingly used in the design of aerospace components due to its ability to reduce the mass of structures without compromising mechanical performance.

This paper analyzes a practical example of the application of topological optimization in an aerospace context: the design of a cargo floor strut (Fig. 1), a structural component in supporting the floor of an aircraft cargo compartment. This type of element is subjected to significant mechanical loading and has an important role in transferring loads from the floor to the fuselage [4].

Therefore, optimizing its weight can contribute to reducing the total mass of the aircraft and, implicitly, increasing flight efficiency.

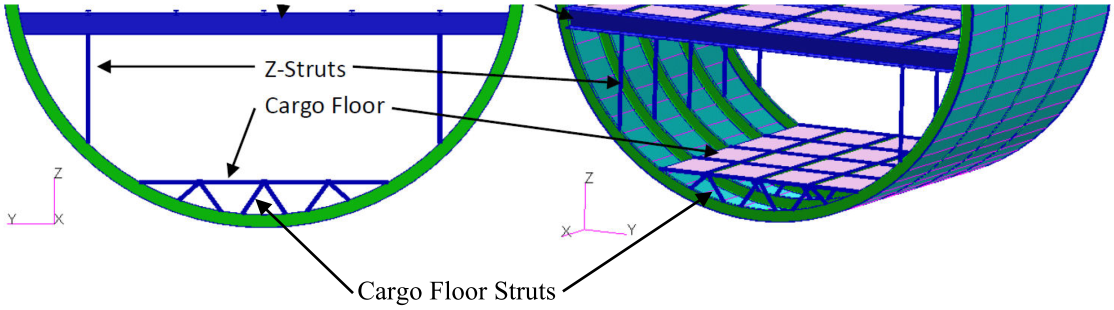


FIG. 1 Cargo Floor Strut fixing the Cargo Floor Crossbeam on the Aircraft Frames.

The analysis was done in the Altair HyperWorks software package. HyperMesh was used for pre-processing: definition of the geometric model, discretization of the domain with finite elements and application of relevant boundary conditions. Optimization was executed with OptiStruct, a specialized solver for structural analysis and optimization, which allows obtaining the material distribution based on specified criteria [5]. Post-processing was carried out in HyperView, for analyzing the numerical results and visualizing the optimized model, highlighting the areas of interest from a structural point of view.

One of the goals of this paper is to demonstrate the applicability of the topology optimization method in the real design of an aerospace component, as well as the integration of this method into the digital engineering development chain. The results are also interpreted in the context of manufacturing possibilities, taking into account technologies such as 3D metal printing – a technology increasingly present in the aerospace sector due to its compatibility with optimized geometries [6].

The present study exemplifies the benefits through a concrete case, in which simulations are used to obtain a functional design, optimized and compatible with modern manufacturing methods.

2. STRUCTURAL OPTIMIZATION METHODOLOGIES

Computer-aided design (CAD) and Finite element method (FEM) have experienced an accelerated development with the advancement of optimization methods, which allow to obtain mechanically, economically and functionally efficient configurations. In the aerospace engineering, where mass reduction and stiffness increase are essential priorities, structural optimization methods are used at all stages of the product development process.

2.1 Types of structural optimization methods. Structural optimization methods are classified according to the level of freedom offered in modifying the shape or material of the structure. The most common categories are:

- size optimization – adjusts the cross-sectional dimensions (thicknesses, heights, etc.) of existing components to meet certain requirements (e.g. minimum mass, maximum allowable deformation) [7].

- shape optimization – modifies the geometric contour of a structure while maintaining topological connectivity (e.g. rounding corners to reduce stress concentrations) [8].

- topological optimization – allows the complete addition or removal of material within the structural domain, without initial constraints related to geometry. It is the most flexible and innovative method, used in the conceptual phases of design [1].

2.2 General principles of topological optimization. Topological optimization aims to determine the ideal distribution of material in a given space in order to maximize structural performance under the defined constraints. The problem is mathematically formulated as an objective function (e.g. maximum stiffness or minimum mass) under mechanical (displacements, stresses), geometric and technological constraints [9].

A classic approach is the SIMP (Solid Isotropic Material with Penalization) method, which involves relaxing the binarity of the material (0 – empty, 1 – full) by introducing a continuous density that varies between 0 and 1. The penalty has the role of forcing the solution towards binary values, avoiding areas of “ghost” material [10].

This method has been successfully extended to complex engineering problems, including in the aeronautical field, offering new shapes of components, adapted for additive manufacturing. Its advantages include: reduction of the mass of components by up to 30–50% without compromising strength, adaptability to various types of loads (static, dynamic, vibrations), possibility of integration into modern manufacturing flows (e.g. 3D printing) [11].

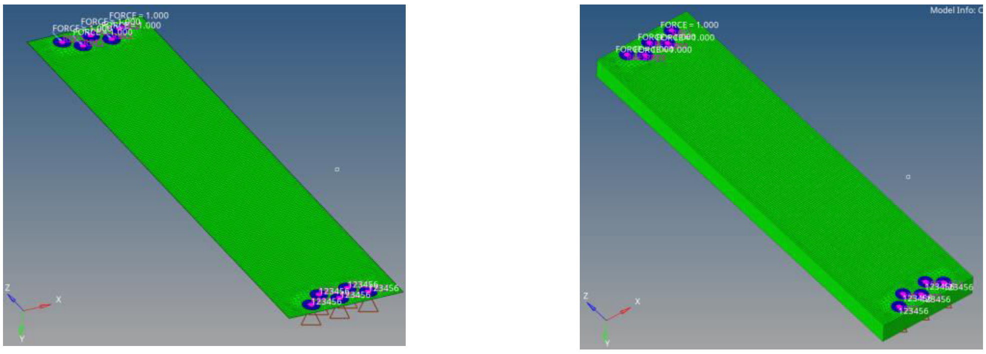
However, topological optimization also presents some challenges, such as the interpretation of numerical solutions, the generation of the post-processed geometry and the technological limitations associated with manufacturing.

2.3 Application of the method in Altair HyperMesh and OptiStruct. In this paper, the topological optimization was performed using the Altair HyperWorks software suite, more specifically the modules HyperMesh (for generating the finite element meshing, defining material properties and applying boundary conditions and loads), OptiStruct (solver for the structural analysis and calculation of the optimal material distribution within the defined volume), HyperView (for visual interpretation of the results and verification of the structural behavior of the optimized solution) [12]. The SIMP method is used to obtain a well-defined solution [13].

The resulting shape can be subsequently used for CAD reconstruction and preparation for manufacturing using light metal alloys [14].

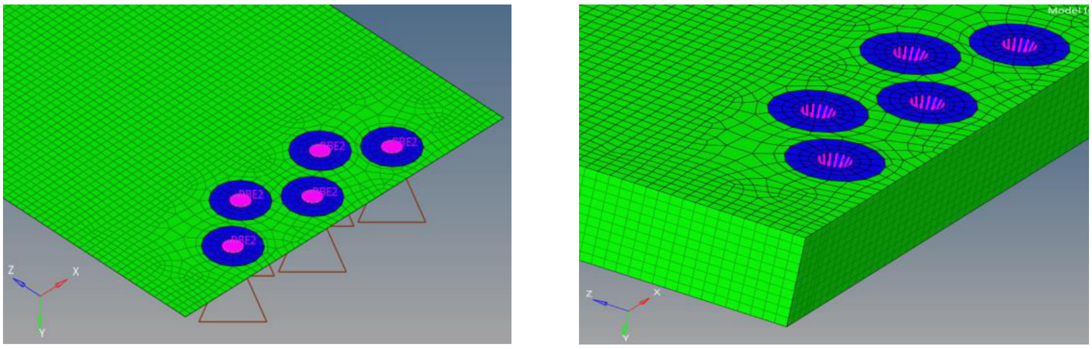
3. STRUCTURAL ANALYSIS, VALIDATION AND COMPARISON OF MODELS

To validate the topology optimization method applied in the design of a cargo floor strut, two separate models were developed and analyzed – one two-dimensional (2D) and one three-dimensional (3D), as presented in Fig. 2 a) and b).



a) 2D model with Shell elements   b) 3D model with tetrahedral elements

FIG. 2 Models used for the topological optimization of the cargo floor strut.



a) 2D model with Shell elements   b) 3D model with tetrahedral elements

FIG. 2 (CONT.) Models used for the topological optimization of the cargo floor strut.

These were compared with two additional models (one with 2D shell elements and one with 3D tetrahedral elements), based on the real geometry of a strut used in industry. Figure 3 presents the sectional geometry of the real strut. The height of the extrude U profile is 400 mm.

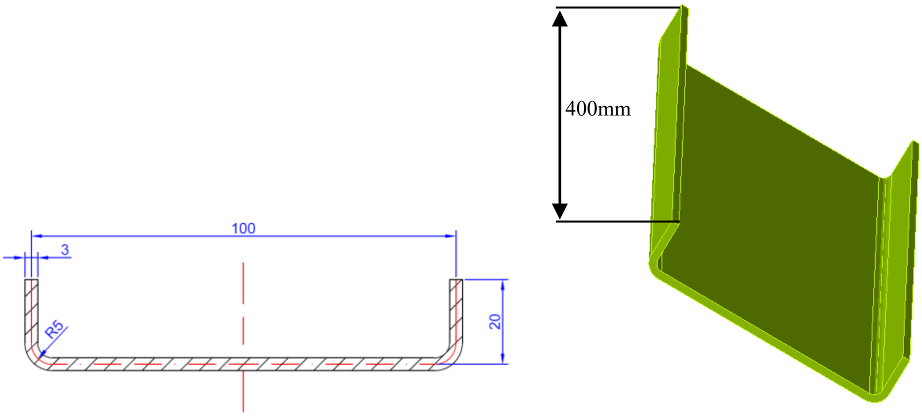


FIG. 3 Sectional geometry (U section) and extruded profile of the real cargo floor strut.

For the additional base models, for the one with 2D elements, the discretization was done on the middle surface, while the 3D model is done with a solid volume (an extruded profile). All models have the same geometry for the holes, located as presented in the 3D model of the real part, as shown in Fig. 4. In all models, around the hole was created a region to account for bearing stresses. This region will remain as is and is not part of the design space that is being optimized.

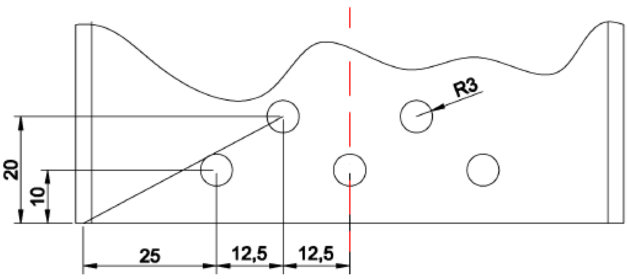
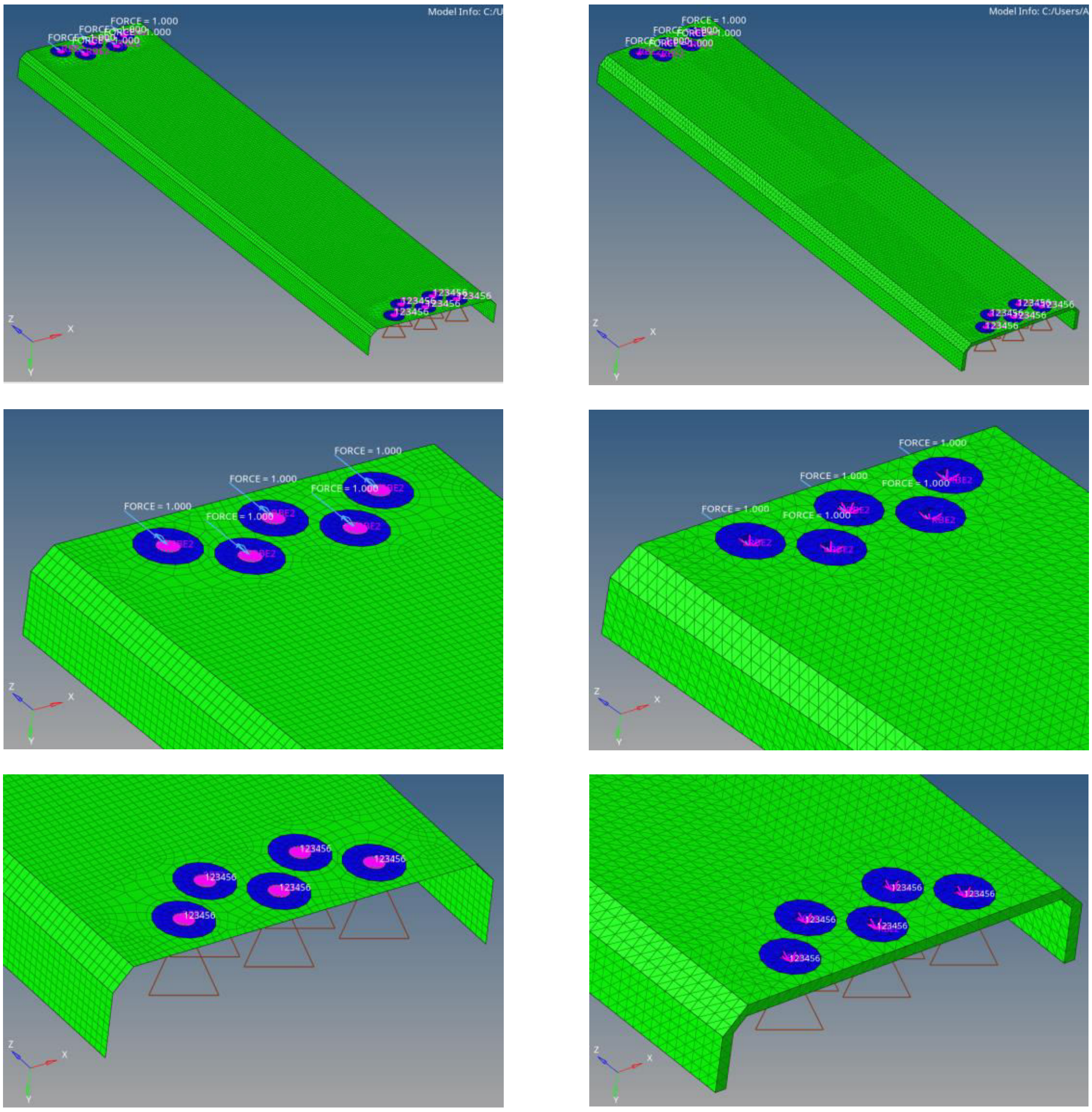


FIG. 4 Fastener holes location and geometry.

The purpose of this multiple analysis is to evaluate the mechanical behavior of the optimized shape and to identify the performance differences between the algorithmically generated solution and the classical component.

Figure 5 presents the two base models (real part model) of the cargo floor strut (one with 2D elements and the other with 3D elements).



a) 2D model with Shell elements b) 3D model with tetrahedral elements

FIG. 5 Base (real part) models of the cargo floor strut.

3.1 Description of the analysis domain and boundary conditions. The design volume, common to both the 2D and 3D models, consists of a rectangular plate with dimensions: length 400 mm, width 100 mm and thickness 50 mm. This volume was considered as the initial structural domain for optimization. Circular holes were defined in the upper and lower areas of the plate that simulate the attachment points with the rest of the structural assembly of the aircraft fuselage: cargo floor crossbeam (at the upper side) and frame (at the lower side) [15].

The fastening system at each extremity involves two rows of bolts, one with 3 and another one with 2 bolts. These were modeled for boundary conditions. The applied load is a 25kN vertical force plus a 2.5kN lateral force distributed between the upper 5 fasteners, simulating the pressure transmitted by the weight of the cargo during the operation of the aircraft. The lower 5 bolts are used to fix the model in all six degrees of freedom.

3.2 Description of the models. The 2D model was created in Altair HyperMesh by discretizing the design volume in a mid-thickness plane, using shell-type planar finite elements. This model allows for a fast preliminary analysis, with a reduced consumption of computational resources. The uniform thickness of 50 mm was considered constant at the beginning of the optimization analysis, and the loads and constraints were applied in the corresponding 2D plane [16].

The topological optimization was applied directly on the two-dimensional domain, resulting in an optimal material distribution, with full preservation of the clamping and loading zones. The optimized model was subsequently subjected to a linear static analysis to determine the maximum deformations and stresses.

For a realistic simulation, a three-dimensional model was also created, using tetrahedral solid elements. This provides a complete representation of the stress distribution in the volume, essential for the evaluation of the parts subjected to applied loads. In this case, the working volume was completely discretized, and the topological optimization was carried out in the same domain, using the SIMP method implemented in the OptiStruct solver [17].

Compared to the 2D model, the three-dimensional simulation involves a considerably longer calculation time, but provides much more detailed results, especially in the stress concentration areas around the clamping holes.

The separate 2D and the 3D models of the cargo floor strut are meshed with an appropriate mesh density to correctly capture stress variations. The support conditions corresponding to the real-world fastenings were applied, and the applied load was defined as a force distributed at the upper side fasteners, simulating the weight of the cargo transmitted through the cargo compartment floor.

To validate the results obtained from the topological optimization, the 2D and the 3D base models are used, representing the geometry of a real strut with a classical U cross-section. These models were analyzed under the same loading and fixing conditions. The comparison was made in terms of the following parameters: mass, stress distribution, deformation [18].

OptiStruct allows the definition of design regions (optimizable areas) and non-design regions (areas that cannot be modified, such as fastening points). A minimization of mass objective was used, with a stress constraint of maximum 300 MPa.

3.3 FEM Results. The optimization results were analyzed in HyperView. The material density distribution showed the formation of an internal reticular structure, indicating a mass reduction without loss of stiffness. The material concentration areas correspond to internal force paths.

In the following figures 6 to 13, the results for all 4 models are presented:

- Base models:
  - the 2D base model
  - the 3D base model
- Optimized models:
  - the 2D optimized model
  - the 3D optimized model.

It is evident that the optimized structures manage to keep the stress flow in a coherent shape, with reduced concentrations and a more efficient use of material.

Note that for the optimized models, the symmetry condition was imposed, since the lateral load can be applied from either side.

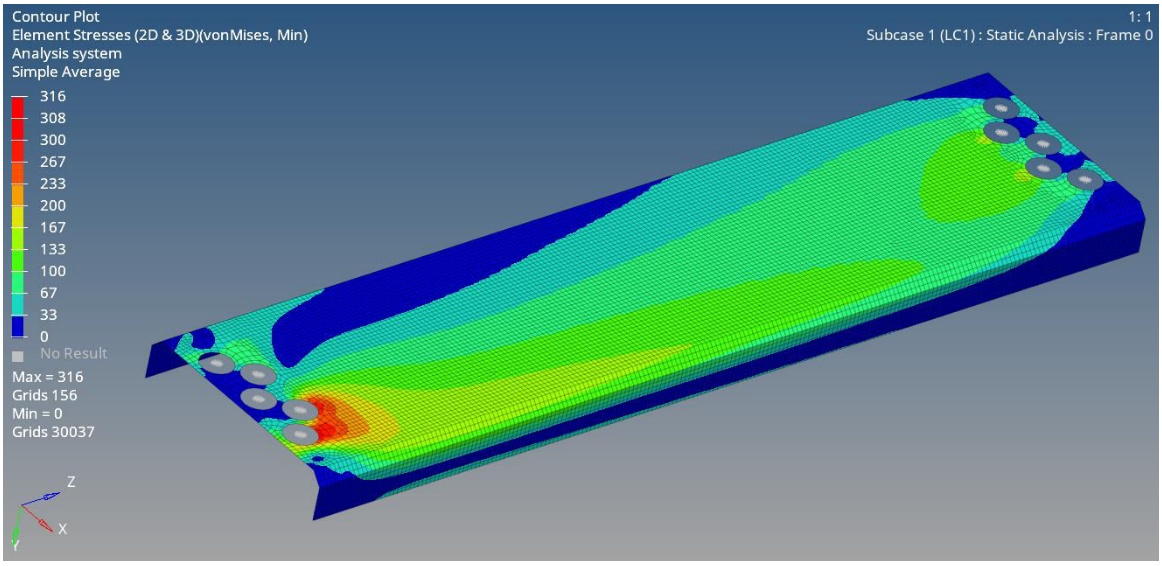


FIG. 6 2D Base (real part) model results – von Mises stress distribution.

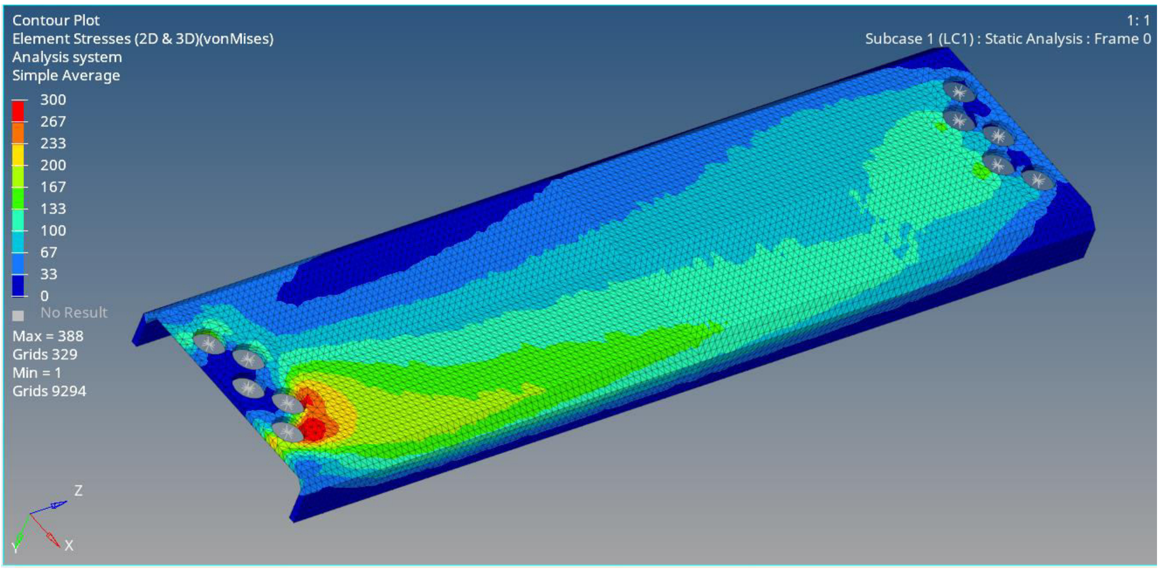


FIG. 7 3D Base (real part) model results – von Mises stress distribution.

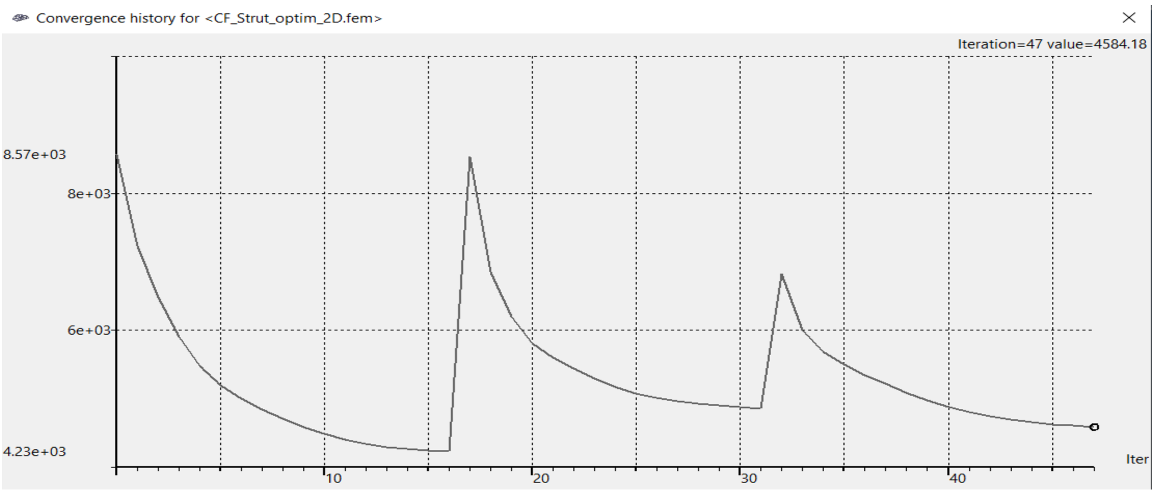


FIG. 8 2D optimization model iteration histogram.

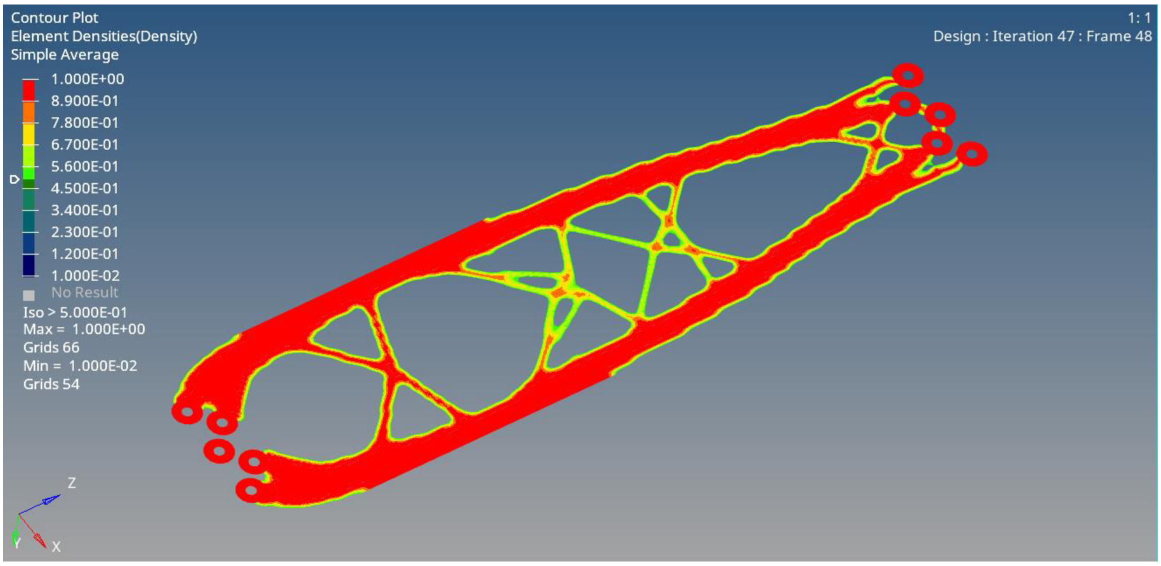


FIG. 9 2D optimization model shape (cut-off at 0.5 element density).

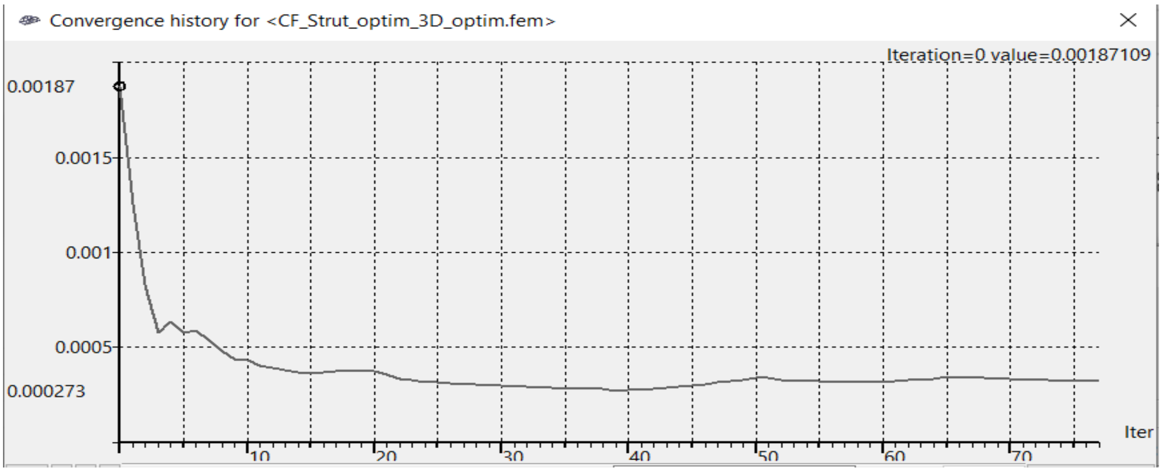


FIG. 10 3D optimization iteration histogram.

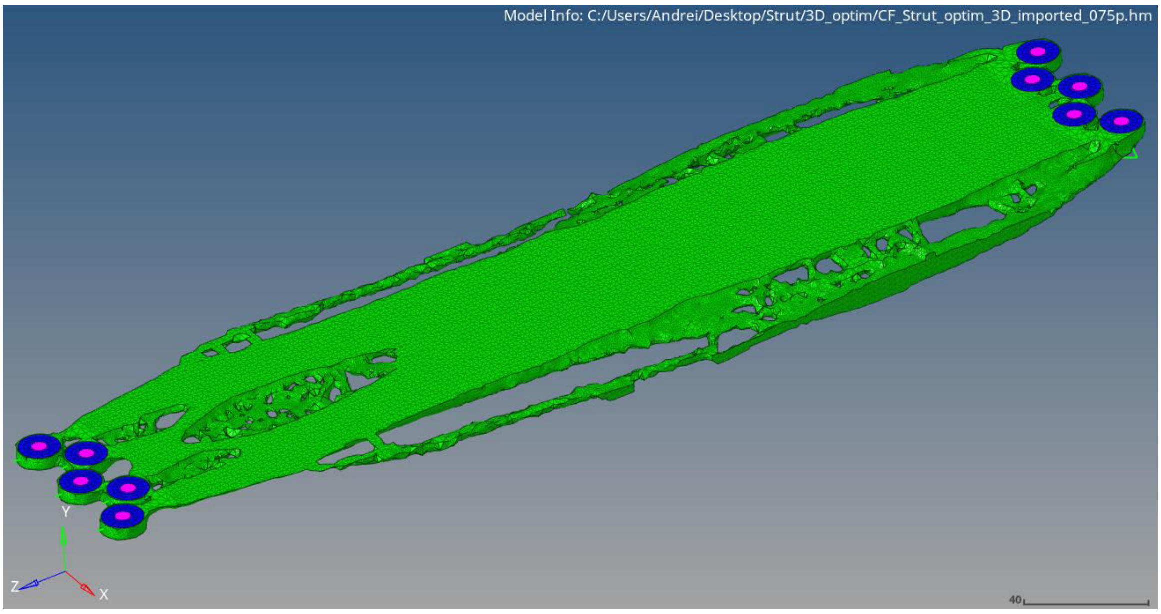


FIG. 11 3D optimization model shape (cut-off at 0.4 element density).

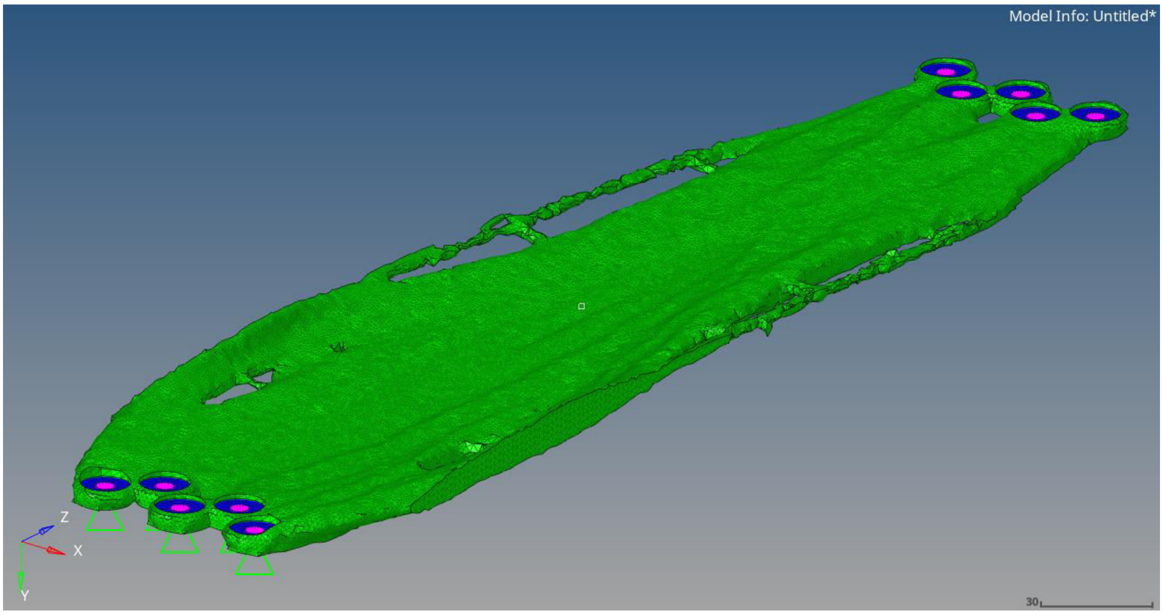


FIG. 12 3D optimization model shape (cut-off at 0.5 element density).

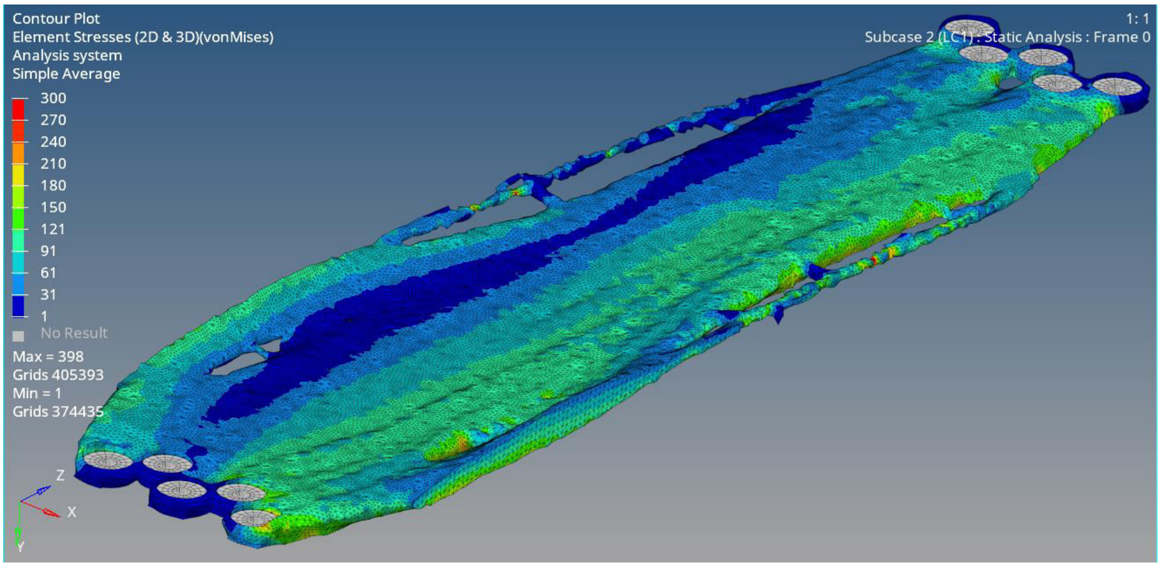


FIG. 13 3D optimization model results – von Mises stress distribution.

The comparative analysis between the two real models (base models) and the two optimized models indicates that the topology optimization method can generate more efficient structural solutions, reducing mass and improving stress distribution. The 3D model provides more accurate and detailed results, but requires more computational resources. The 2D model is suitable for quick assessments and for the early design phases.

4. CONCLUSIONS AND REMARKS

The present study shows the benefit of using topological optimization in the design of lightweight structural components for the aerospace industry, with direct applicability to a cargo floor strut. The chosen method (topology optimization using OptiStruct solver from the Altair suite) permitted the reducing of the mass of components without compromising the mechanical performance.

The 2D and 3D models developed for the simulation demonstrates that by correctly applying constraints, loads and boundary conditions, optimized geometries can be obtained. Comparative results between the optimized models and the real component indicate mass reductions of up to 40-50%, while maintaining the stress distribution and the deformation within acceptable limits. Moreover, the three-dimensional approach has led to more precise and adaptable solutions for subsequent manufacturing.

In the long term, the integration of computational optimization technologies in the initial design phases will lead to significant material, cost and weight savings in complex structural assemblies. Also, the use of these methods allows for an efficient use of the design space, providing new solutions that cannot be achieved by conventional design methods.

In conclusion, the paper demonstrates that topological optimization is a useful solution for improving structural design in aviation.

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STUDY ON THE USE OF 3D PRINTED PARTS FOR AIRCRAFTS AND DRONES

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DOI: 10.19062/2247-3173.2025.26.14

Abstract: *In the last decade it became obvious the need to provide fast manufacturing technologies and to reduce parts costs for the aeronautical industry in general and for the rapidly developing flying drones segment. This demand led to the development of new technologies and materials like CFRP and GFRP composite materials, but also additive manufacturing (3D Printing) using different metallic compounds or thermoplastic materials. In this paper is presented a study related to the possibility of using these new 3D printing materials and technologies in the aeronautical industry (light aircrafts and drones), with emphasis on the reduction of costs versus weight. The main goal of the study is to find if fast printing thermoplastics like ABS, PLA or PETG are acceptable from a design and stress point of view.*

Keywords: *3D printing, additive manufacturing, aircraft, drone, weight, rapid prototyping*

1. INTRODUCTION

Additive manufacturing technologies, commonly known as 3D printing, have revolutionized the way complex technical components are designed and manufactured. Especially in the aerospace industry, where low weight, structural strength and design flexibility are essential, 3D printing technologies have opened up new engineering possibilities [1].

In parallel, the use of aerial drones has seen explosive growth in both commercial and military and research applications. In this context, 3D printing offers major advantages: on-demand production, rapid customization and cost reduction of functional prototypes. This paper aims to analyze the technologies, materials and impact of additive manufacturing on the aerospace industry and the drone field.

2. 3D PRINTING TECHNOLOGIES USED IN THE AEROSPACE INDUSTRY

The main technologies used in the manufacture of aerospace components by 3D printing are described in detail, each method being analyzed from the perspective of operating principles, compatible materials and specific areas of applicability. Also, for a complete understanding, the advantages offered by each technology are highlighted, such as high precision, the possibility of reducing the mass of components or optimizing the structural design, but also the related disadvantages, such as limitations in the size of the parts that can be made, production costs or difficulties associated with post-processing processes. This comparative analysis provides a clear perspective on the real potential and challenges of implementing 3D printing in the modern aerospace industry.

2.1 Fused Deposition Modeling (FDM). Fused Deposition Modeling is the most widespread technology due to its affordable cost and simplicity of the process. It consists of melting a thermoplastic filament which is then deposited layer by layer to build the desired object.

Fused Deposition Modeling (FDM) technology is primarily distinguished by the low cost of both printing equipment and consumables required for the manufacturing process, which makes it extremely affordable for individual users, educational institutions, and even for small-volume industrial prototyping [2]. Another major advantage is its simplicity of operation: users can configure, calibrate, and maintain FDM printers without requiring advanced technical knowledge, an aspect that has significantly contributed to the widespread popularization of this technology. Maintenance of these equipment is also easy and mainly involves cleaning the nozzle, periodic calibration of the print bed, and occasionally replacing consumable components.

However, FDM technology has notable limitations that affect its applicability in high-performance industries, such as aerospace. First, parts made by FDM tend to have lower mechanical strength than those made by other additive manufacturing methods, mainly due to the phenomenon of imperfect adhesion between layers, which can lead to structural weaknesses. Also, the dimensional accuracy of the components is lower, especially for complex geometries or large parts, which can require additional finishing operations. In addition, when printing complicated geometric shapes or with extended cantilevers, it becomes necessary to use support structures, which not only prolong the manufacturing time and material consumption, but can also introduce additional surface imperfections after their removal process.

2.2 Selective Laser Sintering (SLS). Selective Laser Sintering (SLS) is an advanced additive manufacturing technology that uses a high-power laser to sinter polymer or metal powders into solid structures by depositing them layer by layer. The process begins by spreading a thin layer of powder material onto a build platform, after which a high-energy laser focuses on the areas specified by the digital CAD model, selectively melting the powder particles only in those regions [3]. Once the first layer is sintered, the build platform is lowered by a distance equal to the layer thickness, and a new layer of powder is deposited on top, repeating the process until the entire component is completed.

This technology is particularly appreciated in the aerospace field due to its ability to manufacture parts with complex geometry, with superior mechanical properties and a density almost equivalent to that of conventionally processed materials. Additionally, the fact that the unused powder remains stable around the part during the process eliminates the need for additional supports, which reduces post-processing and the risk of geometric defects. SLS thus enables the fabrication of lightweight and topologically optimized structures, adapted to the critical requirements of aerospace and advanced drone applications.

One of the main advantages of Selective Laser Sintering (SLS) technology is the ability to produce parts with excellent mechanical properties comparable to those produced by conventional casting or machining methods [3]. Parts manufactured using SLS are characterized by good mechanical strength, dimensional stability, and high durability under demanding conditions of use, which makes them suitable for critical applications in the aerospace industry. Also, due to the nature of the process, in which the surrounding powder acts as a temporary support, it is not necessary to build auxiliary support structures, as is the case with other additive technologies. This allows the fabrication of very complex geometries, such as internal channels, lattices, and topologically optimized organic shapes, without major design limitations.

In addition, the possibility of reusing part of the remaining powder contributes to reducing waste and optimizing long-term operational costs. However, SLS technology also presents a number of significant disadvantages that must be taken into account. First, the initial costs of sintering equipment are considerable, requiring substantial investments in the acquisition of industrial printers and the necessary supporting infrastructure (such as thermally controlled chambers and powder handling systems) [3]. Also, the materials used, especially metal or polymer powders specially formulated for SLS, are more expensive compared to traditional raw materials. In addition to these aspects, parts obtained by SLS often require additional post-processing operations, such as sandblasting, chemical finishing or heat treatments, to improve the surface quality and final mechanical properties. These additional steps can extend the total production time and increase the costs associated with each manufactured part.

2.3 Stereolithography (SLA). This technology, known as stereolithography (SLA), uses photosensitive liquid polymers that undergo a photopolymerization process under the action of ultraviolet (UV) light, transforming from a liquid material into a solid structure layer by layer. In the process, a UV laser beam or a directed projection light source is used to trace the contour of each layer of the 3D model into the photopolymer material, causing it to selectively harden. By repeating this process for each successive layer, three-dimensional objects of very high geometric fidelity are built.

SLA technology stands out for producing parts with exceptional resolution, both in terms of fine details and surface quality, which makes it extremely valuable in applications that require extreme precision, such as functional prototyping, optical components, or detailed medical models [4]. Also, the thickness of the hardened material layer can reach several microns, allowing the manufacture of parts with tight dimensional tolerances and geometric complexity that would be impossible or extremely expensive to achieve using conventional manufacturing methods.

One of the main advantages of SLA technology is the ability to achieve an exceptionally smooth surface finish, comparable to that of parts made using traditional high-precision manufacturing methods. This feature often eliminates the need for additional post-processing or grinding operations. Also, due to the high resolution of the layer-by-layer polymerization process, SLA printing allows for extremely fine details and complex geometries, making it ideal for the production of highly detailed prototypes, functional test components, or models used in industries such as medical, dental, or optical [4]. Dimensional accuracy is another major advantage, which allows parts made using SLA to fit tightly within the manufacturing tolerances required for critical applications.

Despite these benefits, SLA technology also has some significant limitations. The materials used – mainly photopolymer resins – are often more fragile compared to thermoplastics or metal materials used in other 3D printing methods. This brittleness can lead to cracking or damage in applications where mechanical stress is high. In addition, many of these resins have potentially toxic or irritating chemical compounds, which requires strict safe handling measures, such as the use of personal protective equipment and adequate ventilation of workspaces. Also, the parts produced may require additional post-curing treatments to achieve their optimal mechanical properties, which adds complexity and additional time to the production process.

2.4 Direct Metal Laser Sintering (DMLS). Direct Metal Laser Sintering (DMLS) is an advanced 3D printing method for manufacturing high-performance metal parts, commonly used in industries such as aerospace, medical, and automotive.

The process involves the selective sintering of extremely fine metal powders, layer by layer, using a high-power laser that localizes and partially melts the material only in areas corresponding to the cross-section of the designed part.

This technology allows for the production of components with complex geometries that would be difficult or impossible to achieve using conventional machining methods such as casting or milling [5]. DMLS provides near-full material density, excellent mechanical characteristics, and a high degree of design freedom, making it ideal for manufacturing critical components where mechanical strength, high-temperature resistance, and dimensional accuracy are essential.

In addition, the technology allows the integration of multiple functionalities into a single part, thus reducing the total number of components and the complexity of mechanical assemblies, which brings significant benefits in terms of weight, reliability and maintenance costs of the final systems.

One of the most important features of DMLS technology is the ability to produce extremely complex metal parts, with fine details and tight dimensional tolerances, without the need to manufacture dedicated tools or molds [5]. DMLS also allows the creation of topologically optimized structures, thus reducing the weight of the parts without compromising mechanical strength. The resulting parts have a very high density, close to that of conventional cast or forged materials, which makes them suitable for safety-critical applications. Another great feature of this process is the drastic reduction in production time for prototypes or small series of components, compared to traditional manufacturing methods. In addition, the diversity of materials available for DMLS (aluminum alloys, titanium, stainless steel, nickel, etc.) significantly expands the area of applicability of this technology.

Despite all its obvious advantages, DMLS technology also has a number of limitations. The main disadvantage is the high costs associated with the purchase of printing equipment and the consumables used (special metal powders with strictly controlled characteristics) [5]. In addition, the sintering process requires controlled ambient conditions (such as inert nitrogen or argon atmosphere) to prevent oxidation of the materials, which implies additional investments in infrastructure. Also, most parts obtained by DMLS require post-processing operations, such as support removal, heat treatments, grinding or finishing machining to meet the strict requirements of industrial applications. The size limitations of the build volume and the relatively low manufacturing speed for large objects are other obstacles to the wide-scale adoption of DMLS in mass production.

3. FREQUENTLY USED MATERIALS IN 3D PRINTING

Materials used in 3D printing in the aerospace sector vary considerably, covering a wide range of properties and performances, from standard general-purpose polymers to advanced metal alloys specifically designed for critical applications. The choice of material is determined by factors such as mechanical strength requirements, specific weight, high temperature resistance, chemical compatibility, durability and production costs. Thermoplastic polymers, such as PLA, PETG and ABS, are often used for prototyping, non-structural parts and applications where low cost and ease of processing are a priority. On the other hand, in structural applications or in components intended for use in extreme environments, such as those found in aviation and space exploration, metallic materials such as AlSi10Mg or titanium alloys are preferred, due to their superior mechanical and thermal resistance characteristics [1][5].

The following Table 1 summarizes the main mechanical characteristics of some of the most commonly used materials in 3D printing for the aerospace industry, highlighting the typical ranges of yield strength, tensile strength, ultimate elongation and longitudinal modulus.

These data are essential in the selection process of the right material for the specific application, as they directly influence the structural performance and life cycle of the manufactured components.

Table 1. Mechanical properties of typical 3D printing materials [2][3][5]

Material	Yield Allowable Stress [MPa]	Failure Allowable Stress [MPa]	Maximal Elongation [%]	Longitudinal Elasticity Modulus E [GPa]
PLA	60-70	65-75	4-10	3.5-4.0
PETG	45-55	50-60	20-30	2.0-2.2
ABS	40-50	45-55	10-30	1.8-2.5
Nylon (PA12)	50-75	70-90	50-100	1.5-2.5
AlSi10Mg (DMLS)	230-350	270-310	3-5	70.0

Table 1 highlights the superior mechanical performance of metallic materials (e.g. AlSi10Mg), compared to polymer materials commonly used in FDM printing. Especially for drones, the weight/strength ratio becomes essential, making materials like Nylon or PETG extremely valuable due to their flexibility.

PLA (Polylactic Acid) is one of the most widely used materials in 3D printing due to its affordability and ease of use. Derived from renewable resources such as corn starch or sugarcane, PLA is biodegradable and emits fewer toxic particles during the printing process. Its mechanical properties, with a yield stress of 60–70 MPa and a tensile strength of 65–75 MPa, make it suitable for non-structural applications and lightweight components. However, PLA has low thermal resistance and high brittleness, limiting its use in conditions of mechanical stress or high temperatures [2].

PETG (Polyethylene Terephthalate Glycol-modified) represents an excellent compromise between durability, flexibility and ease of processing. It exhibits higher impact resistance and a maximum elongation of 20–30%, making it ideal for parts that require some flexibility without compromising strength. Higher printing temperatures compared to PLA, combined with good interlayer adhesion, make PETG a popular material in applications where superior mechanical strength and increased durability are required, such as drone housings or components exposed to moderate stress [3].

ABS (Acrylonitrile Butadiene Styrene) is a traditional material in the plastics processing industry, widely used in the manufacture of electronic housings, automotive parts and toys. In 3D printing, ABS offers a good combination of impact resistance and dimensional stability, with an allowable yield stress of 40–50 MPa and a tensile strength of 45–55 MPa. However, printing with ABS requires controlled ambient temperature conditions to prevent warping, and the emissions of ultrafine particles and VOCs during processing require the use of adequate ventilation systems [4].

Nylon (Polyamide), known for its strength and flexibility, is frequently used for functional components in the aerospace industry. With a tensile strength of 70 to 90 MPa and a maximum elongation of up to 100%, this material is ideal for parts that must withstand cyclic loads and repeated impacts. Nylon also has good chemical and abrasion resistance, but is sensitive to moisture absorption from the air, which can affect the printing performance and mechanical properties of the parts [3].

AlSi10Mg (Aluminum-Silicon-Magnesium Alloy) is a metal alloy widely used in 3D printing using direct laser sintering (DMLS) technologies due to its excellent weight-to-mechanical strength ratio. With a yield stress of 230–250 MPa and a tensile strength of 270–310 MPa, this material is suitable for the manufacture of demanding structural parts in the aerospace industry. In addition to its impressive mechanical properties, AlSi10Mg also offers good corrosion resistance, making it ideal for harsh environments or long-term exposure to atmospheric agents. Post-processing, such as heat treatments and mechanical finishing, is often required to optimize the final properties of the printed components [5].

4. PROCESS PARAMETERS FOR COMMON MATERIALS (FDM)

Processing conditions are critical to obtaining quality parts, especially in the industrial context, where precision and reliability are essential. In the aerospace field, especially in the manufacture of drone parts, where each component must meet strict performance and safety requirements, printing parameters play a fundamental role. Temperature, print speed, and cooling settings are just a few of the factors that can directly influence the success of a project.

The following table shows the temperatures required for the correct extrusion and printing of the main thermoplastic materials used in the FDM (Fused Deposition Modeling) process. These materials, such as ABS, PLA, PEEK or Nylon, are chosen according to the specific requirements of the parts to be manufactured. For example, materials such as PEEK, with high thermal resistance, are frequently used for drone components that are exposed to high temperatures or high mechanical loads, while ABS is preferred for components that require a combination of rigidity and low impact.

In addition, it is important that the printing temperature is precisely controlled to avoid part deformation or poor adhesion between material layers. Also, the extrusion speed and cooling conditions must be adjusted according to the material used to prevent the accumulation of internal stresses that could compromise the integrity of the final part. These fine adjustments are essential, especially when working with advanced materials used in the aerospace industry, which have strict requirements in terms of strength, durability and weight of parts.

In this context, choosing the right material and optimizing process parameters are essential to ensure the reliability of parts under the extreme operating conditions encountered in aeronautics, from exposure to strong vibrations to extreme temperature fluctuations that can occur during flight. In addition, surface quality and dimensional accuracy are essential to ensure the correct assembly of components, as well as to guarantee efficient operation and safe operations in the extreme environments in which drones are used.

The Table 2 below shows the essential processing parameters for 3D printing using FDM (Fused Deposition Modeling) technology. These parameters, including extrusion and printing temperatures for various thermoplastic materials, are critical for achieving high-quality components. In the context of the aerospace industry, they directly influence the performance of the manufactured parts, especially for drone applications, where reliability and precision are essential.

Table 2. Processing parameters for FDM printing [2][6]

Material	Nozzle Temperature (°C)	Print Bed Temperature (°C)	Recommended Ambient Temperature (°C)
PLA	190–220	0–60	>15
PETG	220–250	70–90	>20
ABS	230–260	90–110	>25 (closed case required)

Table 2 shows that ABS has stricter temperature requirements than PLA or PETG, and also requires a closed housing to prevent delamination of the layers. This technological requirement adds additional costs to the printing process.

5. EMISSIONS AND IMPACT ON HEALTH

During the 3D printing process, especially when thermoplastic materials such as ABS, PLA or PEEK are used, ultrafine particles and volatile organic compounds (VOCs) can be formed and released into the air. These emissions can be harmful to human health, especially in enclosed or poorly ventilated environments, and have been associated with respiratory irritation, adverse effects on the nervous system and, in extreme cases, risks of cancer or other chronic conditions.

Ultrafine particles are very small particles (typically less than 100 nanometers) that can penetrate deep into the lungs and enter the bloodstream, with the potential to cause lung inflammation and other respiratory problems. Volatile organic compounds (VOCs) include chemicals that can be released into the air as vapors or gases, and prolonged exposure to them can lead to symptoms such as headaches, dizziness, eye and skin irritation, and in severe cases, liver or kidney damage.

To reduce these risks, it is important that 3D printing processes are conducted in a well-ventilated environment and that users wear appropriate protective equipment, such as respirators. The use of safer materials or air filtration treatments can also help minimize exposure to these emissions. Comparative data on emissions from different types of materials used in 3D printing is presented in the following Table 3, providing a clear picture of the potential health impacts depending on the materials and processing conditions used.

Table 3. Emissions of particulate matter and volatile organic compounds from FDM printing [7]

Material	UFP emissions (particles/cm³)	VOC level (ppm)	Health risk
PLA	2×10^5	<0.1	Low
PETG	4×10^5	0.2	Medium
ABS	2×10^6	1.0	High

As shown in Table 3, ABS generates significantly higher levels of harmful emissions compared to PLA or PETG, requiring additional ventilation measures or the use of HEPA-filtered print booths.

6. APPLICATIONS IN THE AEROSPACE INDUSTRY AND AERIAL DRONES

In the aeronautics and drone industry, 3D printing / additive manufacturing has extensive applications, such as:

- manufacturing body components and aerodynamic elements for commercial drones: 3D printing allows the creation of lightweight and highly precise components, essential for the aerodynamic performance of commercial drones. Elements such as the fuselage, rotor arms and aerodynamic panels can be manufactured quickly and efficiently, reducing the costs and time required for the production of traditional parts. The materials used, such as carbon or metal alloys, allow for structures with low weight but high mechanical strength, contributing to greater autonomy of drones.
- making supports for sensors, actuators and transmission systems: Due to the diversity of materials available for 3D printing, it allows the creation of customized

supports for a wide range of sensors (e.g. GPS, video cameras, proximity sensors) and actuators. These supports must be precise, lightweight, and able to withstand the vibrations and environmental conditions specific to drone flights. 3D printing facilitates the rapid adaptation of the design of these supports according to the specific needs of each type of drone.
- building functional prototypes for testing ergonomics or aerodynamic performance: 3D printing plays a key role in rapid prototyping, allowing for the functional testing of new concepts and design improvements before mass production. Prototypes can be made from various materials that simulate the behavior of components in real flight conditions, providing rapid feedback on the ergonomics, user interfaces, stability, and aerodynamic performance of the drone. These prototypes are often essential for evaluating the performance of a design before it is implemented in series production.
- production of lightweight structural elements in experimental aircraft: 3D printing plays a significant role in the development and production of lightweight structural components for experimental aircraft, which are tested to evaluate new technologies and concepts in aviation. The manufacture of complex parts, such as beam structures or wing support elements, can be done quickly and precisely, significantly reducing the overall weight of the aircraft and thus increasing its efficiency and performance. 3D printing also allows the creation of shapes and geometries impossible to obtain using traditional methods, offering the possibility of structural optimization based on strength and performance analyses.

Companies such as Airbus and Boeing use DMLS to manufacture ultra-light, topologically optimized structural metal components to reduce aircraft weight and fuel consumption [5]. These companies benefit from DMLS's ability to produce complex parts with optimized geometry that cannot be achieved by traditional manufacturing methods. The parts manufactured in this way are significantly lighter, which contributes to reducing aircraft fuel consumption, thereby increasing operational efficiency. In parallel, for rapid prototyping and less demanding applications, materials such as PLA, PETG, and ABS are used for test components, housings, supports, and other non-structural parts. PLA is often used for initial prototypes due to its ease of printing and low cost, PETG is ideal for applications requiring impact resistance and flexibility, and ABS is used for parts requiring higher mechanical strength and stability at higher temperatures, often being preferred for prototypes that simulate real operating conditions in functional tests of drones and experimental aircraft.

7. COST COMPARISON BETWEEN CONVENTIONAL METHODS AND 3D PRINTING

Cost is a critical factor in the adoption of additive manufacturing technologies, especially in industries with high performance requirements, such as the aerospace and drone industries. Although 3D printing offers significant advantages in terms of rapid customization, design efficiency and reduced production times, initial costs can be a significant barrier to the widespread adoption of this technology. Compared to conventional manufacturing methods, 3D printing allows for a significant reduction in the number of manufacturing steps, but the costs of materials and equipment can be higher, depending on the complexity of the parts and the technologies used.

To better understand the impact of costs in the manufacturing process, it is essential to compare the expenses associated with producing a functional prototype using conventional methods and 3D printing.

This allows for a detailed assessment of the costs per unit and highlights the potential savings or challenges that may arise when deciding to use additive technologies, especially for medium-sized prototypes, which are commonly found in industries such as aerospace and drone development.

Table 4 compares the average costs for manufacturing a medium-sized functional prototype (1–2 kg) using conventional methods and 3D printing. This comparison provides a clear view of the costs involved in both processes, facilitating informed decisions regarding the most efficient production method for various applications.

Table 4. Average manufacturing costs for a medium-sized functional prototype [2],[6]

Manufacturing method	Setup Cost (€)	Material Cost (€)	Estimated Total Cost (€)	Delivery Time (weeks)
CNC Machining (Milling)	1000–1500	200–400	1200–1900	2-4
Rapid Casting	3000–5000	100–300	3100–5300	3-6
3D Printing FDM/SLS/DMLS	100–300	150–500	250–800	<1

3D printing dramatically reduces both initial production costs and lead times. In addition, the flexibility to modify designs without the need to create new molds provides an undeniable advantage in the rapid prototyping and testing phases.

8. FUTURE TRENDS IN 3D PRINTING FOR THE AEROSPACE AND DRONE INDUSTRY

Additive manufacturing technologies are in continuous evolution, and their future is shaped around major trends that promise to revolutionize the aerospace industry and beyond. These trends reflect the rapid advances in 3D printing technologies and the development of innovative materials and processes that will allow the creation of much higher-performance, lighter and more durable components. In this context, three key directions stand out: advanced materials, post-processing automation and 3D printing in zero gravity conditions.

8.1 Advanced Materials. A major direction of evolution in 3D printing is the development of advanced materials, essential for increasing the performance of manufactured components. New alloys and composites are optimized to cope with the extreme conditions in the aerospace industry, especially in terms of high temperatures and intense mechanical stresses.

- **Nickel-based superalloys.** These materials are essential for the production of components intended to operate in extreme temperature environments, such as aircraft turbines. Nickel-based superalloys are used for parts subjected to high temperatures and mechanical stress, with exceptional thermal stability. In combination with 3D printing, these superalloys can be modeled with high precision and topologically optimized, contributing to more efficient aircraft turbines with lower weight and improved performance [10].

- **Carbon fiber composites.** These materials are already used in many applications, but by using 3D printing, much more complex and lighter structures with superior performance can be created. Carbon fiber composites are particularly suitable for the production of ultra-light drones and small satellite structures such as CubeSats. These structures benefit from remarkable impact resistance, low weight and design flexibility that would not be possible with traditional manufacturing methods.

3D printing allows the creation of complex structures that help reduce the cost and production time of aeronautical and space components [11].

8.2 Processing Automation. Post-processing automation is another emerging direction in additive manufacturing, with a significant impact on the efficiency and accuracy of the production process. Post-processing steps, which include part cleaning, surface finishing, and quality inspection, can be automated to reduce manufacturing time and improve part quality consistency.

- Automated support cleaning. After printing 3D parts, it is sometimes necessary to remove supports used to support complex geometry during the manufacturing process. Automating this step can save time and reduce the risk of human error, providing a fast and accurate solution for the cleaning process, which is essential in obtaining high-quality final parts.

- Robotic surface finishing. Robotic surface finishing of 3D printed parts will allow for smooth and precise surfaces, preparing the parts for precision applications. These methods will include automated grinding and the application of high-quality finishes, thereby reducing the need for manual intervention and ensuring that manufactured parts meet the stringent standards of the aerospace industry.

- Automated part quality inspection using machine vision. Machine vision-based automated inspection technologies are already being used to monitor the quality of parts manufactured through 3D printing. These systems can detect minor defects, such as cracks or surface irregularities, providing a quick and accurate assessment of the quality of each part, which ensures high-precision production, essential in critical areas such as aeronautics and the drone industry [12].

8.3 3D Printing in Zero Gravity. Another promising area for additive manufacturing technologies is 3D printing in zero gravity, an area in which NASA and ESA (the European Space Agency) are investing significantly. 3D printing in zero gravity opens up enormous opportunities for the production of components directly in space, saving resources and reducing the need to transport materials and parts from Earth.

- Manufacturing spare parts directly on the International Space Station (ISS). 3D printing in space allows astronauts to produce spare parts directly in microgravity, which is essential for maintaining the functionality of the International Space Station. This can reduce the dependence on frequent transport of parts from Earth and ensure that astronauts have quick access to the necessary components in case of malfunctions.

- Building structural elements on the Moon or Mars using local resources. Another important goal is to use the resources available on the Moon or Mars to produce the structures needed to build bases or research stations on these celestial bodies. By using local materials and 3D printing technologies, space agencies can build essential structural elements for space exploration and colonization, reducing the need to transport materials from Earth and facilitating the construction of sustainable infrastructure in space [13].

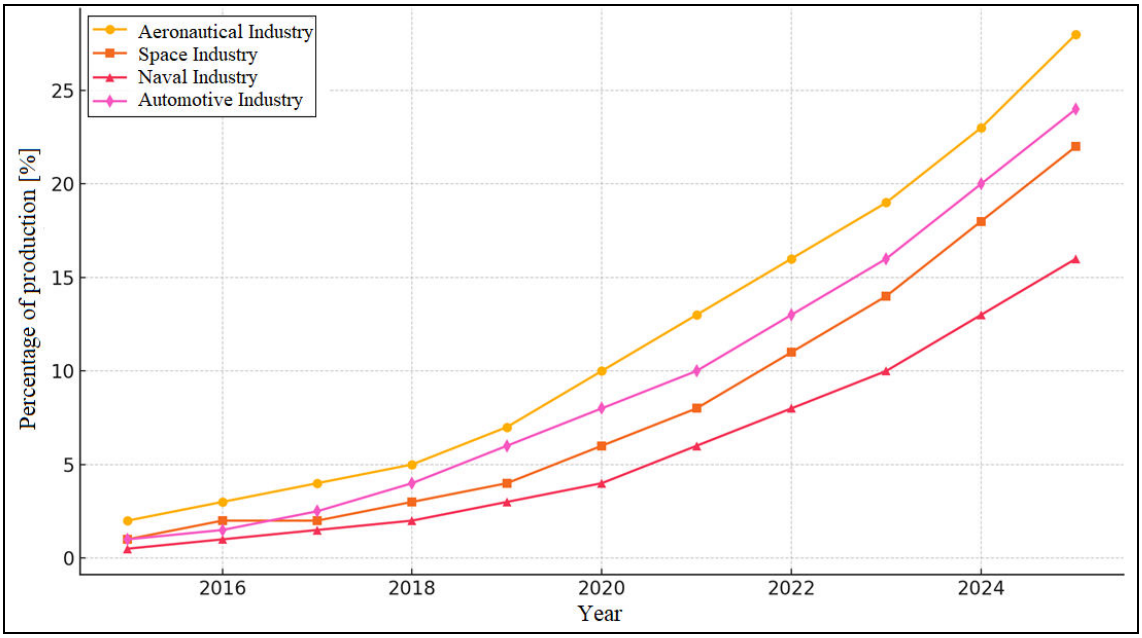
These trends point to a promising future for additive manufacturing, with innovative applications in the aerospace sector, but also in other fields, where 3D printing technologies will profoundly transform production processes, increasing efficiency, reducing costs and opening up new possibilities in the exploration and use of space resources.

3. THE EVOLUTION OF THE 3D PRINTING MARKET IN THE AEROSPACE FIELD

As technologies evolve, 3D printing is becoming more integrated into mass production processes, not just prototyping.

3D printing is expected to continue to grow in industries such as aerospace, automotive, marine and space. Innovations in composite materials, advanced metals and topology optimization software solutions will make these processes faster, cheaper and more sustainable.

The Fig. 1 chart illustrates the growth of 3D printing in global manufacturing for four industry sectors between 2015 and 2025, based on available data from [14].



* Year 2025 is estimated based on the trends.

FIG. 1 Evolution of the share of 3D printing in global industrial production (2015-2025)

This chart highlights the trends in the adoption of 3D printing technologies, with accelerated growth in the aerospace and space sectors, followed by the automotive industry. The marine industry is seeing slower adoption, but interest is growing, especially for on-demand spare parts and optimized structures.

CONCLUSIONS

3D printing has become an indispensable technology in the aerospace industry and in the development of modern drones. It allows: significant reduction of component weight, design freedom unmatched by traditional technologies, reduction of prototyping and small-scale production costs, creation of topologically optimized structures, impossible to achieve using classical methods.

By integrating advanced additive manufacturing technologies, aeronautical companies and drone manufacturers increase their competitiveness and contribute to the development of more sustainable solutions for the air transport of the future.

It is expected that, in the next 10–15 years, 3D printing will become the standard method for the production of customized aerospace components and for the in-situ fabrication of elements required for space missions.

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STRUCTURAL ANALYSIS OF THE MALFUNCTIONSOF THE GAS TURBINE ENGINE AI-25TL

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DOI: 10.19062/2247-3173.2025.26.15

Abstract: *The article presents a structural analysis of the malfunctions of the gas turbine engine AI-25TL based on statistical materials from its maintenance in the Bulgarian Air Force. The reporting and collection of information on the malfunctions of aircraft engines makes it possible to establish the nature of their manifestation and the degree of their recurrence. Based on mass observations of the occurrence and manifestation of various malfunctions, measures are developed and implemented aimed at increasing the level of reliability of aircraft engines.*

***Keywords**: maintenance, aircraft, engine.*

1. INTRODUCTION

The AI-25 TL twin-circuit turbojet engineis used on the L-39ZA trainer aircraft.

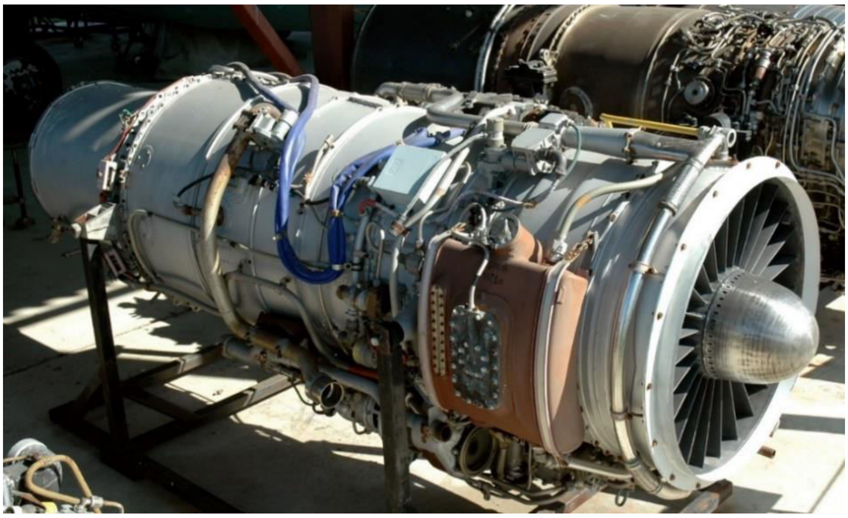

FIG.1 Gas turbine engine AI-25TL

Normal operation of the engine is ensured by the following systems:
- fuel supply system;
- oil system;
- sufflation system;
- drainage system;
- starting system;
- anti-icing system [2].

In accordance with the tactical-technical requirements for the AI-25TL gas turbine engine, the following basic modes of operation have been established: maximum, nominal, cruise (0.85 of nominal) and small throttle.

The normal and trouble-free operation in the process of operation to a considerable extent depends on the timely and qualitative performance of all types of maintenance.

The following types of maintenance shall be performed on the engine:

- engine preparation for flight;
- maintenance every 100+20 hours of flight time;
- performing storage activities;
- test the engine according to a defined programme and check the operability of the systems;
- checking the operability of the engine and aircraft systems aftertroubleshooting [3].

2. STRUCTURE OF MALFUNCTIONS OF THE AI-25TL GAS TURBINE ENGINE

Sources for gathering information on aero engine malfunctions are:

✓ malfunctions reporting cards [4].;
✓ monthly analyses;
✓ aircraft accident precondition reports;
✓ complaint reports [5].;
✓ lists of defects found during repairs [6].

The information gathered using the malfunctions report cards appears to be indispensable material for answering the following questions:

- which engine units and components are the least reliable under service conditions;
- which engine units and components operate reliably in service;
- what is the average life to failure of the different units and components.

The systematic data on the malfunctions of the products is in itself information on their overall technical condition. The systematisation of information is not an end in itself, but serves at all stages as a means of providing designers, production and operation with the necessary reliable data onsuccessful implementation of measures to increase the level of reliability of aircraft engines. This calls for serious attention to be paid to the issues of statistical data collection and processing. It is necessary to know that even if statistical data are processed with the most modern methods and means, the results will be unreliable if the primary information is not reliable.

In view of the particular importance of timely and accurate collection and processing of information, it is necessary:

- constant control of filling in information in malfunction reporting cards and expanding the possibilities for processing the information contained in them;
- the elimination of subjectivity in reflecting faults in malfunction reporting cards.

To obtain the necessary reliable information for the analysis, not only the statistical information on the parameters taken from the control means but also the malfunction report cards shall be used.For the analysis of the most typical malfunctions, data on AI-25TL engines operated in the Air Force for the period 1990 - 2020 are used.

The classification of the malfunctionswas performed based on the classification shown in Fig. 1.

Gradual malfunctions are accompanied by a gradual change in parameters and are mainly related to ageing and wear of materials. They are important in assessing and predicting changes in the reliability of products.

Their dependence on external loads and on the properties of the materials used is more pronounced compared to sudden malfunctions [1].

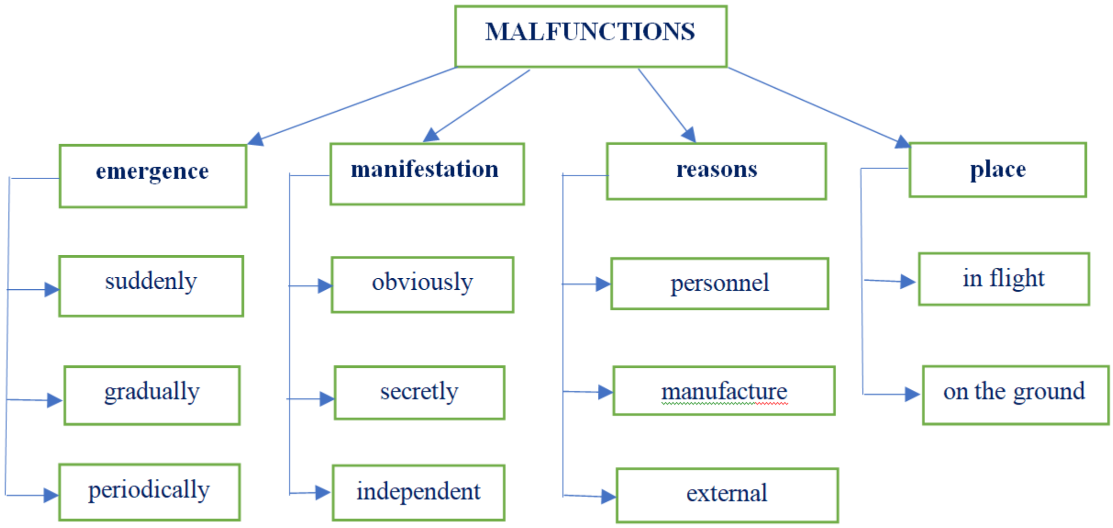

FIG.2 Classification of the malfunctions of AI-25TL gas turbine engine

Sudden malfunctions are accompanied by an accidental change in the functional parameters and technical condition of the engine assemblies. They are usually quite obvious and accompanied by pronounced signs of disruption of normal engine operation.

The main reasons for the occurrence of sudden malfunctions may be:

- manufacturing defects, the detection of which is difficult even with the most modern control methods;
- foreign objects entering the engine;;
- gross violation of flight and technical operation standards.

After processing the statistical data from the mentioned sources for collecting information about the aviation enginesmalfunctions, the results are obtained and presented in graphical form. The pie chart in Fig. 3 depict the distribution of malfunctions by the cause of their occurrence.

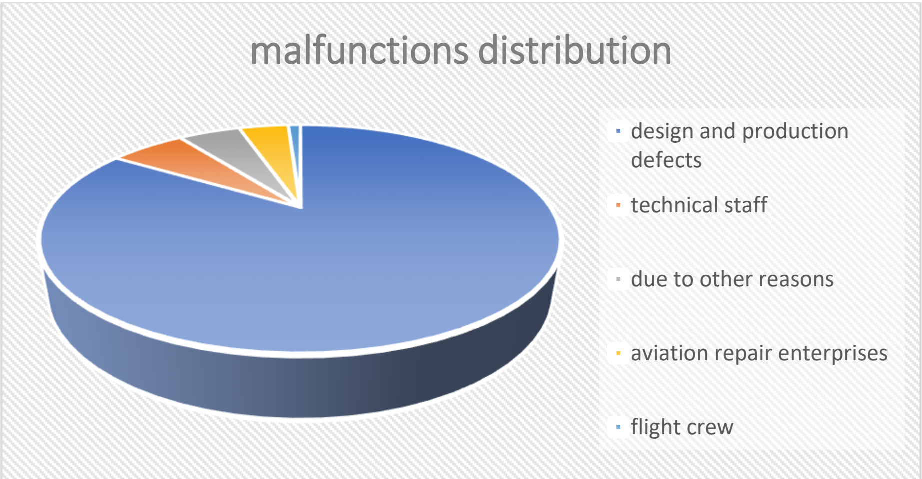

FIG. 3 Distribution of malfunctions according to their cause.

As can be seen from the figure, the largest percentage - 84%, of design and production defects. The second largest group of defects is caused by the technical staff - 6%; due to the fault of the aviation repair enterprises— 4%; for other reasons - 5%. The smallest percentage of defects - 1%, are caused by the flight crew.In order to be able to properly plan measures to increase the operational reliability of the AI-25TL gas turbine engine, it is particularly important to know the distribution of malfunctions among the individual engine units and systems.

The pie chart in Fig. 4 shows the distribution of malfunctions among the individual engine systems.

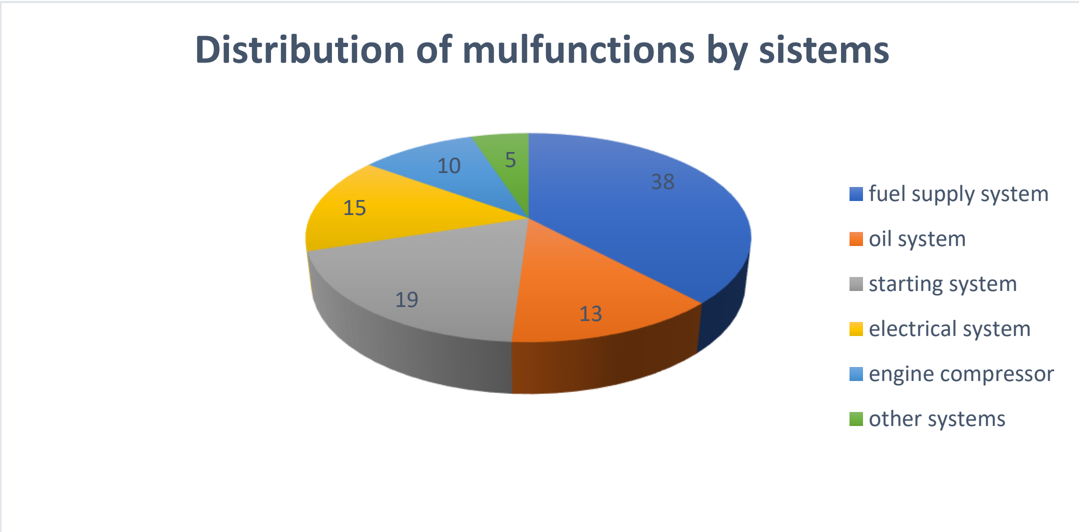

FIG.4 Distribution of malfunctionsby systems.

From Fig.4 it can be seen that the largest share is occupied by fuel supply system malfunctions- 38% . In it, the largest number of malfunctions were registered on the fuel regulator- unit 4000.

Fig.5 shows the distribution of malfunctions depending on the location of their occurrence. It can be seen that the malfunctions manifested on the ground many times exceed those in the air.

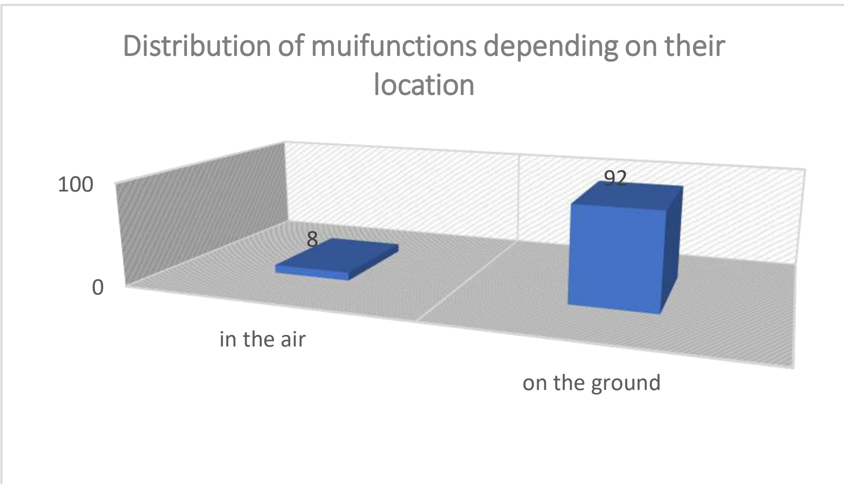

FIG. 5 Distribution of malfunctions depending on their location.

The information on the quantity and nature of the malfunctions of the aviation gas turbine engines obtained during their operation, is of great importance for the development of measures to increase their operational reliability, determination of the technical resource and improvement of the methods of technical operation. On the basis of the analysis of the malfunctions of the gas turbine engines the following main tasks are solved:

- the main directions of experimental and theoretical research on reliability improvement are determined;
- the operational reliability of the existing and commissioned aviation equipment is assessed;
- establish the regularity of change of the operational reliability of gas turbine engines, depending on the service life and storage time;
- develop measures to increase the in-service reliability of existing and entering into service aviation equipment;
- reveal the most unreliable assemblies and parts, design and manufacturing deficiencies;
- development of additions and amendments to the existing technical documentation.

Therefore, on the basis of the results of the statistical malfunctions analysis, it is concluded that the gas turbine engine AI-25TL (and its systems, respectively), like any other technical object in the process of operation, goes beyond the set norms of parameter variation. Taking into account the high requirements in terms offlight safety, it is necessary to continuously monitor the trend of the controlled parameters and not to allow them to exceed their pre-test value. The latter requirement is implemented by timely adjustment actions on the relevant units.

3. CONCLUSION

From the analysis of the malfunctions of the gas turbine engine AI-25TL, it can be seen that most of themalfunctionsoccur on the elements and aggregates of the fuel control apparatus.

For this reason, it is necessary to pay particular attention to the control of the technical condition of the elements and assemblies of the fuel automation of the gas turbine engineAI-25TL,as they are the least reliable.

It is imperative to observe the rules for the use of tools and ground support equipment and the technological frequency when carrying out maintenance and repairs in order to prevent foreign objects from entering the engine.

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AUTOMATIC CONTROL OF A SUPERSONIC AIR INLET WITH VARIABLE INNER CROSS-SECTION

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DOI: 10.19062/2247-3173.2025.26.16

Abstract: *The paper deals with a planar supersonic air inlet with variable inner cross-section, equipped with a fixed geometry centerbody. Its optimal architecture is determined and possible control laws are studied. A control system was presented and modeled, based on the inlet's inner minimum cross-section opening control with respect to the flight regime. System's quality was estimated by some Matlab-Simulink simulations; control system's step response(s) for different flight regime's step input(s) were evaluated, which has permitted important conclusions, discussions and comments to be presented, concerning embedded system's properties an quality.*

Keywords: *inlet, Laval-nozzle, shock-wave, pressure ratio, control, step input.*

1. INTRODUCTION

Supersonic aircraft, because of their need of high-thrust, are equipped with air-breathing engines with afterburning (turbojet- or turbofan-type). Such propulsion systems require large mass airflows, air pressures, velocities and temperatures in front of the compressor as uniform as possible. This desire may be realized by using suitable air inlets; an air inlet, as the first organ of interaction between the engine and the atmosphere, has both connection and correlation important roles: it must transform the air free-stream parameters into suitable air parameters for engine's use, to keep it in a stable operation mode ([1], [2] and [3]).

The higher the flight speed of the supersonic aircraft, the more complex, better designed and manufactured its air inlet must be. In order to assure the necessary air flow for the engine, the supersonic inlet must tune itself to any flight regime (flight speed and altitude, expressed by the aircraft's flight Mach number) and to any engine operating regime (given by engine's rotational speed) ([2], [4] and [5]).

Aircraft designers and manufacturers must choose the inlet's architecture considering the aircraft role (civilian or military purpose), its flight regime (the flight Mach number, speed and altitude), as well as the inlet positioning on the aircraft's frame. According to these requests, different architectures might be chosen: frontal inlets with conical mobile centerbodies, rectangular inlets with/without mobile ramp(s), diverterless inlets or Pitot intakes ([2], [3] and [4]). The option for a certain inlet type and for its control necessity and possibilities is based on the exact knowledge of the aircraft role, the estimated lifespan and the desired level of safety.

Supersonic air inlets have inner and outer complex flows, where shock waves, interfered waves and/or expansion waves might occur.

Likewise, interactions between the shock waves and the boundary layer, early flow separation, as well as buzz/stall instability etc may appear, which may affect the overall operation of the entire propulsion system.

Consequently, inlets' design is an important issue, because it involves not only theoretical studies, but also both deep experimental analysis, meant to better highlight and understand their flow-field, in order to better predict their behavior during a large range of flight regimes (from low subsonic to high supersonic velocity) and to establish their operational characteristics.

The air inlet calculation and design approach has two directions: the 2D approach ([6] and [7]) - suitable for rectangular inlets, provided with fixed or mobile flat panels, or for axisymmetric inlets, and the 3D approach ([8] and [9]) - suitable for a large class of asymmetrical inlets. However, phenomena specific to the 3D approach can also be encountered in some stages of operation of 2D (planar or axisymmetric) inlets, for example due to some particular flows (cross flows and sidewall), flow separation and/or shock wave-boundary layer interaction, which sometimes might be considerable, and induce supplementary loses and drag forces (as stated in [6], [7], [8] and [9]).

The control laws of these inlets must take into account all these observations; therefore, the shape, dimensions and control method must be chosen carefully. For planar inlets, provided with mobile panels or with sliding spikes, control (adjusting) laws and control methods were determined, as described in [4], [10], and [11] and [12]. Similarly, for axisymmetric inlets, control laws and methods were determined and studied in [4] and [13]. A different type of inlet is the one with inner compression, of Laval-nozzle shape, described and studied in [14], but difficult to use because of its lack of adaptability. However, its particular shape is often used in other types of inlets.

2. PROBLEM FORMULATION

Supersonic air inlets with mixed compression (both external and internal) are built with two different zones: a) the outerl zone, where the centerbody (wedge or spike) triggers a system of shock-waves (oblique- or conic-type); b) the internal (inner) zone, also known as the flow channel, which is often built and profiled similarly to a Laval-nozzle. Both supersonic inlets (with mixed compression and with inner supersonic buffer zone) have an inner normal shock wave (developed at the throat- the minimum section area zone, or slightly behind it, in the divergent zone of the inlet's channel), which position is determined by the flight regime (through the amount of the total pressure after the outer shock waves) and by the engine's operating regime (through the amount of the static pressure in front of the engine's compressor). Behind this normal shock-wave the air flow becomes subsonic and continue decelerates (because of channel's divergent shape) until it reaches the compressor.

An important issue of this kind of supersonic inlets is their activation, or their "starting", which means the generation of the inner normal shock-wave and then maintaining it in the desired area throughout the operation of the inlet-engine tandem, at any flight regime and at any engine speed.

This paper intends to study a supersonic air inlet with external fixed geometry and variable inner cross-section (as Fig. 1.a shows), in order to determine its control law and to evaluate the behavior of its automatic control system's performance.

A similar study was performed earlier, for an inlet presented in [14], but using a control law for an inner sliding diaphragm, useful for axisymmetric inlets. However, it is quite difficult (virtually impossible) to design an adjustable throat for an axisymmetric air inlet, in order to adapt it to various flight altitudes/speeds, so the solution developed in [14] is the only one to be applied.

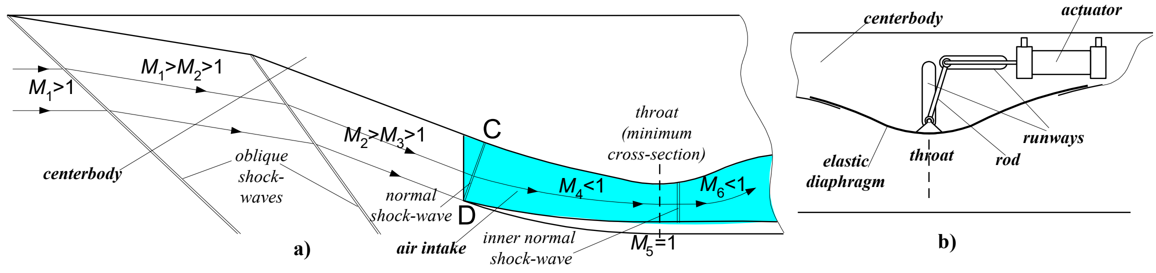


FIG. 1. Supersonic air inlet with fixed geometry centerbody and variable geometry throat

And yet, it is possible to build such a variable throat for a planar parallel inlet; it can be manufactured based on a much simpler geometry, since the cross-section of a rectangular shape with constant depth may be scaled by scaling only the other dimension of the rectangle (the height), as shown in Fig.1.b.

3. SUPERSONIC INLET GEOMETRY

As Fig. 1 shows, the studied inlet has a wedge-shape centerbody, which triggers the outer oblique shock-waves' system, while the intake's lip triggers a normal shock-wave, behind which the flow becomes subsonic; inside the rectangular flow channel the elastic diaphragm assures channel's Laval-shape by forming its throat of variable opening. Thus, the flow initially accelerates, becomes sonic at the throat and then jumps into subsonic through the normal shock-wave near the throat.

In fact, the most important phenomenon is the "starting" of the Laval-shape zone. The process with its challenges and its limits was presented in [14] and partly in [15]. Its initial conditions depends on the flow velocity and pressure behind the outer shock-waves system, as determined in [4], in [10] or in [13].

3.1. Inlet's outer configuration. As presented in [10], the optimal inlet configuration (as in Fig. 2) must define the geometry of the centerbody, which is obtained using an algorithm based on the Oswatitch condition, consisting of the total pressure recovery maximization. The total pressure recovery coefficient of the inlet is the product of the pressure recovery coefficients of the shock-waves:

$$\sigma_i^* = \sigma_{osw1}^* \sigma_{osw2}^* \sigma_{nsw}^* \sigma_d^* , \tag{1}$$

where σ_{osw1}^*, σ_{osw2}^* are oblique shock-waves' total pressure recovery ratios, σ_{nsw}^* – normal shock-wave's total pressure recovery ratio and σ_d^* – total pressure recovery ratio inside the channel (which can be considered constant, independent of flight and engine operation modes).

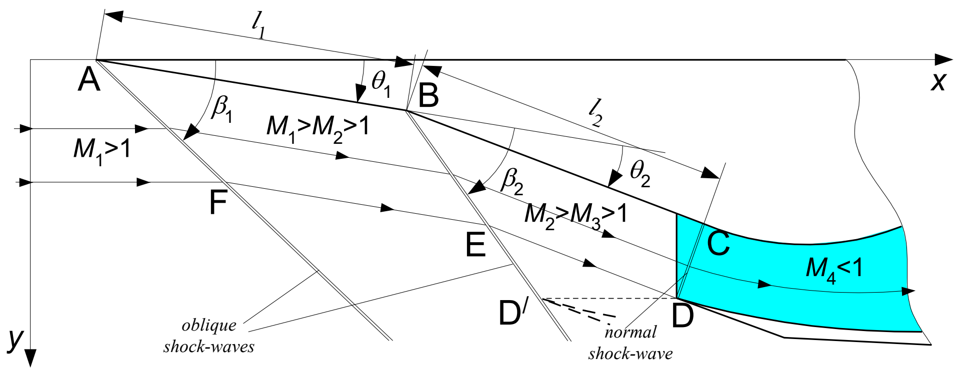


FIG. 2 Supersonic inlet outer configuration

These values must be calculated together with the other shock-waves parameters, using specific formulas:

- for the oblique shock waves

$$\sin^2\beta_k = \frac{1}{M_k^2} + \frac{\chi+1}{2}\frac{\sin\beta_k \cdot \sin\theta_k}{\cos(\beta_k\text{-}\theta_k)}, \tag{2}$$

$$M_{k_{av}}^2 = \frac{1}{\sin^2(\beta_k-\theta_k)}\frac{(\chi-1)M_k^2\sin^2\beta_k+2}{2\chi M_k^2\sin^2\beta_k-(\chi-1)}, \tag{3}$$

$$\sigma_{oswk}^* = \left[\frac{(\chi+1)M_k^2\sin^2\theta_k}{2+(\chi-1)M_k^2\sin^2\theta_k}\right]^{\frac{\chi}{\chi-1}}\left[\frac{\chi+1}{2\chi M_k^2\sin^2\theta_k-(\chi-1)}\right]^{\frac{1}{\chi-1}}, \tag{4}$$

where $k=\overline{1,2}$, M_k – Mach number in front of the shock-wave, $M_{k_{av}}$ – Mach number behind the shock-wave; θ_k – centerbody's flare angles, β_k – shock-waves' angles, χ – air's adiabatic exponent.

- for the normal shock-wave

$$M_{av}^2 = \frac{(\chi-1)M_k^2+2}{2\chi M_k^2-(\chi-1)}, \tag{5}$$

$$\sigma_{nsw}^* = \left[\frac{(\chi+1)M_k^2}{2+(\chi-1)M_k^2}\right]^{\frac{\chi}{\chi-1}}\left[\frac{\chi+1}{2\chi M_k^2-(\chi-1)}\right]^{\frac{1}{\chi-1}}, \tag{6}$$

where M_k – Mach number in front of the normal shock-wave, M_{av} – Mach number measured after the normal shock-wave.

For a flight Mach number $M_1 = 2.1$ considered as Mach in front of the inlet, applying the above described algorithm in order to maximize the total pressure recovery σ_i^*, one has obtained the optimal flare angles: $\theta_{1_{\mathrm{opt}}} = 11.14^\circ$, $\theta_{2_{\mathrm{opt}}} = 12.22^\circ$. The other geometrical elements are calculated as $l_1 = 0.8849$, $l_2 = 0.7624$, while characteristic points in Fig. 2 have the coordinates:

$\mathrm{A}(0;0); \mathrm{B}(0.874;0.142); \mathrm{C}(1.569;0.454); \mathrm{D}(1.324;1)$.

For lower upstream Mach numbers, $M_1^/ < M_{1_{\mathrm{nom}}}$, the intensity of both external oblique shock-waves is decreasing, so they are depleting and their angles β_1 and β_2 are consequently growing, which also leads to the pressure recovery coefficient σ_i^* modifying.

3.2. Inlet's inner Laval-nozzle. As presented in [14], an intake with inner compression of Laval-nozzle shape must be activated by a favorable sequence of closing/openings of the minimum section (throat).

One assume that the nozzle geometry (A_{cr} - the throat area and A_e - the exit area, as well as the variation of nozzle's cross section area versus its length $A = A(x)$) is known, then the air flow rate $\dot{m}_a$ passing through the nozzle is also known as supplied by the outer part of the inlet, as well as the upstream air's parameters (pressure p^* and temperature T^* or enthalpy i^*).

Applying the Saint-Venant equation (as presented in [2]), considered for the important sections (throat and exit section), one may obtain

$$\beta_e^{\frac{2}{\chi}}\left(1-\beta_e^{\frac{\chi-1}{\chi}}\right)=\frac{\chi-1}{2}\left(\frac{2}{\chi+1}\right)^{\frac{\chi+1}{\chi-1}}\left(\frac{A_{cr}}{A_e}\right)^2, \tag{7}$$

where $\beta_e=\dfrac{p_e}{p^*}$ is the pressure ratio; it may be calculated if p_e (static pressure in front of the engine) and p^* (total pressure after the outer shock-wave system) are known. The two roots of the equation (7) are: the first for the subsonic mode $\beta_e^{/}>\beta_{cr}$, the second for the supersonic mode $\beta_e^{/}<\beta_{cr}$, where $\beta_{cr}=\left(\dfrac{2}{\chi+1}\right)^{\frac{\chi}{\chi-1}}$; each one corresponds to a pressure value in the exit section $p_e^{/}$, respectively $p_e^{//}$.

For a pressure in front of the engine $p_e \geq p_e^{/}$, the flow mode inside the nozzle is completely subsonic (see curves 1, 2, 3 in Fig. 3). The curve 3 is reached when the pressure value becomes equal to $p_e^{/}$ (it is the limit curve of the subsonic flow). If the pressure value is $p_e<p_e^{//}$, the flow mode in the divergent zone becomes supersonic (curve 4) and the Laval nozzle is considered completely started. When $p_e^{//}<p_e<p_e^{/}$ a mixed flow mode occurs in the nozzle's divergent zone, where a normal shock wave might appear.

One may restrain the pressure range even more, considering the nozzle's starting as complete if the above-mentioned normal shock-wave appears in nozzle's output section. Applying the flow rate equation where one has chosen the solution $\left(\lambda_e^{///}>1\right)$, the velocity coefficient before the shock-wave ($\lambda_e^{///}$) can be calculated as

$$q\left(\lambda_e^{///}\right)=\frac{\dot{m}\sqrt{T^*}}{KA_e p^*}, \tag{8}$$

while the velocity coefficient behind the shock-wave is $\dfrac{1}{\lambda_e^{///}}$ and the flow rate function is

$$q(\lambda)=\lambda\left[\frac{\chi+1}{2}\left(1-\frac{\chi-1}{\chi+1}\lambda^2\right)\right]^{\frac{1}{\chi-1}}. \tag{9}$$

Through the normal shock-wave the total pressure drops so, behind it, on may calculate the pressure using the flow conservation equation, as folows

$$p_{av}^*=\frac{\dot{m}\sqrt{T^*}}{KA_e q\left(\dfrac{1}{\lambda_e^{///}}\right)}, \tag{10}$$

The limit-value of the outer pressure $p_e^{///}$ (in front of engine's compressor), below which one may consider the de Laval nozzle as fully started, may be calculated from

$$p_e^{///} = p_{av}^* \Pi\left(\frac{1}{\lambda_e^{///}}\right) = \left[\dot{m}\sqrt{T^*}\,\Pi\left(\frac{1}{\lambda_e^{///}}\right)\right] / \left[KA_e q\left(\frac{1}{\lambda_e^{///}}\right)\right], \tag{11}$$

where $\Pi(\lambda) = 1 - \frac{\chi - 1}{\chi + 1}\lambda^2$ is the thermodynamic funcion of the pressure.

Thus, depending on the static pressure's value downstream of the divergent zone of the Laval nozzle, during its starting three different situations may occur:

a) if $p_e \geq p_e^{/}$ the nozzle is totally under subsonic flow;

b) if $p_e^{/} > p_e > p_e^{///}$ a mixed flow appears in its divergent zone, where a normal shock-wave is triggered; its upstream flow is supersonic, then subsonic downstream (see Fig. 3, curve 5);

c) if $p_e < p_e^{///}$, the normal shock-wave is completely evacuated from the divergent zone of the nozzle, and, consequently, the nozzle is fully started.

The emergence of a normal shock-wave in Laval nozzle's divergent zone (case b) - corresponding to curve 5 in Fig. 3) raises an important issue to be studied: the determination of its position. As far as the upstream (p^*, T^*) and downstream (p_e)parameters are dtermined by the operational regimes and the variation of nozzle section its longitudinal coordinate $A = A(x)$ is also known, one has to determine the shock-wave position measured from the throat (or from the nozzle's entry). Firstly, the pressure will drop, following the curve 4, in the initial part of the nozzle, being supersonic up to the shock-wave. The pressure undergoes a jump through the normal shock-wave, then it follows the curve 5 in Fig. 3 untill the exit section, where it reaches the value p_e.

3.3. Inlet's control law. The work line of the inlet has precise positioning, as Fig. 4 shows. Possible control laws of the inlet were determined in [14] and [4]. The limits of the working lines are the curves I and II; between them all control laws should be developed. However, not all of these laws are suitable for this type of inlet, since the upstream flow velocity varies differently due to the presence of the oblique shock-waves.

The control law must consider some important situations, as follows:

a) the start of the engine, which corresponds to point A. The whole inlet must be completely open, so its throat (the critical area) should have the maximum area;

b) the acceleration, until the upstream reaches the sound speed (the slice A-B in Fig. 4). The inlet's throat must keep the same maximum opening. When the sound speed was reached, a normal shock wave is triggered in front of the air inlet; however, the air intake meets a subsonic flow and the inlet is still working in subsonic mode;

c) acceleration in the supersonic mode, section B-C, until the shock wave is triggered in the throat zone. Continuing the acceleration, one must gradually reduce the throat (see curve I), with respect to the air speed increasing. Shock-wave's position must be stabilized once reaching the Mach number limit, so the minimum section (the throat) must close, until the point D, close to the second limit curve (II); a certain reserve must be kept from curve II, in order not to disable (to „deactivate") the intake. However, the position of points C and D are determined knowing the flight Mach number value. Further acceleration must be done following the curve EF, near the first border curve I, or to maintain the opening of the point E;

d) when the oblique shock-waves of the outer inlet's configuration are detaching, the conditions of the upstream flow are changing and the "reopening" of the throat is necessary, so the control law must follow the path DC or a new path from E to C on the first border curve.

Considering these observations, one must choose the control law so that the shock wave inside the channel is maintained in the throat area, behind it. Consequently, the control parameter of the inlet must be connected to this shock-wave; the most important parameter is the total pressure recovery, but it might be replaced with the pressure ratio φ_m between the total and the static pressure, which indirectly gives information about the Mach number in the throat zone M_5:

$$\varphi_m = \frac{p_m^*}{p_m} = \left(1 + \frac{\chi - 1}{2} M_5^2\right)^{\frac{\chi}{\chi - 1}}. \tag{12}$$

So, this parameter must be measured and a control system based on it may be imagined, which must open/close the throat with respect to the flow conditions in the throat zone.

4. INLET'S CONTROL SYSTEM'S ARCHITECTURE

The operational block diagram is depicted in Fig. 5, which explains the way of action of the control system, while the architecture of inlet's automatic control system is depicted in Fig. 6. The control system is equipped with an elastic diaphragm with pressure intakes; this diaphragm assures the variation of throat's cross-section, being moved by the hydraulic actuator.

The position of both pressure intakes was chosen to facilitate the measuring of both mean total pressure p_m^* and mean static pressure p_m at throat's level. From aerodynamic and thermodynamic points of view, the pressures' ratio φ_m is a function of M_5 - the upstream Mach number, as Eq. (12) shows. Inlet's control law is non-linear-type; however, it could be linearized, but only accepting positioning errors, which leads to higher total pressure losses and, possibly, inlet's operational errors.

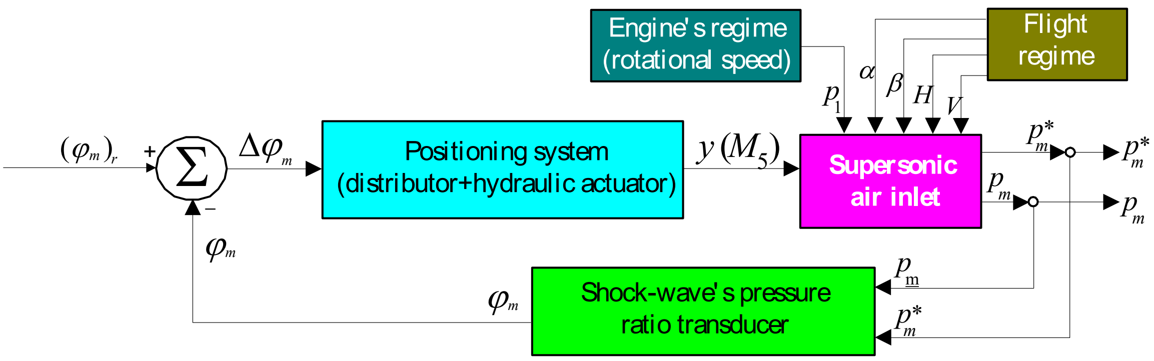
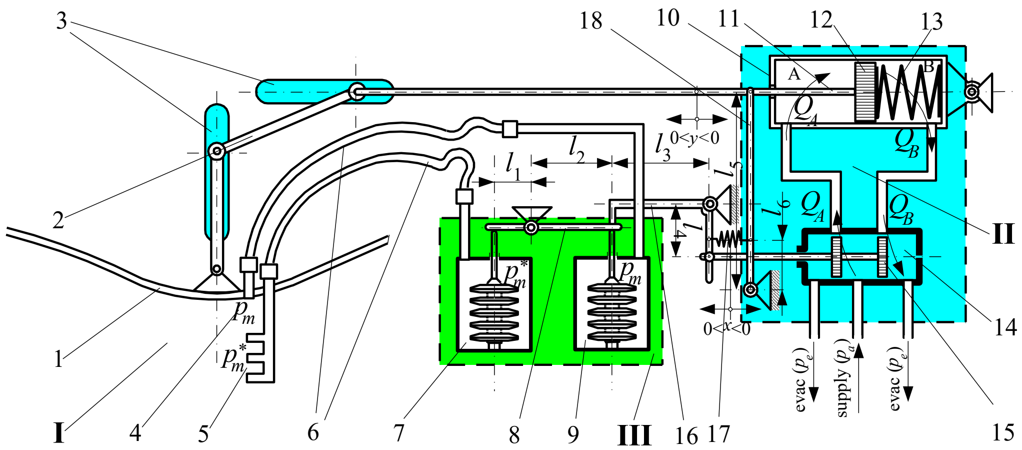


FIG. 5. Automatic control system's operational block diagram



System's main parts:
I-supersonic inlet's throat area; **II**-actuator; **III**-pressure sensor;

1-elastic diaphragm; 2-rod; 3-runways; 4-static pressure intake; 5-total pressure intakes ramp; 6-flexible pipes; 7-total pressure sensor (capsules); 8-pressure sensor's lever; 9-static pressure sensor (with capsules); 10-hydraulic actuator (cylinder); 11-actuator's main rod; 12-actuator's piston; 13-actuator's spring; 14-distributor; 15-distributor's slide-valve; 16-rocking lever; 17-main feedback's spring; 18-main feedback's lever.

FIG. 6 Automatic control system’s architecture

5. CONTROL SYSTEM’S MATHEMATICAL MODEL

The mathematical model of the control system consists of its main parts non-linear equations, as follows:

a) The equation of the pressure ratio’s transducer:

$$S_{a1} l_1 p_m^* - S_{a2} l_2 p_m - \frac{l_2 l_4}{l_3}\left(m\frac{\mathrm{d}^2 x}{\mathrm{d}t^2} + \xi\frac{\mathrm{d}x}{\mathrm{d}t}\right) - \left(k_{r1} l_1 + k_{r2} l_2\right)x = 0, \tag{13}$$

where k_{r1}, k_{r2} – transducer’s capsule’s elastic constants; m – mobile rod and accessories mass; ξ – viscous friction co-efficient; l_1, l_2 – transducer’s lever arms’ length; l_3, l_4 – transducer’s rocking lever arms’ length; S_{a1}, S_{a2} – aneroid capsules surface areas (usually considered as equal $S_{a1} = S_{a2} = S_a$); x – distributor’s slide-valve’s displacement;

b) The equations of the actuator and of the distributor:

$$Q_A = \mu_a L_d x\sqrt{\frac{2}{\rho_{hf}}}\sqrt{p_a - p_A}, \tag{14}$$

$$Q_B = \mu_a L_d x\sqrt{\frac{2}{\rho_{hf}}}\sqrt{p_B - p_e}, \tag{15}$$

$$Q_A = S_p\frac{\mathrm{d}\left(y_r - y\right)}{\mathrm{d}t} + \beta_{hf} V_{A0}\frac{\mathrm{d}p_A}{\mathrm{d}t} \tag{16}$$

$$Q_B = S_p \frac{\mathrm{d}(y_r + y)}{\mathrm{d}t} - \beta_{hf} V_{B0} \frac{\mathrm{d}p_B}{\mathrm{d}t}, \tag{17}$$

$$S_p(p_A - p_B) = m_p \frac{\mathrm{d}^2(y + y_r)}{\mathrm{d}t^2} + \xi_f \frac{\mathrm{d}(y + y_r)}{\mathrm{d}t} + k_{ea}(y_r + y + y_0), \tag{18}$$

where Q_A, Q_B – hydraulic fluid's flow rates; μ_a – flow rate co-efficient; L_d – distributor's orifice's width; p_A, p_B – actuator's chambers' pressures; y – actuator's rod's displacement; V_A, V_B – transducer's chambers volume; β_{hf} – hydraulic fluid's compressibility co-efficient; k_{ea} – actuator's spring's elastic constant; m_p – actuator's mobile rod and accessories mass; ξ_f – viscous friction co-efficient; p_a – hydraulic fluid supplying pressure; p_e – fluid's pressure in the low pressure circuit (which may be neglected, because of its small value compared to p_A and p_B).

Obviously, this mathematical model (Eqs. (13) to (18)) is a non-linear one, not suitable for further studies. It must be brought to a linear form, then adimensionalized and, finally, submitted to the Laplace transformation. This algorithm was described in [4] and [16], and applied for studies in [10], [13], [14] and [15]. It uses the small perturbation hypothesis and the finite differences method, which considers any variable X as $X = X_0 + \Delta X$ and $\overline{X} = \dfrac{\Delta X}{X_0}$, where ΔX – deviation, X_0 – steady state regime's value and $\overline{X}$ – non-dimensional deviation.

Mathematical model's linearized dimensionless form has resulted as:

$$k_{mt}\overline{p}_m^* - k_m \overline{p}_m = \overline{x} \tag{19}$$

$$k_x \overline{x} - \tau_y \mathrm{s} \overline{y} = (\tau_{Ap}\mathrm{s} + 1)(\overline{p}_A - \overline{p}_B), \tag{20}$$

$$\overline{y} = k_y(\overline{p}_A - \overline{p}_B), \tag{21}$$

with the used notations

$$k_{Ax} = \mu_a L_d \sqrt{\frac{p_a - p_e}{\rho_{hf}}}, T_x = \sqrt{\frac{m l_2 l_4}{(k_{r1}l_1 + k_{r2}l_2)l_3}}, 2T_x\omega_0 = \frac{\xi\, l_2 l_4}{(k_{r1}l_1 + k_{r2}l_2)l_3}, T_y = \sqrt{\frac{m_p}{k_{ea}}},$$

$$2T_y\omega_0 = \frac{\xi_f}{k_{ea}}, k_{Ap} = \mu_a L_d x_0 \sqrt{\frac{1}{\rho_{hf}(p_a - p_e)}},$$

$$k_{xS} = \frac{S_a}{k_{r1}l_1 + k_{r2}l_2}, k_{px} = \frac{2k_{Ax}}{k_{Ap}}, \tau_{py} = \frac{2S_p}{k_{Ap}}, \tau_{Ap} = \frac{\beta_{hf}V_0}{k_{Ap}}, k_{py} = \frac{S_p}{k_{ea}}. \tag{22}$$

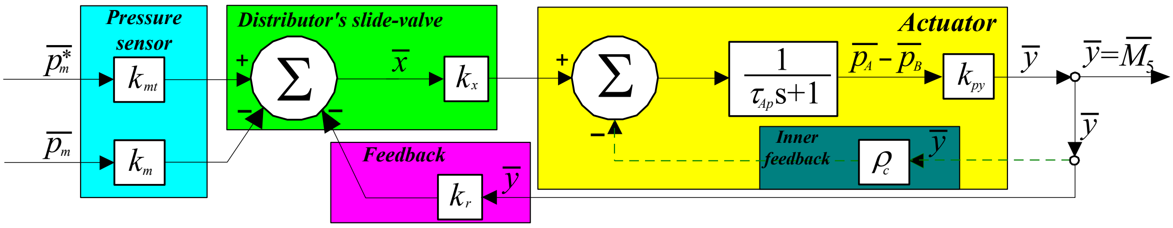


FIG. 7 Automatic control system's block diagram with transfer functions

$$k_{mt} = \frac{l_1 k_{xS} p^*_{m0}}{x_0},\; k_m = \frac{l_2 k_{xS} p_{m0}}{x_0} \approx k_{mt},\; k_x = \frac{k_{px} x_0}{p_{A0}},\; \tau_y = \frac{\tau_{py} y_0}{p_{A0}},\; k_y = \frac{k_{py} p_{A0}}{y_0}.$$

Assuming that the compressibility coefficients and the viscous friction coefficient may be neglected, the new (simplified) form of the mathematical model becomes:

$$k_x k_y \left(k_{mt}\bar{p}^*_m - k_m \bar{p}_m\right) = \left(k_y \tau_y \mathrm{s} + 1\right)\bar{y}, \tag{23}$$

$$\bar{y} = \frac{k_x k_y}{\left(k_y \tau_y \mathrm{s} + 1\right)}\left(k_{mt}\bar{p}^*_m - k_m \bar{p}_m\right) = \frac{k}{\left(\tau \mathrm{s} + 1\right)}\left(k_{mt}\bar{p}^*_m - k_m \bar{p}_m\right). \tag{24}$$

that means that system's transfer function is a first order one, where the expressions of the time constant τ and of the gain co-efficient k are, as follows:

$$\tau = k_y \tau_y = \frac{2 S_p^2 \sqrt{\rho_{hf}\left(p_a - p_e\right)}}{k_{ea}\mu_a L_d x_0}, \tag{25}$$

$$k = k_x k_y = \frac{2 S_p \left(p_a - p_e\right)}{k_{ea} y_0}. \tag{26}$$

Based on these equations, the block diagram with transfer functions was built, and is depicted in Fig. 7.

An important remark must be done, regarding the actuator's architecture. It might be used in its simple form, or it might contain an additional internal feedback for the purpose of improving performance, as studied in [10]; the inner feedback is highlighted in Fig. 7 inside the actuator with dashed line.

Consequently, the mathematical model changes, becoming:

$$\bar{y} = \frac{k_x k_y}{\left(k_y \tau_y \mathrm{s} + k_y \rho_s + 1\right)}\left(k_{mt}\bar{p}^*_m - k_m \bar{p}_m\right) = \frac{k_1}{\left(\tau_1 \mathrm{s} + 1\right)}\left(k_{mt}\bar{p}^*_m - k_m \bar{p}_m\right), \tag{27}$$

with new forms of the time constant and of the gain:

$$\tau_1 = \frac{k_y}{k_y \rho_s + 1}\tau_y, \quad k_1 = \frac{k_x k_y}{k_y \rho_s + 1}. \tag{28}$$

Obviously, the system remains a first order – one, but its coefficients have received new forms and new values, both of them becoming smaller than for the basic system.

6. CONTROL SYSTEM'S STABILITY AND QUALITY EVALUATION

Both transfer functions of the studied system (with respect to each one of the input pressures), have, obviously, first order characteristic polynomials. Their expressions are:

$$H_{mt}(\mathrm{s}) = \frac{k_x k_y k_{mt}}{\left(k_y \tau_y \mathrm{s} + k_r\right)} \overline{p}_m^*,\ H_m(\mathrm{s}) = -\frac{k_x k_y k_m}{\left(k_y \tau_y \mathrm{s} + k_r\right)} \overline{p}_m . \tag{29}$$

Consequently, according to the Routh-Hurwitz criteria, in order to assure the stability of the control system, the polynomial coefficients must have the same sign, strictly positive in this particular case $\left(k_y \tau_y > 0 \text{ and } k_r > 0\right)$; these conditions lead to

$$l_1 > \frac{S_a p_{m0}^2 l_4}{p_{m0}^* \left(l_3 k_{r2} - l_3 k_{r1} + S_a p_{m0}\right)},\ l_2 > \frac{S_a p_{m0}^2 \left(S_a p_{m0} - l_3 k_{r1}\right)}{p_{m0}^* l_4 k_{r2} \left(l_3 k_{r2} - l_3 k_{r1} + S_a p_{m0}\right)} . \tag{30}$$

If it is chosen that the capsules have identical geometric parameters, one obtains for the minimum value of the lever arms:

$$l_1 = \frac{p_{m0}}{p_{m0}^*} l_3,\ l_2 = \frac{p_{m0}\left(S_a p_{m0} - l_3 k_r\right)}{p_{m0}^* k_r} \frac{l_4}{l_3} . \tag{31}$$

If the improved architecture of the actuator is chosen to be used, the stability conditions remain the same.

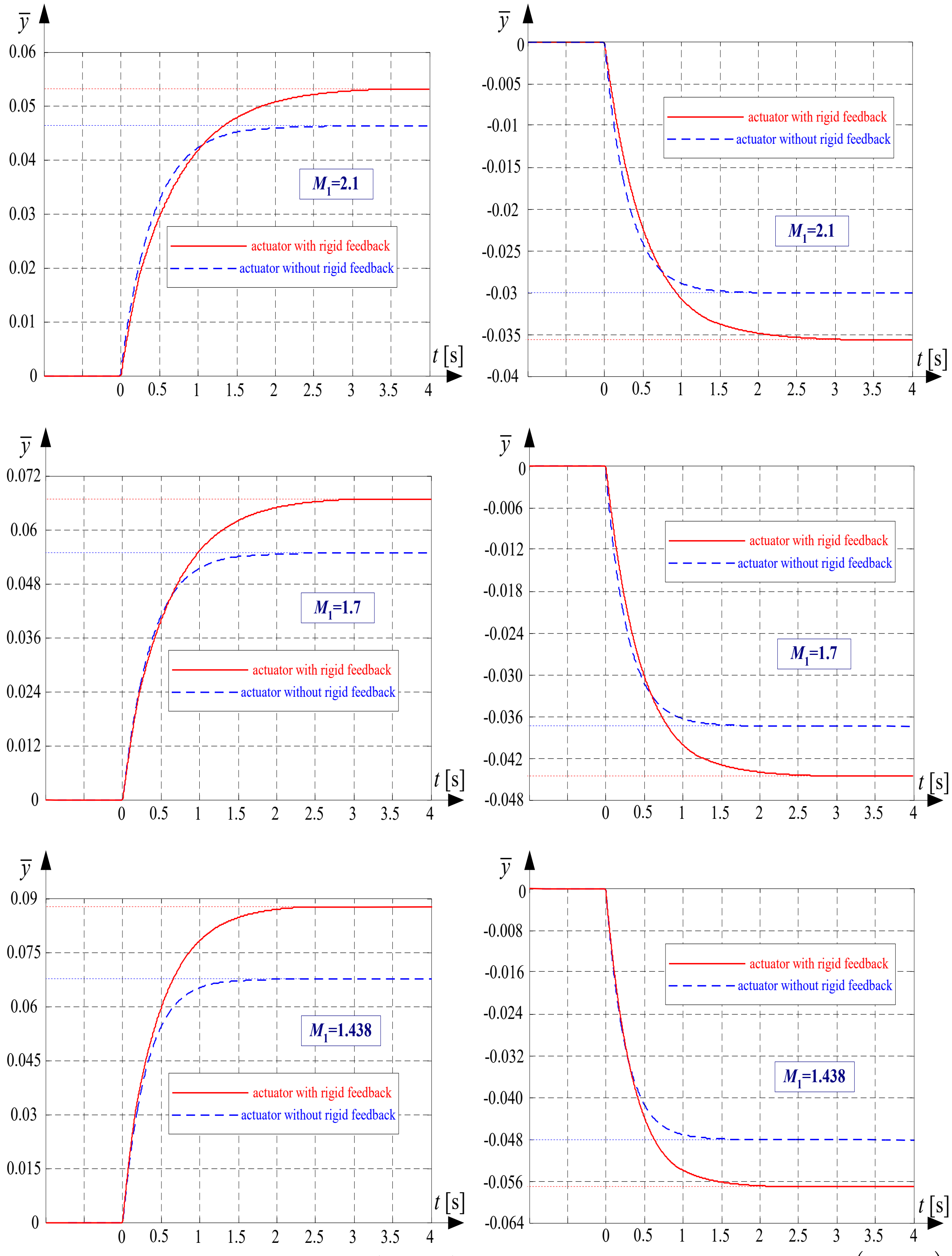
The quality of the automatic control system of the air inlet's internal cross-section is estimated, based on its transfer functions' form, by studying its response to the step input of the pressure parameters. The study was conducted for three values of the Mach number of flight in front of the inlet, namely for the maximum speed ($M_1 = 2.1$), for the situation of detachment of the second oblique shock wave ($M_1 = 1.7$), and for the situation of detachment of the first oblique shock wave ($M_1 = 1.438$).

System's step response is presented in Fig. 8. Both actuator configurations were used for the studies: the basic actuator (without internal feedback), but also the actuator with internal feedback. The system response was plotted with a solid line for the basic actuator, and with a dashed line for the improved actuator. Figures 8.a depict system's step response for $\overline{p}_m^*$ and constant $p_m\left(\overline{p}_m = 0\right)$ for different Mach numbers, while Fig.8.b depict system's step response for $\overline{p}_m$ and constant $p_m^*\left(\overline{p}_m^* = 0\right)$ for different Mach numbers.

As expected, all step response curves behave asymptotically, with static errors and various settling times values (as presented in Table 1).

Table 1. Static errors and settling times

	Step input parameter	$\overline{p}_m^*$ and constant $p_m\left(\overline{p}_m = 0\right)$		$\overline{p}_m$ and constant $p_m^*\left(\overline{p}_m^* = 0\right)$	
Flight Mach number	Actuator / Parameter	With feedback	Without feedback	With feedback	Without feedback
$M_1 = 2.1$	Static error	5.3%	4.7%	3.6 %	3 %
	Settling time	3.2 sec	2.6 sec	3.0 sec	2.0 sec
$M_1 = 1.7$	Static error	6.8%	5.6%	4.7%	3.8%
	Settling time	2.7 sec	2.3 sec	2.6 sec	1.6 sec
$M_1 = 1.438$	Static error	8.5%	7.2%	5.8%	4.8%
	Settling time	2.3 sec	1.9 sec	2.0 sec	1.4 sec



a) step input for $\overline{p}_m^*$ and constant $p_m\left(\overline{p}_m = 0\right)$ b) step input for $\overline{p}_m$ and constant $p_m^*\left(\overline{p}_m^* = 0\right)$

FIG. 8 System's step response for different Flight Mach numbers and different actuator's architecture

From studying the graphs in Fig. 8, the values of the static errors and settling times were determined; analyzing the results in Table 1, it can be stated that the flight regime has an important influence on the behavior of the automatic system. Thus, the more intense the flight regime (the higher the flight Mach number), the more the settling times increase in value; however, automatic system's static errors have an opposite behavior, being smaller the more intense the flight regime. The static errors of the system in the case of step input of the static pressure parameter are negative, as expected from the transfer function form.

Both the settling times and the static errors are higher for the step input of the total pressure parameter than for the static pressure one; consequently, it can be stated that the flight mode influences more than the engine operating mode.

CONCLUSIONS

The paper studied a plan supersonic air inlet for aircraft use with variable inner cross-section and fix geometry centerbody as controlled object. Based on inlet's operation for different flight regimes, its optimal geometry for the centerbody was determined, as well as the conditions for inlet's activation (starting) using the inner flow channel's throat opening in order to preserve the normal shock-wave at the desired position and intensity.

Possible control laws for the inlet were discussed and the one that best suited the operating conditions of the inlet was chosen. In order to accomplish this task, an automatic control system for the throat's opening was issued, then described through its mathematical model. As controlled parameter of this system, the throat's opening (in fact the actuator's rod positioning) was obviously chosen; the control parameter was chosen between a lot of possibilities, but the pressure ratio through the inner shock-wave (proportional to the upstream flow's Mach number) was the first option.

The control system consists of a pressure ratio transducer and a hydraulic actuator; the pressure transducer is very important for the system's operation, because it should fulfill two main tasks: first of all - the sensing task (both pressures measuring), then the comparing task - to compare the measured pressure ratio to the preset pressure ratio value (which was determined from the construction along with the choice of the lengths of the lever arms). For the chosen system, the constructive values of the lever arms' length were determined from the condition of ensuring stability.

From studying the system's response to step input, it resulted that the system is always asymptotically stable, but with a static error, the value of which is all the greater the less intense the flight regime.

The system behavior was compared for the two possible actuator architectures (with or without internal rigid feedback); it resulted that the presence of an additional feedback, although it complicates the system architecture, has a beneficial influence on its operation, reducing both its settling times and its static errors.

The results may be used for inlet's control system pre-design, but for effective using of such a system, real-time experiments must be performed and corrections might be added.

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VERSATILITY, ADAPTABILITY AND FLEXIBILITY OF HELICOPTER ARMAMENT VARIANTS

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DOI: 10.19062/2247-3173.2025.26.17

Abstract: *The article will analyze the types of missiles that can be attached to the IAR 330 Puma SOCAT helicopter, compatible with its modern avionics and armament system. The key element is the presentation of the missiles that Rafael has designed, compatible with this type of helicopter, and finally a multi-criteria analysis will be performed based on their characteristics. The study will highlight the best existing constructive variant of the missiles that are compatible with the SOCAT system.*

Keywords: *multicriteria analysis, integration, smart munitions, various weapons, agility.*

1. INTRODUCTION

The SOCAT system (optoelectronic anti-tank reconnaissance and combat system) has an avionics architecture with armament systems, developed for the IAR Puma 330 helicopter at an advanced level foldable for the national specifics.

The SOCAT system has advanced technology regarding display, operation, armament and man-machine connection methods.

Thanks to this system, crews intended and trained on the Puma SOCAT are capable of performing attack and assault missions with a high probability of achieving the intended purpose, also benefiting from an increased survivability in a hostile environment (Fig.1).

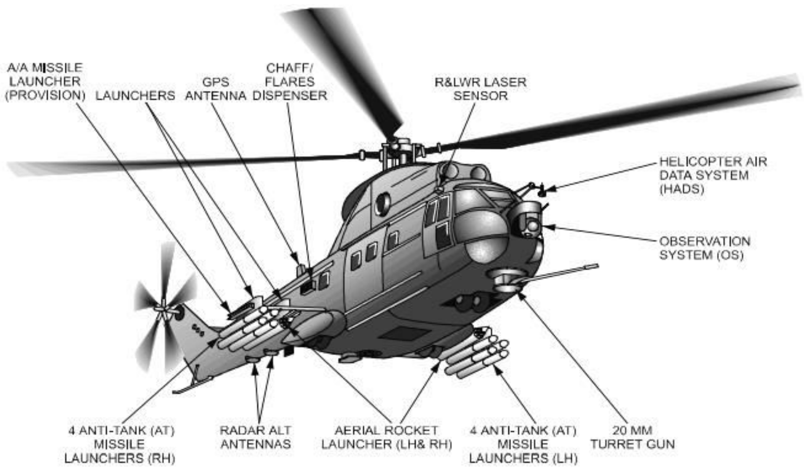

FIG.1 Weapons layout on the helicopter [4]

The increased performance and combat capabilities resulting from the modernization of the IAR-330 helicopters upgraded with the SOCAT system are summarized in general terms as follows[1,2,3]:

– safe and precise air navigation over long distances, with the possibility of flying at low altitude and in areas with difficult terrain geography, both day and night, in difficult weather conditions;

– communication and research data transmission systems with increased resistance to jamming, on the trajectory of the tactical field to ground-based equipment and to other combat aircraft, in real time;

– the advanced HOCAS- Hands on Collective and Stick concept (the concept in which the pilot metaphorically plays the piano) the use of onboard weapons without the pilot taking his hands off the flight controls;

– discovery capacity, high resolution for identifying and combating enemy targets from long distances and with increased precision;

– protection and self-defense systems that increase the survivability on the battlefield.

The IAR 330 Puma SOCAT helicopter, in general, we can recall the following from the armament line:

- Onboard cannon: 1 × 20 mm GIAT THL20 turreted cannon;
- Unguided missiles: PRND S-5K/M, 57 mm caliber;
- Guided missiles: 8 × anti-tank missiles. [1,2,3]

The following will be presented the types of missiles that are compatible with the SOCAT system [4,5,6]:

X-5 missile

The X-5 missile is a wire-guided, anti-tank missile, capable of destroying armored ground targets or fortifications. The X-5 system automatically ensures the activation of the CHECK mode. This mode is the system status reporting mode when it reports to the operating system the current status of the missiles loaded on the launchers.[6]

X-8** missile

The X-8** anti-tank missile has the same specifications as the X-5 missile, the same operating mode, the only significant difference between the two missiles would be the length of the wire through which information is transmitted to the missile, this being up to 9 km, therefore the range is between 400 m and 9000 m. [6,7]

SPIKE ER Missile

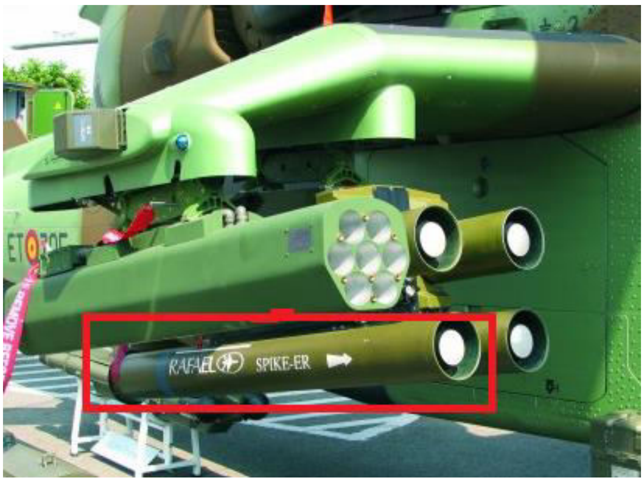

FIG.2 *SPIKE ER Missile* [11]

The Spike ER missile is an anti-tank missile with a range of 8 km, which can be guided by laser or radar. It has an electro-optical guidance system, compatible with the IAR 330 Puma SOCAT helicopter's target acquisition, search and targeting system (fig.2). It has two cameras, one CCD, used during the day, and one IIR with infrared that can be used at night with a viewing accuracy of the CCD. [7,8,]

The technical-tactical characteristics and specifications of the missiles are presented in table no. 1.

Table no. 1

Characteristic	Performance	Rocket
Distance	400m - 6 km	X-5
Flight time	36 s	
Flight speed	150 m/s	
Image sensor type	Channel/IR channel;	
Guidance modes	Fire and forget -Fire, observe and correct	
Blow mass:	32 kg	
Blow length	1.67m	
Blow diameter:	171mm	
Distance	400m to 9000m	X-8**
Flight time	40	
Flight speed	225 m/s	
Image sensor type	channel or IR channel	
Guidance modes	Fire and forget -Fire, observe and correct	
Blow mass	32 kg	
Blow length	1.67m	
Blow diameter:	171mm	
Distance	400m to 8000m	Spike ER
Flight time	50s	
Flight speed	160-180m/s	
Image sensor type	channel or IR channel	
Guidance mode	Fire and forget -Fire, observe and correct	
Blow mass	34 kg	
Blow length	1.450m	
Blow diameter	150mm	

2. MULTICRITERIA ANALYSIS

To prepare a multicriteria analysis of the main characteristics of the presented missiles, it will be carried out with the model largely [9].

The calculation will be carried out in the following stages:

Establishment of criteria:

The actual values of the characteristics of the systems that we compare. In table 4, the following notations will be used:

- ✓ C1 – criterion 1 – maximum firing range [km] – maximum;
- ✓ C2 – criterion 2 – flight speed [m/s] – maximum;
- ✓ C3 – criterion 3 – flight time [s] – maximum;
- ✓ C4 – criterion 4 – strike mass [kg] – maximum

The three criteria were established in accordance with the common characteristics of the aircraft analyzed previously.

Criterion 1 is an important characteristic because the possibility of launching a missile from a greater distance significantly increases the chances of survival of the crew.[8]

The following two criteria are missile performance characteristics that influence the chances of hitting targets, are presented in table no.2.

Table no.2

Rocket	C_1	C_2	C_3	C_4
X-5	7	150	36	32
X-8**	9	225	40	32
Spike ER	8	180	50	34

Ince the importance of the criteria differs, a table is established as follows:

- If, when comparing criterion “i” with criterion “j”, criterion “i” is more important, the value 1 is entered in the table next to criterion “i”;
- The summation is made, obtaining a value for each criterion;
- The weight coefficient for criterion “i” results from the relationship [9,10]:

$$p_i = \frac{\sum_j M_p(i,j)}{\max_k \sum_j M_p(k,j)} \tag{1}$$

Table no.3 presents the weight matrix, Mp, and in the last row the values of the weight coefficients for the criteria are given.

Tabel no.3 Weight matrix

	C_1	C_2	C_3	C_4
C_1	0,60	0,60	0,00	0,80
C_2	0,60	0,60	0,60	0,80
C_3	1,00	0,60	0,60	0.90
C_4	0,70	0,70	0,70	0,80
S	2,90	2,50	1,90	3,30
P	1,00	0,87	0,64	1,00

In the utility matrix (table 3) the characteristics for each criterion will be compared according to the rule: 1 the best and 0 the worst.

Since the table with the characteristics of each component contains values given in different units of measurement, it is transformed into table 4, which contains only dimensionless values:

For maximization [9,10]

$$U_{ij} = \frac{a_{ij}}{a_{ij\max}} \leq 1 \tag{2}$$

For minimization [9,10]

$$U_{ij} = \frac{\min a_{ij}}{a_{ij}} \leq 1 \tag{3}$$

3. PERFORMANCE MATRIX

In the performance matrix, the characteristics for each criterion will be compared according to the rule: 1 the best and 0 the worst.

The performance matrix is presented in table 4. The utility matrix is multiplied by the weight vector.

Table 4. Utilities and performance matrix

Racheta	C_1	C_2	C_3	C_4	P_1C_1	P_2C_2	P_3C_3	P_4C_4	SP_iC_i
X-5	0,66	0,66	0,72	0,66	0,76	0,59	0,46	0,46	**2,27**
X-8**	1,00	1,00	0,80	0,66	1,00	0,85	0,51	0,46	**2,82**
Spike ER	0,88	0,80	1,00	0,8	0,9	0,65	0,60	0,60	**2,75**

In this chapter, we have analyzed the compatible missiles that can be used on the IAR-330 Puma Socat helicopter, namely: X-5, X-8**, Spike ER

To prepare the ranking, the technical and tactical characteristics of each missile were presented and the important common elements were compared.

The comparison was made using three criteria, namely: C1 – maximum firing distance, C2 – maximum flight speed, C3 – maximum flight time, C4 – strike mass.

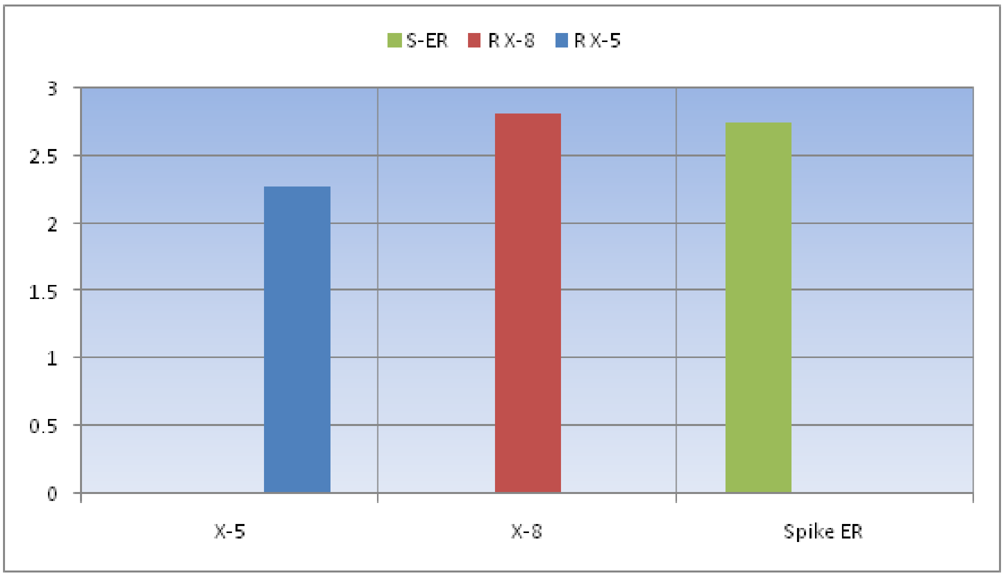

FIG.1 Rocket compatibility chart

4. CONCLUSIONS

In this article, we analyzed the missiles that can be used on the IAR-330 Puma Socat helicopter, namely: X-5, X-8**, Spike ER. We conducted a multi-criteria analysis, focusing on 4 criteria considered the most important.

The comparison was made using four criteria, namely: C1 – maximum firing distance, C2 – maximum flight speed, C3 – maximum flight time, C4 – strike mass.

From the calculations performed and presented above, we concluded that for the selected criteria, the 3 missiles have similar compatibility with a slight advantage for the X-8** missile (Fig.1).

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NONLINEAR DYNAMICS AND ADAPTIVE CONTROL USING THE DYNAMIC INVERSION CONCEPT AND NEURAL NETWORKS FOR A GUIDANCE GYROSYSTEM (GG) WITH ONE GYROSCOPE AND TWO SUSPENSION GIMBALS (GAR) PART 1.OBTAINING THE NONLINEAR DYNAMIC MODEL

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DOI: 10.19062/2247-3173.2025.26.18

***Abstract**: This paper series presents a study on the nonlinear dynamics and adaptive control of the guidance (GG) with a fast astatic gyroscope in external gimbal suspension (GAR), using the concept of dynamic inversion and neural networks. In part 1, a new nonlinear dynamic model is derived for the GG placed on an aircraft (rocket), which expresses the GG dynamics relative to the absolute trihedron; generalized Euler equations are used for its dynamic elements (rotor-inner gimbal assembly and outer gimbal). The absolute angular velocities of the GG's dynamic elements have as components their angular velocities relative to the trihedron linked to the guidance line, and the perturbing angular velocities induced by the rocket's angular velocities around its axes. The obtained nonlinear equations are then expressed in equivalent forms, where the new variables are the angular rotation velocities of the guidance line (the target coordinator axis, i.e., the gyroscope's proper angular momentum axis). The angular rotation velocities of the guidance line are chosen as the output variables of the GG, with respect to which the relative degrees of the equations are equal to 2. The input variables of the nonlinear dynamic model are the command currents applied to the command coils of the motors located in the axes of the two gyroscopic gimbals, which create, by gyroscopic effect, correction angular velocities the orientation of the target coordinator axis (guidance line) in the direction of the target line. The obtained equations contain terms that are functions of the input and output variables, as well as terms that are functions of the transport angular velocities of the guidance line and perturbing terms (functions of the rocket's angular velocities).*

***Keyords:** GG, GAR, guidance line, line of sigh.*

1. INTRODUCTION

Gyroscopic systems for orientation and stabilization represent an important category of gyrosystems, which are monoaxial or constructed on the principle of biaxial or triaxial force gyrostabilizers. These systems are used for orienting and stabilizing an axis (the target coordinator axis) along the guidance direction (an axis oriented towards a fixed point in space, called the target point). In the case of a platform with one, two, or three stabilization axes, the stabilized axis (guidance line) is the axis perpendicular to the plane of the stabilized platform, which can be terrestrial, maritime, aerial, or spatial [1-10].

The gyroscopes used are of the GAR type or speed gyroscopes, mounted on gimbals with mechanical suspension or magnetic suspension [11-18].

In most specialized works, the dynamic models used and the control laws are linear, the mathematical models being obtained by linearization around specific orientation and stabilization directions. Some works utilize nonlinear models without decoupling or with decoupling and independent control of dynamic elements (rotor, inner gimbal, outer gimbal) [9-11, 19-25].

In Part 1 of this paper series is presented the structure of the monoaxial GG with GAR, with the trihedrons and the associated angular magnitudes of the GG is presented (Section 2), new nonlinear forms of dynamic models are derived (Section 3), and conclusions are formulated in Section 4.

In Part 2 of this paper series is presented the design of the adaptive control architecture for the GG's stabilization and orientation using the Matlab/Simulink model, and the theoretical results are validated through numerical simulation.

2. GG STRUCTURE, TRIEDRAS AND ASSOCIATED ANGULAR MAGNITUDES

Such a guidance gyrosystem (GG), shown in Fig. 1, consists of the following subsystems: GAR; target coordinator (TC), located on the inner gimbal (IC); adaptive controller, consisting of two correction networks; gyroscopic gimbals rotation motors (CM1 and CM2). TC measures angular deviations α and β between its axis, that is, the line of sight (view) *oz* and the line of the target (guidance line) ox_T ,highlighted in Fig. 2.a.

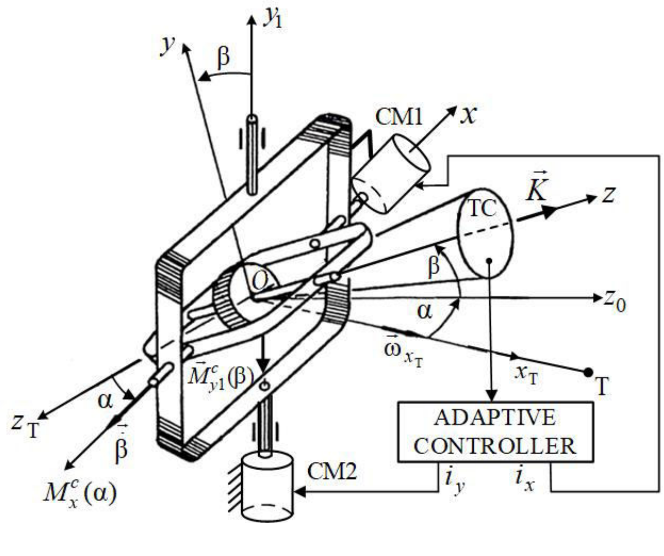


FIG.1 Guidance gyrosystem (GG) structure

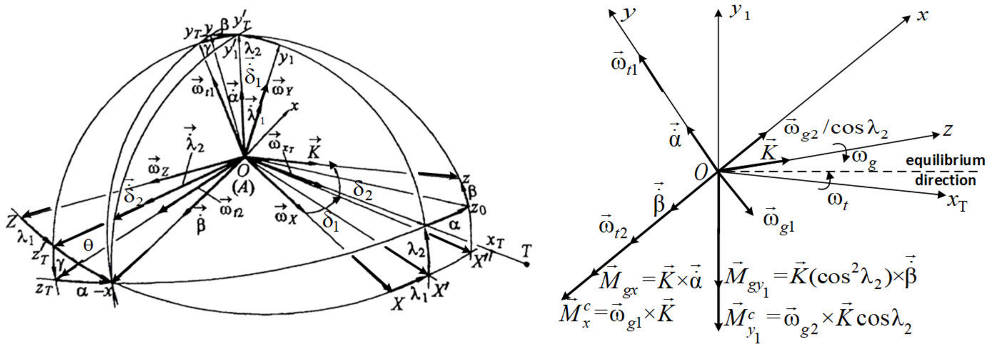
The trihedron that refers to the base (the aircraft, A) is *OXYX*, the trihedron that refers to the outer gimbal (OG) is oxy_1z_0, the trihedron that refers to the inner gimbal (IG) is $oxyz$ (RESAL's trihedron) and the trihedron that refers to the target line (OT) is $ox_Ty_Tz_T$; the axis ox_T is oriented to the target (T), and oy_T and oz_T rotate around the axis ox_T with with angular velocity ω_{x_T} . The bearing of the target line is expressed by the angle λ (with the components λ_1 and λ_2 in the two planes), and the bearing of the line of sight is expressed by the angle δ (with the components δ_1 and δ_2 in the two planes).

The aircraft A rotates around its axes with angular velocities $\omega_X, \omega_Y, \omega_Z$. These generate angular velocity ω_{x_T} which, according to Fig.2.a, has the expression [12]

$$\omega_{x_T} = \frac{\omega_X \cos\lambda_1 - \omega_Z \sin\lambda_1}{\cos\lambda_2} \tag{1}$$

If ω_{x_T} would be null, the trihedron that refers to the target line would be $ox_T y'_T z'_T, \theta = 0$ and $\vec{\alpha}$ oriented along the axis $oy'_T \square oy'_1$. But, because $\omega_{x_T} \square \omega_X = \dot{\gamma} \neq 0$ it follows that the trihedron $ox_T y'_T z'_T$ rotates with angular velocity $\vec{\dot{\gamma}}$ (with angle γ) thus passing in $ox_T y_T z_T$.

Angular velocity of rotation of the target line (OT, ω_{x_T}) relative to the inertial frame of reference is ω_t (with the components ω_{t1} and ω_{t2}) and and the angular velocity of rotation of the target line relative to the trihedron connected to the base (A) is $\dot{\lambda}$ (with the components $\dot{\lambda}_1$ and $\dot{\lambda}_2$ in the two planes), $\vec{K}$ is the angular momentum of the gyroscope (the axis of the target coordinator TC).



a. b.

FIG.2 Trihedral coordinate systems and related angular measurements GG

3. NONLINEAR FORMS OF GG DYNAMICS

To obtain the equations of the dynamics of GG with GAR, the generalized Euler equations of motion of the assembly (R+IG) – gyroscopic rotor + IG around the axis *ox* and of the outer gimbal (OG) around the axis oy_1 are used. These equations, for GAR located on a mobile base, are

$$\frac{\partial K_x^{R+IG}}{\partial t} + \Omega_y^{R+IG} K_z^{R+IG} - \Omega_z^{IG} K_y^{R+IG} = M_x^{R+IG}, M_x^{R+IG} = M_x \tag{2}$$

$$\frac{\partial K_x^{R+OG}}{\partial t} + \Omega_{z0}^{OG} K_x^{OG} - \Omega_x^{OG} K_{z0}^{OG} = M_{y1}^{OG} \tag{3}$$

the angular velocities of the assembly (R+IG), respectively of the outer gimbal OG, were indexed superiorly with (R+IG), IG or OG, suggesting that the respective dynamic element (R, IG,OG) does not rotate directly around the respective axis, mentioned by the (lower index).

From the relationship

$$M_{y1} = M_{y1}^{R+IG+OG} = M_{y1}^{OG} + M_{y1}^{R+IG} = M_{y1}^{OG} + M_{y}^{R+IG}\cos\beta + M_{z}^{R+IG}\sin\beta \tag{4}$$

is expressed M_{y1}^{OG}

$$M_{y1}^{OG} = M_{y1} - M_{y}^{R+IG}\cos\beta - M_{z}^{R+IG}\sin\beta \tag{5}$$

$$M_{y}^{R+IG} = \frac{\partial K_{y}^{R+IG}}{\partial t} + \Omega_{z}^{IG}K_{x}^{R+IG} - \Omega_{x}^{R+IG}K_{z}^{R+IG} \tag{6}$$

$$M_{z}^{R+IG} = \frac{\partial K_{z}^{R+IG}}{\partial t} + \Omega_{x}^{R+IG}K_{y}^{R+IG} - \Omega_{y}^{R+IG}K_{x}^{R+IG} \tag{7}$$

$$\Omega_{x}^{R+IG} = \Omega_{x}^{R} = \Omega_{x}^{IG}, \Omega_{y}^{R+IG} = \Omega_{x}^{R} = \Omega_{x}^{IG} \tag{8}$$

$$\begin{aligned}
&K_{x}^{R+IG} = K_{x}^{R} + K_{y}^{IG}, K_{y}^{R+IG} = K_{y}^{R} + K_{y}^{IG}, K_{z}^{R+IG} = K_{z}^{R+IG} = K_{z}^{R} + K_{z}^{IG}\\
&K_{x}^{R} = A\Omega_{x}^{R}, K_{y}^{R} = B\Omega_{y}^{R}, K_{z}^{R} = C\Omega_{z}^{R}\\
&K_{x}^{IG} = A_1\Omega_{x}^{IG}, K_{y}^{IG} = B_1\Omega_{y}^{IG}, K_{z}^{IG} = C_1\Omega_{z}^{IG}\\
&K_{x}^{OG} = B_2\Omega_{x}^{OG}, K_{y1}^{OG} = A_2\Omega_{y1}^{OG}, K_{z0}^{OG} = C_2\Omega_{z0}^{OG}
\end{aligned} \tag{9}$$

$A,B = A,C$ are the moments of inertia of R about to the axes of the trihedron $oxyz, A_1, B_1, C_1$ - the moments of inertia of IG about the axes of the trihedron $oxyz$ and A_2, B_2, C_2 - the moments of inertia of OG about the axes of the trihedron oxy_1z_0.

The absolute angular velocities, with the following expressions, are expressed as sums between the angular velocities of the dynamic elements (R, IG, OG) relative to the trihedron connected to the target line $ox_Ty_Tz_T$, angular transport velocities of the target line ω_{t1} and ω_{t2}, ω_{xT}, with respect to the inertial trihedron and angular velocities $\omega_x, \omega_y, \omega_z$ induced by angular velocities $\omega_X, \omega_Y, \omega_Z$ of the base (A); according to Fig.2.a,

$$\begin{aligned}
&\Omega_{x}^{R} = -(\beta + \omega_{t2}\cos\alpha + \omega_{x_T}\sin\alpha) + \omega_x \approx -(\dot\beta + \omega_{t2} + \omega_{x_T}\alpha) + \omega_x\\
&\Omega_{y}^{R} = \dot\alpha\cos\beta + \omega_{t1} - \omega_{x_T}\cos\alpha\sin\beta + \omega_y \approx \dot\alpha + \omega_{t1} + \omega_{x_T}\beta + \omega_y\\
&\Omega_{z}^{R} = \dot\varphi + \Omega_{z}^{IG} = \dot\varphi + \dot\alpha\sin\beta + \omega_{x_T}\cos\alpha\cos\beta + \omega_z \approx \dot\varphi + \dot\alpha\beta + \omega_{x_T} + \omega_z\\
&\Omega_{x}^{IG} = \Omega_{x}^{R}, \Omega_{y}^{IG} = \Omega_{y}^{R}, \Omega_{x}^{OG} = \omega_x, \Omega_{y_1}^{OG} = \dot\alpha + \omega_y\cos\beta \approx \dot\alpha + \omega_y, \Omega_{z0}^{OG} = \omega_z\cos\beta \approx \omega_z
\end{aligned} \tag{10}$$

With $\dot\varphi$ the angular velocity of rotation of the gyroscopic rotor R was denoted. The angular velocities $\omega_x, \omega_y, \omega_z$ have the following expressions

$$\begin{aligned}
&\omega_x = -\omega_X\sin(\lambda_1 + \theta) - \omega_z\cos(\lambda_1 + \theta) \approx \omega_X\sin\lambda_1 - \omega_Z\cos\lambda_1\\
&\omega_y = -\omega_X\cos\delta_1\sin\delta_2 + \omega_Y\cos(\lambda_2 + \beta) + \omega_Z\sin\delta_1\sin\delta_2 \approx -\omega_X\cos\lambda_1\sin\lambda_2 +\\
&\quad + \omega_Y\cos\lambda_2 + \omega_Z\sin\delta_1\sin\delta_2 = -\omega_{x_T}\sin\lambda_2\cos\lambda_2 + \omega_Y\cos\lambda_2\\
&\omega_z = \omega_X\cos\delta_1\cos\delta_2 - \omega_Z\sin\delta_1\cos\delta_2 \approx \omega_X\cos\lambda_1\cos\lambda_2 - \omega_Z\sin\delta_1\cos\delta_2 = -\omega_{x_T}\cos\lambda_2
\end{aligned} \tag{11}$$

The moments acting about the axes ox and oy_1 are expressed as sums of the disruptive moments $(M_x^e$ and $M_{y1}^e)$ with dynamic damping moments $(M_x^v$ and $M_{y1}^v)$ and with correction moments $(M_x^c$ and $M_{y1}^c)$

$$M_x = M_x^e + M_x^v + M_x^c, M_{y1} = M_{y1}^e + M_{y1}^v + M_{y1}^c \tag{12}$$

Given that the external disruptive moments are produced by the angular velocities of the base $\omega_X, \omega_Y, \omega_Z$, will be omitted from now on M_x^e and M_{y1}^e, their role being taken by the disruptive moments generated by these angular velocities. The dynamic damping moments are expressed as

$$M_x^v = F_x \dot{\delta}_2 \cos\theta \square F_x \dot{\lambda}_2, M_{y1}^v = -F_y \dot{\delta}_1 \square F_y \dot{\lambda}_1 \tag{13}$$

with $\dot{\lambda}_1$ and $\dot{\lambda}_2$ by forms

$$\begin{aligned} \dot{\lambda}_1 &= \frac{\dot{\alpha} + \omega_{t1}}{\cos\lambda_2} - \frac{\omega_{x_T}\beta}{\cos\lambda_2} + \omega_X \cos\lambda_1 - \omega_Z \sin\lambda_1 - \omega_Y \\ \dot{\lambda}_2 &= \dot{\beta} + \omega_{x_T}\alpha - \omega_X \sin\lambda_1 - \omega_Z \cos\lambda_1 \end{aligned} \tag{14}$$

Equations (3) and (1) for ox and oy_1, with (5) ÷ (12), become

$$\begin{aligned} & B_0\ddot{\alpha} + [F_y - (A+B_1)\omega_{t2}]\dot{\alpha} + \omega_{x_T}(\omega_{t1} + \omega_{x_T}\sin^2\lambda_2)\alpha + [K\cos^2\lambda_2 + (B_1 - A_1)\omega_{x_T}]\dot{\beta} + \\ & +(A+B_1)(\omega_{t1} + \omega_{x_T}\omega_{t2}\dot{\omega}_{x_T})\beta + (A+B_1)\omega_{x_T}^2\alpha\beta - (A+B_1)\omega_{x_T}\dot{\alpha}\alpha - A_0\omega_{t2}\alpha\beta\cdot\omega_{x_T}\beta\dot{\beta} - \\ & -A_0\beta\dot{\alpha}\dot{\beta}(A+B_1)\alpha\dot{\beta} + K\omega_{x_T}\alpha\beta\dot{\alpha} + +C\beta\dot{\alpha}\dot{\beta} - M_{y1}^c(\beta) = -K\omega_{t2}\cos^2\lambda_2 - B_0\dot{\omega}_{t1} + \\ & +F_y(\omega_Y\cos\lambda_2 - \frac{1}{2}\omega_{x_T}\sin^2\lambda_2 - \omega_{t1}) - (A_2 + C_1)\frac{1}{2}\dot{\omega}_{x_T}\sin^2\lambda_2 - -\omega_{t1}\omega_Y\tan\lambda_2 - \\ & -\omega_{t1}\omega_X\cdot\sin\lambda_2\tan\lambda_2 + \omega_{x_T}\omega_{t2}\cos^2\lambda_2 + (A_2 + B_2 - C_2)[\omega_X\omega_Y\cos^2 2\lambda_1 + \frac{1}{2}(\omega_X^2 - \omega_Y^2)\sin 2\lambda_1] \\ & A_0\ddot{\beta} + F_x\dot{\beta} + K\omega_{x_T}\beta + (-K + D_0\omega_{x_T})\dot{\alpha} + (A_0\dot{\omega}_{x_T} + F_x\omega_{x_T})\alpha - (C + C_1)(\omega_{t1}\omega_Y)\dot{\alpha}\beta + \\ & +E_0\dot{\alpha}^2\beta + E_0\omega_{x_T}\dot{\alpha}\beta^2 + M_x^c(\alpha) = K\omega_{t1} + A_0\dot{\omega}_{t2} + F_x(\omega_X\sin\lambda_1 + \omega_Z\cos\lambda_1 - \dot{\omega}_{t2}) \end{aligned} \tag{15}$$

From the stability conditions, the correction moments $(M_x^c$ and $M_{y1}^c)$ have the same signs as the correction moments:

$M_{gx} = -K\dot{\alpha}$ and $M_{gy_1} = M_{gy}\cos\beta\cos\lambda_2 \square M_{gy}\cos\lambda_2 = -K(\cos^2\lambda_2)\dot{\beta};$

The correction moments are chosen by next forms

$$\begin{aligned} & M_x^c = -k_1\alpha = -r_1 K\alpha = K\omega_{g1}, M_{y1}^c = M_y^c\cos\beta\cos\lambda_2 \square M_y^c\cos\lambda_2 = \\ & \quad = -k_2\beta\cos\lambda_2 = -r2(K\cos\lambda_2)\beta = K(\cos\lambda_2)\omega_{g2} \end{aligned} \tag{16}$$

with the notations

$$\begin{aligned} & \omega_{g1} = -r_1\alpha, \omega_{g2} = -r_2\beta, r_1 = k_1 / K, r_2 = k_2 / K, F_x / K = f_x, F_y / K = f_y, \\ & B_0 / K = b_0, A_0 / K = a_0, A / K = a_3, A_1 / K = a_1, A_2 / K = a_2, B_1 / K = b_1, \\ & B_2 / K = b_2, C / K = c, C_1 / K = c_1, C_2 / K = c_2, D_0 / K = d_0 = A_0 - (C - C_1) / K, \\ & E_0 / K = e_0 = [(C + C_1) - (B + B_1)] / K, \end{aligned} \tag{17}$$

the ecuations (15) becomes

$$b_0\ddot{\omega}_{g1}+[f_y-(a_3+b_1)\omega_{t2}]\dot{\omega}_{g1}+(\omega_{x_T}\omega_{t1}+\omega_{x_T}^2\sin^2\lambda_2)\omega_{g1}+\frac{r_1}{r_2}[\cos^2\lambda_2+$$
$$+(b_1-a_1)\omega_{x_T}]\dot{\omega}_{g2}+r_1(a_3+b_1)(\omega_{t1}+\omega_{x_T}\omega_{t1}+\dot{\omega}_{x_T})\omega_{g2}-\frac{a_3+b_1}{r_2}\omega_{x_T}^2\omega_{g1}\omega_{g2}-$$
$$-\frac{a_3+b_1}{r_1}\omega_{x_T}\omega_{g1}\dot{\omega}_{g1}+\frac{a_0}{r_2}\omega_{t2}\dot{\omega}_{g1}\dot{\omega}_{g2}+\frac{r_1}{r_2^2}(a_3+b_1)\cdot\omega_{x_T}\omega_{g2}\dot{\omega}_{g2}-\frac{a_0}{r_2^2}\dot{\omega}_{g1}\omega_{g2}\dot{\omega}_{g2}+$$
$$+\frac{a_3+b_1}{r_2}\omega_{g1}\dot{\omega}_{g2}+\frac{\omega_{x_T}}{r_1r_2}\omega_{g1}\dot{\omega}_{g2}\omega_{g2}+\frac{c}{r_2^2}\dot{\omega}_{g1}\omega_{g2}\dot{\omega}_{g2}+r_1(\cos\lambda_2)\omega_{g2}=r_1(\cos^2\lambda_2)\omega_{t2}+N_y(t) \tag{18}$$
$$a_0\ddot{\omega}_{g2}+f_x\dot{\omega}_{g2}+\omega_{x_T}\omega_{g2}\frac{r_2}{r_1}(1+d_0\omega_{x_T})\dot{\omega}_{g1}+\frac{r_2}{r_1}(a_0\dot{\omega}_{x_T}+f_x\omega_{x_T})\omega_{g1}-\frac{c+c_1}{r1}(\omega_{t1}+\omega_Y)\dot{\omega}_{g1}\omega_{g2}+$$
$$+\frac{e_0}{r_1^2}\dot{\omega}_{g1}^2\omega_{g2}+\frac{e_0}{r_1r_2}\omega_{x_T}\dot{\omega}_{g1}\omega_{g2}\dot{\omega}_{g2}-r_2\omega_{g1}=-r_2\omega_{t1}+N_x(t)$$

Where $N_x(t)$ and $N_y(t)$ are perturbation terms that do not contain the angular velocities ω_{g1},ω_{g2} and accelerations $\dot{\omega}_{g1},\dot{\omega}_{g2}$, that is, they contain only external disruptive terms;

$$N_x(t)=-r_2a_0\dot{\omega}_{t2}-r_2f_x(\omega_Y\sin\lambda_1+\omega_Z\sin\lambda_1-\omega_{t2}$$
$$N_y(t)=-r_1b_0\dot{\omega}_{t1}-r_1f_y(\omega_Y-\frac{1}{2}\omega_{x_T}\sin 2\lambda_2-\omega_{t1})-r_1(a_2++c_1)\cdot$$
$$\cdot(\frac{1}{2}\dot{\omega}_{x_T}\sin 2\lambda_2-\omega_{t1}\omega_Y\cdot\tan\lambda_2\omega_{t1}\omega_X\sin\lambda_2\tan\lambda_2+\omega_{x_T}\omega_{t2}\cos^2\lambda_2)- \tag{19}$$
$$-r_1(a_2+b_2-c_2)\cdot[\omega_X\omega_Y\cos 2\lambda_1+\frac{1}{2}(\omega_X^2-\omega_Y^2)\sin 2\lambda_1]\cos\lambda_2$$

In the absence of disturbances $(N_x(t)=N_y(t)=\omega_{x_T}=\dot{\omega}_{x_T}=0)$, that is, **in orientation mode**, with $\omega_{t1}=\text{const.}$ and $\omega_{t2}=\text{const.}$, at equilibrium $\omega_{g1}=\text{const.}=\omega_{t1}$and $\omega_{g2}=\text{const.}=\omega_{t2}\cos\lambda_2$ (for $M_x^c/K=\omega_{g1}$and $M_y^c/K=\omega_{g2}$); the sighting line tends to follow the target line, which, in turn, overlaps the equilibrium direction (the straight line with the dashed line in Fig.2.7.b resulting from the rotation of the axis ox_T with the angular ω_t velocity).

Coefficients r_1 and r_2 can be chosen, for example, as follows. If the maximum values are known $\omega_{g1maximum},\omega_{g2maximum},\alpha_{maximum},\beta_{maximum}$, then

$$r_1=\frac{k_1}{K}=\frac{\omega_{g1maximum}}{\alpha_{maximum}},_1 r_2=\frac{k_2}{K}=\frac{\omega_{g1maximum}}{\beta_{maximum}} \tag{20}$$

taking into account that in orientation mode (equation (18)), $\omega_{g1}=M_x/K$, $\omega_{g1maximum}=$ $=\omega_{t1maximum}$, $\omega_{g2maximum}=\omega_{t2maximum}\cos\lambda_2^*$ and chosen $\omega_{t1maximum}/\alpha_{maximum}=\omega_{t2maximum}/$ $/\beta_{maximum}=r$, results

$$r_1=r=\frac{\omega_{t1maximum}}{\alpha_{maximum}},r_2=\frac{\omega_{t2maximum}}{\beta_{maximum}}\cos\lambda_2^*=r\cos\lambda_2^* \tag{21}$$

with λ_2^* its average value of λ_2.

Rotation of the sighting line (marking) *oz* with the angles α and β, so with angular velocities $\vec{\dot{\alpha}}$ and $\vec{\dot{\beta}}$, will generate gyroscopic torques,

$\vec{M}_{gx} = \vec{K} \times \vec{\dot{\alpha}}$ and $M_{gy_1} = \vec{K}(\cos^2 \lambda_2) \times \times \vec{\dot{\beta}}$ (Fig.2.b and the equations (16)).

Over these gyroscopic torques are superimposed correction torques ($\vec{M}_x^c$ and $\vec{M}_{y1}^c$), (16), $\vec{M}_x^c = \vec{\omega}_{g1} \times \vec{K}, \vec{M}_{y1}^c = \vec{\omega}_{g2} \times \vec{K}(\cos \lambda_2)$. These torques rotate the axis *oz* towards the axis ox_T and this, in turn, rotates with the angular velocity of transport ω_T (having the components ω_{t1} and ω_{t2} along the axes oy_T and oz_T). So, in orientation mode, the two axes (*oz* and ox_T) overlap the equilibrium direction (the line represented by the dashed line); the equilibrium direction marks the overlap of the reference line *oz* (axis TC, that is, the vector $\vec{K}$) over the target line ox_T; $\vec{\boldsymbol{\omega}}_g + \vec{\boldsymbol{\omega}}_t = 0$ ($\omega_{g1} = \omega_{t1}, \omega_{g2} = \omega_{t2} \cos \lambda_2$).

Relative degrees of the dynamic model of GG in relation to the output variables $y_1 = \omega_{g1}$ and $y_2 = \omega_{g2}$ are equal to 2; the equations (18) (in which $\omega_{g1} = \dfrac{M_x^c}{K} = \dfrac{k_x}{K} i_x$ and $\omega_{g2} \cos \lambda_2 = \dfrac{M_{y1}^c}{K} = \dfrac{k_y}{K} i_y$) can be expressed in the following forms

$$\begin{aligned}
\ddot{y}_1 = & -\frac{f_y - (a_3 + b_1)\omega_{t2}}{b_0} \dot{y}_1 - \frac{\omega_{x_T}\omega_{t1} + \omega_{x_T}^2 \sin \lambda_2^*}{b_0} y_1 - \frac{r_1}{r_2} \frac{\cos^2 \lambda_2^* + (b_1 - a_1)}{b_0} \dot{y}_2 - \\
& -r_1 \frac{a_3 + b_1}{b_0} (\omega_{t1} + \omega_{x_T}\omega_{t2} + \dot{\omega}_{x_T}) y_2 + \frac{a_3 + b_1}{r_2 b_0} + \omega_{x_T}^2 y_1 y_2 + \frac{a_3 + b_1}{r_1 b_0} y_1 \dot{y}_1 - \frac{a_0 + b_0}{r_2 b_0} \cdot \\
& \cdot \omega_{t2} \dot{y}_1 y_2 - \frac{r_1}{r_2^2} \frac{(a_3 + b_1)\omega_{x_T}}{b_0} y_2 \dot{y}_2 - \frac{a_3 + b_1}{r_2} y_1 \dot{y}_2 - \frac{\omega_{x_T}}{r_1 r_2 b_0} y_1 \dot{y}_1 y_2 + \frac{a_0 - r_1 c}{r_2^2 b_0} \cdot \\
& \cdot \dot{y}_1 y_2 \dot{y}_2 - \frac{r_1}{b_0} \frac{k_y}{K} i_y + \frac{N_y^*}{b_0} \\
\ddot{y}_2 = & -\frac{f_x}{a_0} \dot{y}_2 - \frac{\omega_{x_T}}{a_0} y_2 + \frac{1 - d_0 \omega_{x_T}}{a_0} \frac{r_2}{r_1} \dot{y}_1 - \frac{a_0 \dot{\omega}_{x_T} + f_x \omega_{x_T}}{a_0} \frac{r_2}{r_1} y_1 + \frac{c + c_1}{r_1 a_0} (\omega_{t1} + \omega_Y) \cdot \\
& \cdot \dot{y}_1 y_2 - \frac{e_0}{r_1^2 a_0} \dot{y}_1^2 y_2 - \frac{e_0}{r_1 r_2 a_0} \omega_{x_T} \dot{y}_1 y_2 \dot{y}_2 + \frac{r_2}{a_0} \frac{k_x}{K} i_x + \frac{N_x^*}{a_0}
\end{aligned} \tag{22}$$

with N_x^* and N_y^* by forms (19), in which they were replaced λ_1 and λ_2 with their average values λ_1^* and λ_2^*; in (18) the correction moments were expressed

$$M_{y1}^c = k_y i_y, M_x^c = k_x i_x \tag{23}$$

where i_x and i_y are the control currents applied to the two motors in the axes *ox* and oy_1, and k_x and k_y are the coefficients of proportionality with the torque/current dimension.

The system of nonlinear equations (22) (nonlinear dynamics of GG) can be expressed in the form

$$\ddot{\boldsymbol{y}} = \hat{\boldsymbol{v}} + \boldsymbol{\varepsilon}, \hat{\boldsymbol{v}} = \begin{bmatrix} -m_2 y_1 - m_4 y_2 + m_5 y_1 y_2 - m_{12} i_y \\ -n_4 y_1 - n_2 y_2 + n_8 i_x \end{bmatrix} \tag{24}$$

4. CONCLUSIONS

The nonlinear equations of the dynamics of the GG placed on a rocket, relative to an absolute reference trihedron, are derived using the generalized Euler equations, taking into account the angular velocities of the sighting line relative to the trihedron connected to the guidance line, the angular transport velocities of the guide line and the angular velocities of rocket. In the obtained equations, the new variables represented by the angular velocities of the line of sight are introduced ω_{g1} and ω_{g2} ,oriented so that α and β the deviation angles of the sighting line from the guide line (according to Fig.2) cancel out. These angular precession speeds oriented around the cardanic suspension axes are created by gyroscopic effect by the correction moments (16) produced by the control moments (M_x^c and M_{y1}^c) produced by CM1 and CM2 engines.Through the action of these motors, the effects of external disturbances N_x^* and N_y^* are compensated . These effects are due to the angular velocities of the base and orient the line of sight over the guide line. The control moments M_x^c and M_{y1}^c are chosen proportionally to ω_{g1} and ω_{g2} (these are of the form (17), with the proportionality coefficients r_1 and r_2 (respectively, k_1 and k_2) functions of maximum transport angular velocities $\omega_{t1maximum}$ and $\omega_{t2maximum}$ of the guide line and the angles $\alpha_{maximum}$ and $\beta_{maximum}$ of the sighting line relative to the target line (21). The directions of control moments M_x^c and M_{y1}^c are the same as the directions of the gyroscopic torques created by the angular velocities $\vec{\dot{\alpha}}$ and $\vec{\dot{\beta}}$ of the sighting line (Fig.2.b). In orientation mode, according to equations (18) and Fig.2.b, $\omega_{g1} = \omega_{t1}$ and $\omega_{g2} = \omega_{t2} \cos \lambda_2^*$, relations that impose the input vector of GG on the output vector $\boldsymbol{y} = [\omega_{g1} \;\; \omega_{g2}]^T$. For reducing the bearing λ_2 of the sighting line so that $\omega_{g2} \to \omega_{t2}$, the rocket must be ordered through its pilot automatically so that $\lambda_2 \to 0$.

Relative degrees of the nonlinear dynamic model of GG (according to equations (22) in relation to the output vector variables ω_{g1} and ω_{g2} are equal with 2. By dynamic inversion, the vector of control currents i_y and i_x is calculated, these currents are applied to CM2 and CM1 engines.

For the nonlinear dynamic model (22), an adaptive controller is designed to stabilize and orient the line of sight over the guide line, using the concept of dynamic inversion and a neural network.

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NONLINEAR DYNAMICS AND ADAPTIVE CONTROL USING THE DYNAMIC INVERSION CONCEPT AND NEURAL NETWORKS FOR A GUIDANCE GYROSYSTEM (GG) WITH ONE GYROSCOPE AND TWO SUSPENSION GIMBALS (GAR) PART 2. ADAPTIVE CONTROL ARHITECTURE DESING AND VALIDATION

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DOI: 10.19062/2247-3173.2025.26.19

Abstract: *This paper presents the design of the adaptive control system of GG with GAR, consisting of a stabilization controller and an orientation controller; the concept of dynamic inversion is used. The equations of nonlinear dynamics of GG were obtained in Part 1 of this paper series.The stabilization controller (for the stabilization mode) consists of a 2nd order reference model, a linear dynamic compensator, of the P.D type, a linear state observer and a neural network. The neural network models the adaptive component of the control law, which has the role of compensating for the dynamic inversion error. The orientation controller is chosen as P.I. type. In stabilization mode, the system compensates for the effect of external disturbances induced by the rotations of the base (rocket), and in orientation mode, the system controls the rotation of the target coordinator TC so that the sighting line (TC axis) overlaps the guidance line. By numerical simulations, using the Matlab/Simulink model, the dynamic characteristics of GG are drawn for the stabilization mode and for the orientation mode.*

Keyords*: stabilization, guidance, dynamic inversion, neural network*

1. INTRODUCTION

The automatic control of the dynamics of gyroscopic systems for orientation and stabilization mono, bi and triaxial is addressed in many specialized works. In most of these, linearized dynamic models are used, with linear control laws, as for example, in the papers [1-7]. It is also worth mentioning the works in which the control laws used are nonlinear [8-18]. Nonlinear models and nonlinear control laws can be used for gyrosystems with GAR obtained by particularizing those deduced for DGMSCMG [19-22].

In this article, adaptive control based on the concept of dynamic inversion and the use of neural networks is used [23-26]. The controllers used for the orientation mode are of the P.I. or P.I.D. type, while those for the stabilization mode have linear dynamic compensators, linear state observers and neural networks as components. The neural network models the adaptive component of the control law, having the role, through its effect, to compensate for the influence of the dynamic inversion error.

The design of the two controllers is done in Section 2. Section 3 presents the Matlab Simulink model and, with it, the GG characteristics for the stabilization mode and for the orientation mode are plotted. In Section 4, conclusions are formulated.

2. DESIGN OF ADAPTIVE CONTROL SYSTEM OF GG WITH GAR

The concept of dynamic inversion and a neural network [23,24] are used to model the adaptive component, which has the role of compensating for the dynamic inversion error $\boldsymbol{\varepsilon} = [\varepsilon_1 \ \ \varepsilon_2]^T$.

Choosing output variables $y_1 = \omega_{g1}, y_2 = \omega_{g2}$ and input variables $u_1 = i_y$ and $u_2 = i_x$, equations (22) (from Part 2 of this paper series) can be expressed as follows

$$\ddot{y}_1 = v_1 = \hat{v}_1 + \varepsilon_1,\ \ddot{y}_2 = v_2 = \hat{v}_2 + \varepsilon_2;\ \hat{v}_1 = \hat{h}_{r1}(\boldsymbol{y}, \hat{\boldsymbol{u}}),\ \hat{v}_2 = \hat{h}_{r2}(\boldsymbol{y}, \hat{\boldsymbol{u}}); \tag{1}$$

ε_1 and ε_2 (dynamic inversion errors) contain all the other terms in (22)-from Part 1 of this paper series.

With the notations

$$\begin{aligned}
&m_1 = -\frac{f_y - (a_3 + b_1)\omega_{t2}}{b_0}, m_2 = \frac{\omega_{x_T}(\omega_{t1} + \omega_{x_T}\sin^2\lambda_2^*)}{b_0}, m_3 = \frac{r_1}{r_2}\frac{\cos^2\lambda_2^*(b_1 - a_1)\omega_{x_T}}{b_0},\\
&m_4 = r_1\frac{a_3 + b_1}{b_0}(\omega_{t1} + \omega_{x_T}\omega_{t1} + \dot{\omega}_{x_T}), m_5 = \frac{a_3 + b_1}{r_2 b_0} + \omega_{x_T}^2, m_6 = \frac{a_3 + b_1}{r_1 b_0}, m_7 = \frac{a_0}{r_2 b_0}\omega_{t2},\\
&m_8 = \frac{r_1(a_3 + b_1)}{r_2^2 b_0}\dot{\omega}_{x_T}, m_9 = \frac{a_3 + b_1}{r_1}, m_{10} = \frac{\omega_{x_T}}{r_1 r_2 b_0}, m_{11} = \frac{a_0 - r_1 c}{r_2^2 b_0}, m_{12} = \frac{r_1 k_y}{b_0 K},\\
&n_1 = \frac{f_x}{a_0}, n_2 = \frac{\omega_{x_T}}{a_0}, n_3 = \frac{r_2}{r_1}\frac{1 - d_0\omega_{x_T}}{a_0}, n_4 = \frac{r_2}{r_1}\frac{a_0\dot{\omega}_{x_T} + f_x\omega_{x_T}}{a_0}\frac{r_2}{r_1}, n_5 = \frac{c + c_1}{r_1 a_0}(\omega_{t1} + \omega_Y),\\
&n_6 = \frac{e_0}{r_1^2 a_0}, n_7 = \frac{e_0\omega_{x_T}}{r_1 r_2 a_0}, n_8 = \frac{r_2 k_x}{a_0 K},
\end{aligned} \tag{2}$$

the following results

$$\hat{v}_1 = \hat{h}_{r1}(\boldsymbol{y}, \hat{\boldsymbol{u}}) = -m_2 y_1 - m_4 y_2 + m_5 y_1 y_2 - m_{12} i_y; \tag{3}$$

$$\hat{v}_2 = \hat{h}_{r2}(\boldsymbol{y}, \hat{\boldsymbol{u}}) = -n_4 y_1 - n_2 y_2 + n_8 i_x; \tag{4}$$

$$\boldsymbol{\varepsilon}_1 = -m_1\hat{\dot{y}}_1 - m_3\hat{\dot{y}}_2 + m_6 y_1\hat{\dot{y}}_1 - m_7\hat{\dot{y}}_1 y_1 - m_8 y_2\hat{\dot{y}}_2 - m_9 y_1\hat{\dot{y}}_2 - m_{10} y_1\hat{\dot{y}}_1 y_2 + m_{11}\hat{\dot{y}}_1 y_2\hat{\dot{y}}_2 + N_y^*/b_0 \tag{5}$$

$$\boldsymbol{\varepsilon}_2 = n_3\hat{\dot{y}}_1 - n_1\hat{\dot{y}}_2 + n_5\hat{\dot{y}}_1 y_1 - n_6\hat{\dot{y}}_1^2 y_2 - n_7\hat{\dot{y}}_1 y_2\hat{\dot{y}}_2 + N_x^*/a_0 \tag{6}$$

The variables $\hat{\dot{y}}_1$ and $\hat{\dot{y}}_2$ represent the estimates of the variables $\dot{y}_1$ and $\dot{y}_2$, components of the output vector of the state observer.

The previous equations can be expressed in vector form

$$\ddot{\boldsymbol{y}} = \hat{\boldsymbol{v}} + \boldsymbol{\varepsilon}, \ddot{\boldsymbol{y}} = [\ddot{y}_1 \ \ddot{y}_2]^T, \hat{\boldsymbol{v}} = [\hat{v}_1 \ \hat{v}_2]^T, \boldsymbol{\varepsilon} = [\varepsilon_1 \ \varepsilon_2]^T, \tag{7}$$

$$\hat{\boldsymbol{v}} = \hat{\boldsymbol{h}}_r(\boldsymbol{y},\hat{\boldsymbol{u}}) = \begin{bmatrix} \hat{h}_{r1}(\boldsymbol{y},\hat{\boldsymbol{u}}) \\ \hat{h}_{r2}(\boldsymbol{y},\hat{\boldsymbol{u}}) \end{bmatrix} = -\begin{bmatrix} m_2 & m_4 \\ n_2 & n_4 \end{bmatrix}\boldsymbol{y} + \begin{bmatrix} m_5 \\ 0 \end{bmatrix} y_1 y_2 + \begin{bmatrix} -m_{12} & 0 \\ 0 & n_8 \end{bmatrix}\hat{\boldsymbol{u}} \tag{8}$$

$$\boldsymbol{\varepsilon} = \begin{bmatrix} \boldsymbol{\varepsilon}_1 \\ \boldsymbol{\varepsilon}_2 \end{bmatrix} = \begin{bmatrix} -m_1\hat{\dot{y}}_1 - m_3\hat{\dot{y}}_2 + m_6 y_1\hat{\dot{y}}_1 - m_7\hat{\dot{y}}_1 y_1 - m_8 y_2\hat{\dot{y}}_2 - m_9 y_1\hat{\dot{y}}_2 - m_{10} y_1\hat{\dot{y}}_1 y_2 + m_{11}\hat{\dot{y}}_1 y_2\hat{\dot{y}}_2 + N_y^*/b_0 \\ n_3\hat{\dot{y}}_1 - n_1\hat{\dot{y}}_2 + n_5\hat{\dot{y}}_1 y_1 - n_6\hat{\dot{y}}_1^2 y_2 - n_7\hat{\dot{y}}_1 y_2\hat{\dot{y}}_2 + N_x^*/a_0 \end{bmatrix} \tag{9}$$

The inverse dynamics, obtained from (8), is described by the equation

$$\hat{\boldsymbol{u}} = \begin{bmatrix} \hat{\boldsymbol{u}}_1 \\ \hat{\boldsymbol{u}}_2 \end{bmatrix} = \begin{bmatrix} \hat{i}_y \\ \hat{i}_x \end{bmatrix} = \hat{\boldsymbol{h}}_r^{-1}(\boldsymbol{y},\hat{\boldsymbol{v}}) = \begin{bmatrix} -m_{12} & 0 \\ 0 & n_8 \end{bmatrix}^{-1} (\hat{\boldsymbol{v}} + \begin{bmatrix} m_2 & m_4 \\ m_2 & n_4 \end{bmatrix}\boldsymbol{y} - \begin{bmatrix} m_5 \\ 0 \end{bmatrix} y_1 y_2) \tag{10}$$

In Fig. 1.a. the structure of the adaptive control system of the GG is given. Since the relative degrees of the components of the output vector are equal to 2 according to [25], a reference model of order 2 is chosen, having the transfer matrix

$$H_m(s) = \frac{\omega_0^2}{\mathrm{s}^2 + 2\xi\omega_0\mathrm{s} + \omega_0^2} I_2 \tag{11}$$

The linear dynamic compensator of the stabilization subsystem and, respectively, the orientation controller are chosen as P.D and P.I types, with the transfer matrices

$$H_{gg}(\mathrm{s}) = K_p + K_d\mathrm{s},\ K_p = k_p I_2, K_d = k_d I_2, \tag{12}$$

$$H_o(\mathrm{s}) = K_{p0} + \frac{K_{i0}}{\mathrm{s}},\ K_{p0} = k_{p0} I_2, K_{i0} = k_{i0} I_2, \tag{13}$$

with I_2 - unity matrix (2×2).

The output of the linear dynamic compensator is

$$\hat{\boldsymbol{v}}_{pd} = K_p\tilde{\boldsymbol{y}} + K_d\dot{\tilde{\boldsymbol{y}}} = D_c\boldsymbol{e}, D_c = [K_p\ K_d] = [k_p I_2\ k_d I_2] \tag{14}$$

$$\boldsymbol{e} = [\tilde{\boldsymbol{y}}^T\ \dot{\tilde{\boldsymbol{y}}}^T] = [\boldsymbol{e}_1^T\ \boldsymbol{e}_2^T]^T, \tilde{\boldsymbol{y}} = \bar{\boldsymbol{y}} - \boldsymbol{y},\ \tilde{\boldsymbol{y}} = [\tilde{y}_1\ \tilde{y}_2]^T = [(\bar{y}_1 - y_1)(\bar{y}_2 - y_2)]^T,\ \dot{\tilde{\boldsymbol{y}}} = [\dot{\tilde{y}}_1\ \dot{\tilde{y}}_2]^T = [(\dot{\bar{y}}_1 - \dot{y}_1)(\dot{\bar{y}}_2 - \dot{y}_2)]^T, \tag{15}$$

Equation $\ddot{\boldsymbol{y}} = \boldsymbol{v} + \boldsymbol{\varepsilon}$ with $\hat{\boldsymbol{v}} = \hat{\boldsymbol{v}}_{pd} + \ddot{\bar{\boldsymbol{y}}} - \hat{\boldsymbol{v}}_a$ (according to Fig.1.a) and $\hat{\boldsymbol{v}}_{pd}$ of the form (14), becomes

$$\ddot{\tilde{\boldsymbol{y}}} = -K_p\tilde{\boldsymbol{y}} - K_d\dot{\tilde{\boldsymbol{y}}} + (\hat{\boldsymbol{v}}_a - \boldsymbol{\varepsilon}) \tag{16}$$

equivalent to the system of equations of state

$$\begin{aligned} \dot{\boldsymbol{e}}_1 &= \boldsymbol{e}_2 \\ \dot{\boldsymbol{e}}_2 &= -K_p\boldsymbol{e}_1 - K_d\boldsymbol{e}_2 + (\hat{\boldsymbol{v}}_a - \boldsymbol{\varepsilon}) \end{aligned} \tag{17}$$

respectively with the equation of state of the linear subsystem with the input $(\hat{\boldsymbol{v}}_a - \boldsymbol{\varepsilon})$ and the output $\tilde{\boldsymbol{y}}$,

$$\dot{\boldsymbol{e}} = A\boldsymbol{e} + B(\hat{\boldsymbol{v}}_a - \boldsymbol{\varepsilon}) \tag{18}$$

in wich

$$A=\begin{bmatrix}0_{2\times2} & I_2\\ -K_p & -K_d\end{bmatrix}_{(4\times4)},\ B=\begin{bmatrix}0_{2\times2}\\ I_2\end{bmatrix}_{(4\times2)} \tag{19}$$

The equation of state of the linear observer is [9]

$$\dot{\hat{\boldsymbol{e}}}=A\hat{\boldsymbol{e}}+L(\tilde{\boldsymbol{y}}-\hat{\tilde{\boldsymbol{y}}}) \tag{20}$$

with L-amplification matrix (4×2) and $\hat{\boldsymbol{e}},\hat{\tilde{\boldsymbol{y}}}$ – vector estimates of $\boldsymbol{e},\tilde{\boldsymbol{y}}$

$$\tilde{\boldsymbol{y}}=\boldsymbol{e}_1=C\boldsymbol{e},\hat{\tilde{\boldsymbol{y}}}=\hat{\boldsymbol{e}}_1=C\hat{\boldsymbol{e}},C=[I_2\ 0_{2\times2}]_{(4\times2)} \tag{21}$$

With (20), equation (21) becomes

$$\dot{\hat{\boldsymbol{e}}}=\bar{A}\hat{\boldsymbol{e}}+L,\bar{A}=A-LC \tag{22}$$

The amplification matrix L is chosen so that the matrix $\bar{A}$ has its eigen values located in the left complex half-plane (the matrix $\bar{A}$ is asymptotically stable).

The training vector of the neural network NNc is [23]

$$\bar{\boldsymbol{e}}=\hat{\boldsymbol{e}}^T PB \tag{23}$$

with P – matrix (4×4), solution of the Lyapunov equation.

$$\bar{A}^T P+P\bar{A}=-Q \tag{24}$$

with Q – positive definite matrix (4×4).

The adaptive command is calculated with the formula [25]

$$\hat{\boldsymbol{v}}_a=W^T(V^T\eta) \tag{25}$$

W and V the NNc weights, solutions of the system of differential equations of the forms (27), and η is the NNc driving vector, of the form (33) from [20], σ' is the derivative of the sigmoidal function $\sigma(z)=\sigma(V^T\eta)$;

$$\begin{aligned}\dot{W}&=-S_W[2(\sigma-\sigma' V^T\eta)\bar{\boldsymbol{e}}+k(W-W_0)],W_0=W(0)\\ \dot{V}&=-S_V[2\sigma\bar{\boldsymbol{e}}W^T\sigma'+k(V-V_0)],V_0=V(0)\end{aligned} \tag{26}$$

The inner (stabilizing) contour has the transfer matrix of the form

$$H_s(\mathrm{s})=\frac{1}{\mathrm{s}^2+k_d\mathrm{s}+k_p}I_2 \tag{27}$$

and the outer (orientation) contour has the transfer matrix

$$H_c(\mathrm{s})=\frac{k_{p0}\mathrm{s}+k_{i0}}{\mathrm{s}^3+k_d\mathrm{s}^2+(k_{p0}+k_p)\mathrm{s}+k_{i0}}I_2 \tag{28}$$

To calculate the coefficients k_{i0} and k_{p0}, the roots of the characteristic equation are required

$$\mathrm{s}^3+k_d\mathrm{s}^2+(k_{p0}+k_p)\mathrm{s}+k_{i0}=0 \tag{29}$$

in the left complex half-plane.

In order not to use sensors to measure angular velocities $\dot{y}_1=\dot{\omega}_{g1}$ and $\dot{y}_2=\dot{\omega}_{g2}$, in the calculation relationship of inversion errors $\boldsymbol{\varepsilon}$ (9) their estimated values are used $\hat{\dot{y}}_1$ and $\hat{\dot{y}}_2$, components of the estimated state vector $\hat{\boldsymbol{e}}_2=\hat{\dot{\boldsymbol{y}}}=[\hat{\dot{y}}_1\ \hat{\dot{y}}_2]^T$. Thus, from (16),

$$\tilde{\boldsymbol{y}} = \boldsymbol{e}_2 = \dot{\bar{\boldsymbol{y}}} - \dot{\boldsymbol{y}} \tag{30}$$

And and for the estimated vector $\hat{\dot{\boldsymbol{y}}}$ the calculation relationship is

$$\hat{\dot{\boldsymbol{y}}} = \hat{\boldsymbol{e}}_2 = \dot{\bar{\boldsymbol{y}}} - \hat{\dot{\boldsymbol{y}}} \tag{31}$$

From (31) it follows

$$\hat{\dot{\boldsymbol{y}}} = \dot{\bar{\boldsymbol{y}}} - \hat{\boldsymbol{e}}_2 = \dot{\bar{\boldsymbol{y}}} - [0_{2\times 2}\ I_2]\hat{\boldsymbol{e}} = \dot{\bar{\boldsymbol{y}}} - Mat\_3\hat{\boldsymbol{e}} \tag{32}$$

with $Mat\_3 = [0_{2\times 2}\ I_2]$.

3. NUMERICAL SIMULATIONS

In Fig.2 the Matlab/Simulink model of the system in Fig.1 is presented.

The following values were chosen: A=B=0.008 N×m×s^2/rad , $A_1 = 0.02$N×m×s^2/rad , $A_1 = 0.02$N×m×s^2/rad , $B_1 = 0.01$N×m×s^2/rad , $C_1 = 0.02$N×m×s^2/rad , $A_2 = 0.58$ N×m ×s^2/rad, $B_2 = 0.02$ N×m×s^2/rad, $C_2 = 0.45$ N×m×s^2/rad, $A_0 = 0.02$ N×m×s^2/rad, $B_0 =$ $= 0.66$ N×m×s^2/rad, $D_0 = 0.01$ N×m×s^2/rad, $K = 2.5$ N×m×s , $F_x = 0.1$N×m×s/rad, $F_y = 0.1$ N×m×s/rad, $\lambda_1^* = 0.52$ rad, $\lambda_2^* = 1$ rad, $\omega_{t1} = 0.2$ rad/s, $\omega_{t2} = 0.15$ rad/s, $\dot{\omega}_{t1} =$ 0 rad/s^2, $\dot{\omega}_{t2} = 0$ rad/s^2, $\omega_{x_T} = 0.15$ rad/s^2, $\dot{\omega}_{x_T} = 0$ rad/s^2, $\omega_X = 0.33$ rad/s, $\omega_Y = 0.05$ rad/s, $\omega_Z = 0.05$ rad/s, $\omega_{g1}(0) = \omega_{g2}(0) = 0.05$ rad/s, $\dot{\omega}_{g1}(0) = \dot{\omega}_{g2}(0) = 0$ rad/s^2, $f_x =$ 0.004 rad^{-1}, $a_3 = 0.32$ s, $f_y = 0.004$ rad^{-1}, $a_1 = 0.08$ s, $a_2 = 0.232$ s, $b_0 = 0.264$ s, $b_1 = 0.004$s, $b_2 = 0.16$s, $c = 0.036$s, $c_1 = 0.004$s, $c_2 = 0.232$s, $d_0 = 0.04$s, $e_0 = 0.004$s, $r_2 = r\cos\lambda_2^* = 0.59$s^{-1}, $r_1 = r = \omega_{t1maximum}/\alpha_{maximum} = 1.18$s^{-1}, $k_x = 1$N×m×A, $k_y = 0.2$ N×m×A, $k_p = 6$s^2.

For NNc the following values were chosen:

$Q_1 = I_4$ (unit matrix),

$d = 0.1, k = 20, \mathrm{Sv} = \mathrm{Sw} = 0.01, b_w = 1$, ,

$W_0 = 0_{11\times 1}, V_0 = 0_{10\times 10}$, $n_1 = 9$ neurons, $n_2 = 10$ neurons, $n_3 = 2$ neurons,

$a_j = [1\ \ 0.9\ \ 0.8\ \ 0.7\ \ 0.6\ \ 0.5\ \ 0.4\ \ 0.3\ \ 0.2\ \ 0.1]$,

With these values, the dynamic characteristics in Fig.3 were constructed.

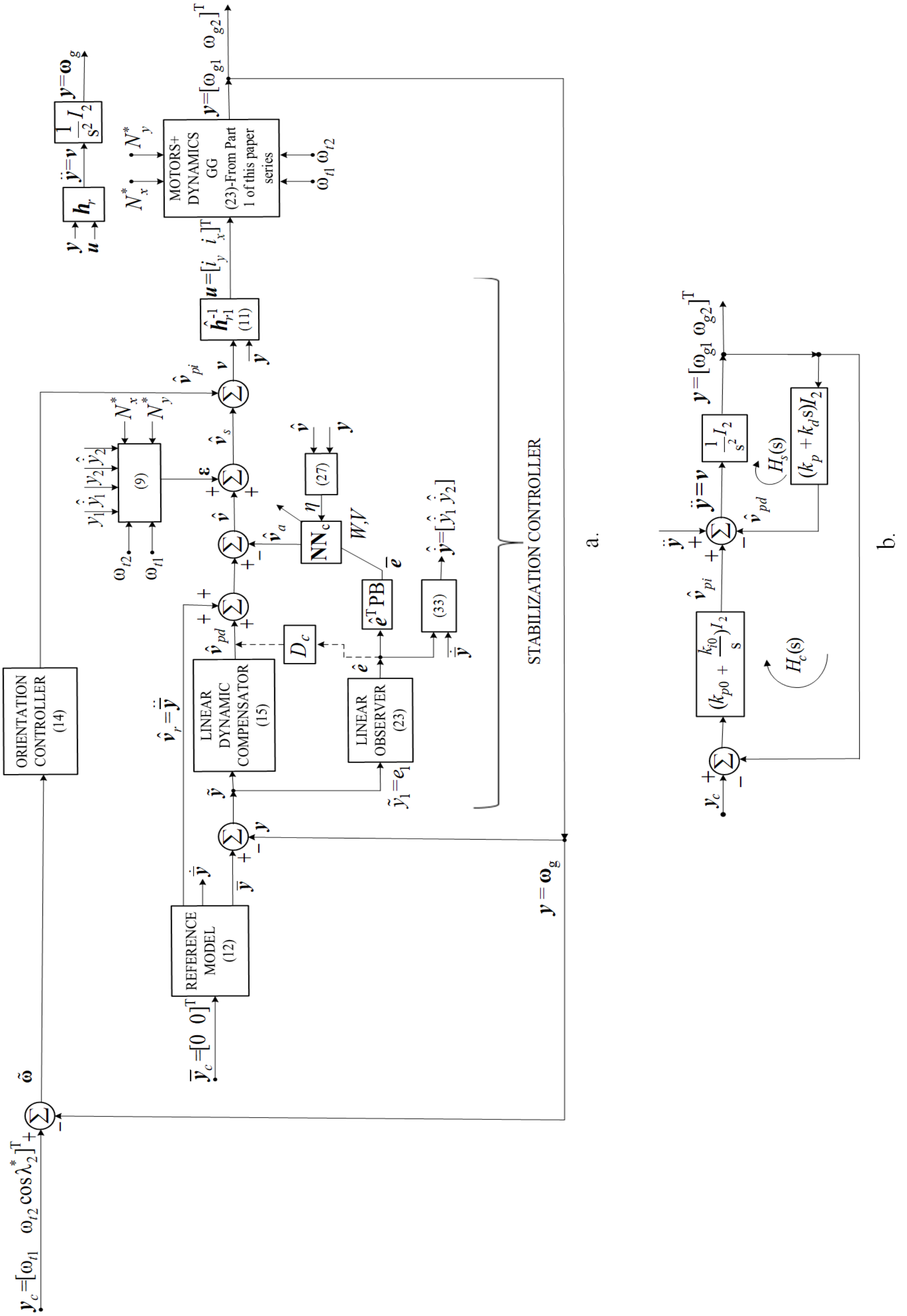


FIG.1 Adaptive control system of nonlinear dynamics of GG: a) complete block diagram; b) block diagram of the linear subsystem

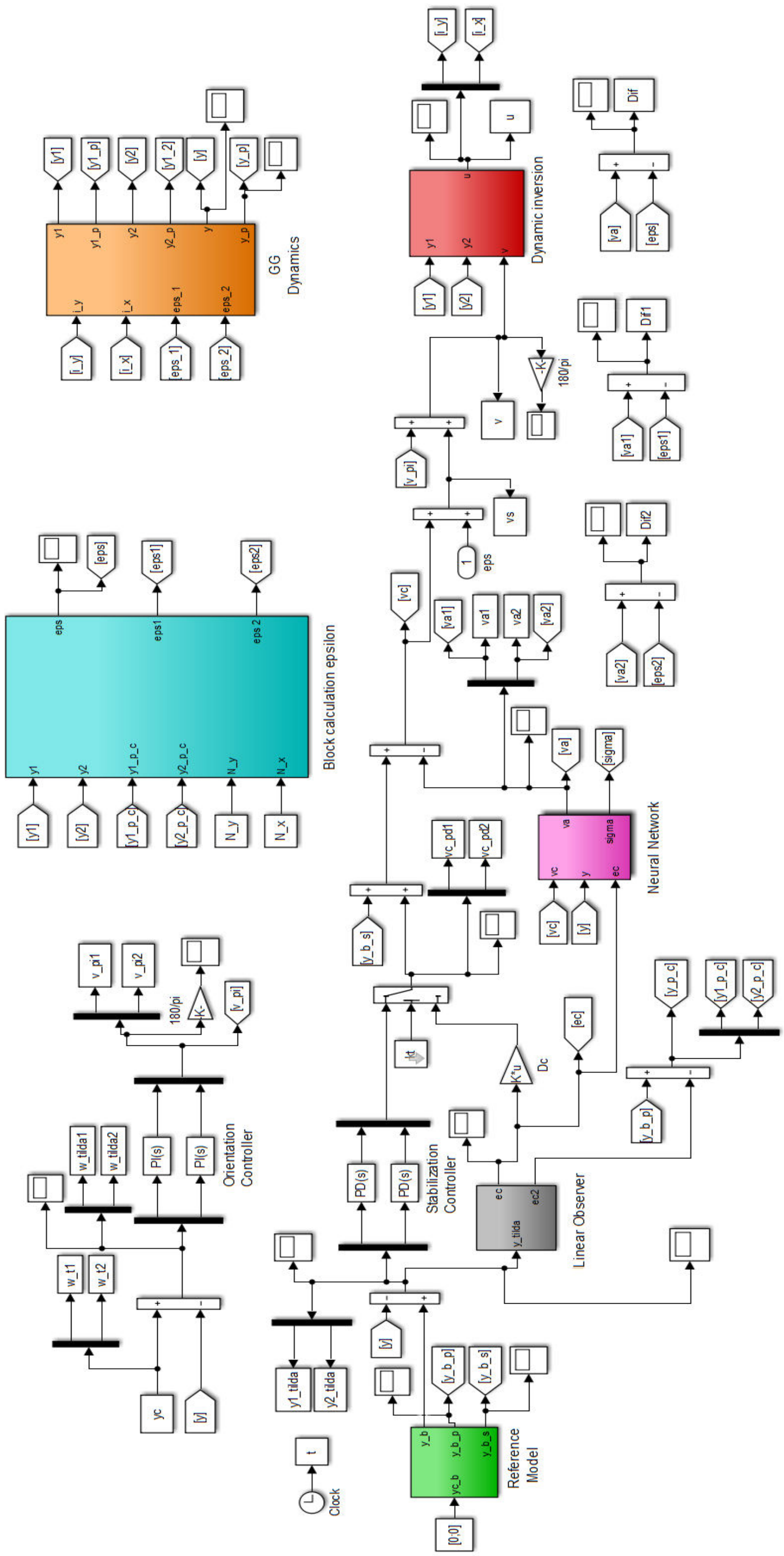
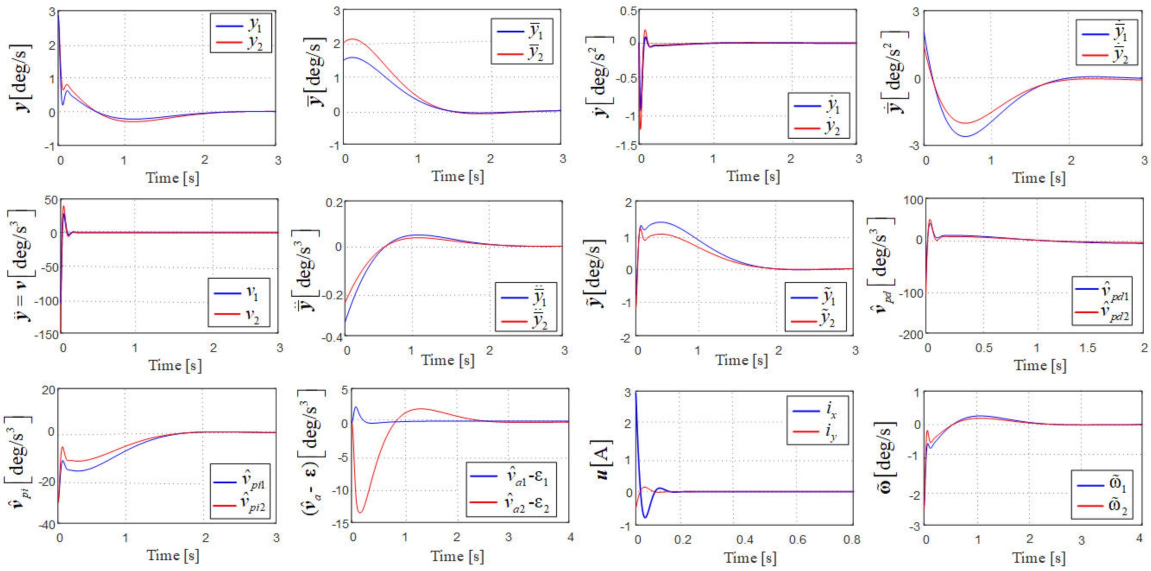
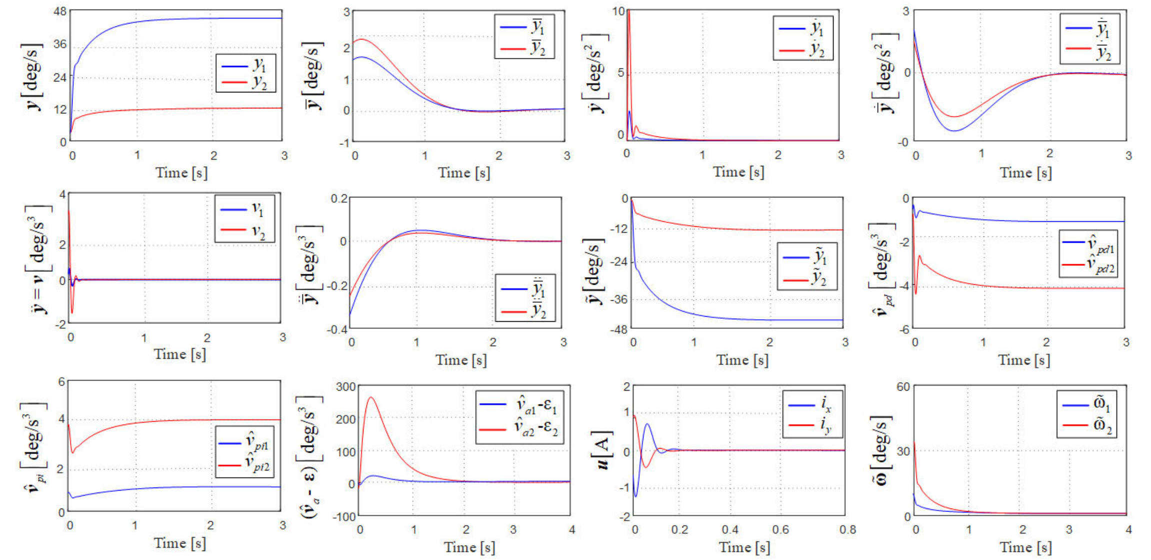


FIG.2 Matlab/Simulink model of the system in Fig.1



a.



b.

FIG.3 Dynamic characteristics of the subsystems in Fig.2: a – for the stabilization mode; b – for the orientation mode

4. CONCLUSIONS

The nonlinear dynamics equations of the GG derived in Part 1 of this paper series are expressed in the form (7), with (8) and (9), and the inverse dynamics in the form (11). Using these, the system in Fig.1 was designed for the stabilization mode and for the orientation mode. The Matlab/Simulink model in Fig.2 was built and, with these, the dynamic characteristics in Fig.3 were plotted for the two operating modes.

For the stabilization mode $\bar{\boldsymbol{y}}_c = \boldsymbol{y}_c = [0\ 0]^T \text{deg/s}$, and disturbances $N_x(t)$ and $N_y(t)$ (functions of the angular velocities of the base), are non-zero values; In orientation mode $\boldsymbol{y}_c = [\omega_{t1}\ \ \omega_{t2} \cos\lambda_2^*]^T$ and $\boldsymbol{y}_c = [0\ 0]^T \text{deg/s}$, and $N_x = N_y = 0$.

Analyzing the dynamic characteristics of the GG in Fig.3.a and b, the following conclusions result.

Compared to linear GG, with linear control, the nonlinear ones with adaptive control based on the use of the dynamic inversion method and neural networks contain very fast dynamic regimes (under 2 seconds), with very small overshoots and stationary errors in the two regimes practically zero. Adaptive control vector quickly compensates for dynamic inversion error $(\boldsymbol{v}_a - \boldsymbol{\varepsilon} \to [0\ 0]^T)$ in both modes (stabilization and orientation), so that GG with nonlinear dynamics behaves very close to 2nd order linear systems.

The dynamic characteristics in Fig.3.a confirm the following:

$\boldsymbol{y} \to \overline{\boldsymbol{y}}(\tilde{\boldsymbol{y}} \to [0\ 0]^T, \dot{\boldsymbol{y}} \to \dot{\overline{\boldsymbol{y}}}(\dot{\tilde{\boldsymbol{y}}} \to [0\ 0]^T)$ and $\boldsymbol{y} = \boldsymbol{v} \to \boldsymbol{y} = [0\ 0]^T (\ddot{\tilde{\boldsymbol{y}}} \to [0\ 0]^T)$, $\hat{\boldsymbol{v}}_{pi} + \hat{\boldsymbol{v}}_s =$

$= \hat{\boldsymbol{v}}_{pi} + \hat{\boldsymbol{v}}_{pd} \to [0\ 0]^T$, and $\hat{\boldsymbol{v}}_a - \boldsymbol{\varepsilon} = [0\ 0]^T$.

So, the output $\tilde{\boldsymbol{y}}$ of the subsystem with the input $(\boldsymbol{v}_a - \boldsymbol{\varepsilon})$ and its derivatives tend to $[0\ 0]^T$ with the input $[0\ 0]^T$; thus $\hat{\boldsymbol{e}}$ and $\overline{\boldsymbol{e}} \to [0\ 0]^T$.

Similarly, we can say about the characteristics in Fig.3.b, with the difference that $\tilde{\boldsymbol{\omega}} \to [0\ 0]^T$ and $\tilde{\boldsymbol{y}} \to -\boldsymbol{y} = -\boldsymbol{y}_c$.

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THE CLIMATOLOGY OF AVIATION HAZARDS IMPACTING ROMANIAN AIRPORTS

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DOI: 10.19062/2247-3173.2025.26.20

Abstract: *The increasing air traffic at Romanian airports in recent years has necessitated a heightened focus on aviation safety standards. Simultaneously, climate change has altered the frequency of meteorological phenomena that impact aviation activities. This study aims to establish a baseline climatology and identify evolving trends of hazardous weather phenomena for the main airports in Romania between 1941 and 2022. The study uses ERA5 data to derive the most important parameters to study the occurrence of thunderstorms, low-level wind shear, reduced visibility, and snowfall, the weather phenomena that are relevant for the air traffic safety. The results show an increase in the number of hours with thunderstorms in the eastern part of the country and a rising trend in events with low-level wind shear in the western and central regions. Conversely, events with significant snowfall are decreasing in the eastern Carpathians and Muntenia region, while those with limited visibility are decreasing in the coastal regions and northeastern Romania. These findings can inform aviation safety regulations and help mitigate the impact of hazardous weather conditions on aeronautical activities.*

Keywords: *climatology, weather hazards, climate changes, thunderstorms, wind shear, low visibility, snowfall, safety regulations.*

1. INTRODUCTION

In Europe and Romania, aviation transport has grown significantly over 20 years. According to the Romanian National Institute of Statistics [1], passenger numbers at airports increased from 9 million in 2008 to over 24 million in 2023 (**FIG. 1**). This aviation sector expansion has significantly increased carbon dioxide (hereafter CO_2) emissions, making it a major CO_2 contributor [2]. Jet fuel combustion releases CO_2 and greenhouse gases during flights, while airport infrastructure, aircraft manufacturing, and support activities add to environmental impact. International Air Transport Association (IATA) estimates aviation contributes 2.5% of global CO_2 emissions [3]. Though this percentage seems small compared to other sectors, aviation emissions have steadily increased with industry growth. The impact is amplified by greenhouse gas release at high altitudes, where warming effects are more significant. The industry is implementing measures to reduce environmental impact through fuel-efficient aircraft, sustainable aviation fuels, and optimized flight routes. However, due to fossil fuel dependence and projected growth, addressing emissions remains challenging. Studies predict air traffic will triple in 20 years [4] CO_2 emissions from aviation contribute approximately 4% to global warming [2], driving anthropogenic climate change that has modified severe weather phenomena affecting the aviation industry. Williams (2017) predicts increased clear air turbulence over the transatlantic region when doubling CO_2 levels [5], showing expansion in airspace affected by light, moderate, and severe turbulence.

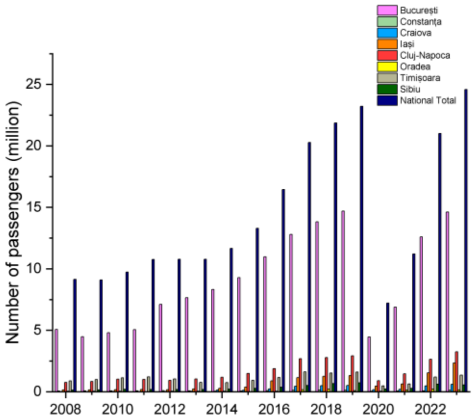


FIG. 1: Statistics on growth of passengers number on Romanian airports. Source: adapted from Wikipedia.

Flight operations face safety hazards including turbulence, storms, lightning, wind shear, reduced visibility, and snow [6]. Aviation safety regulations have become more restrictive due to meteorological hazards causing delays, cancellations, and casualties. Studies show 20-30% of global aviation accidents stem from unfavorable weather [7], while in Europe, weather causes 22% of air traffic delays [8].

Romania lacks climatology of severe weather conditions threatening aviation, including thunderstorms, wind shear, limited visibility, and snowfall. This study examines weather phenomena formation over Romania from 1941-2022, focusing on hazard trends at major airports.

2. SEVERE WEATHER PHENOMENA IMPACTING FLIGHT ACTIVITY

Aeronautical activity signifies transportation and access to international facilities. For flight safety, operational airports maintain essential measures regarding communications, air traffic services, weather monitoring and forecasting. Meteorological analysis and documentation are necessary for flights [9]. Key meteorological elements reported include: air and dew point temperatures, atmospheric pressure at sea level, weather phenomena, cloud coverage and cloud base, wind parameters, and visibility. Certain meteorological phenomena pose dangers to aviation, potentially causing delays, cancellations, safety incidents and accidents. These hazards are emphasized in Table 1:

Table 1. Weather hazards impacting flight activity.

Airport terminal hazards	En route hazards
Storms: microbursts, hail, wind shear, thunderstorms	Storms (hail, turbulence)
Wake turbulence during takeoff/landing	Clear-air turbulence (CAT)
Frost on parked aircraft	Frost at lower altitudes
Low ceilings and reduced visibility	

This analysis focuses on thunderstorms, low-level wind shear, limited visibility, and snowfall [10]. These hazards' impact and formation are detailed in the following section.

2.1. Thunderstorms

Deep convection is the upward movement of warm, moist air into the atmosphere, often resulting in towering cumulonimbus clouds.

This process is a key driver of thunderstorms and severe weather events, as it releases latent heat, fueling the upward motion. This can lead to intense precipitation, strong winds, lightning, and hail. Storms are conditioned by three ingredients: conditionally unstable environment, sufficient moisture for air particles to reach free convection, and a triggering mechanism determining upward movement. Atmospheric convection can lead to simple storm structures from a single cumulonimbus cloud or developed storms from a group of clouds, extending hundreds of km. Storm formation is supported by wind shear, turbulent movements, and convergent surface winds [11].

Lightning is a visible electrical discharge produced by a storm, occurring in various forms such as within a cloud, from one cloud to another, cloud to ground lightning, and occasionally between a cloud and clear air. It is the result of the buildup and discharge of electrical energy between regions with differing electric potentials. The process begins in cumulonimbus clouds, where turbulent air currents cause ice and water particles to collide and interact, resulting in electron transfer and a separation of charges within the cloud. This separation can generate an extremely strong electric field, which causes the ground to become positively charged due to electrostatic induction. When the electric field strength exceeds the dielectric breakdown strength of air, a sequence of events leads to lightning. This discharge neutralizes the accumulated charges, equalizing the electric potential between the cloud and the ground or within the cloud itself [11].

2.2. Wind shear

Wind is a physical phenomenon characterized by the circulation of air in the Earth's atmosphere, typically in the troposphere. In conditions with different thermal and pressure characteristics, air moves vertically or horizontally, resulting in advection motions caused by differences in atmospheric pressure. Local winds can be caused by orographic winds, katabatic winds, anabatic winds, maritime and land breezes. Wind parameters, such as speed, direction, intensity, duration, and structure, can be observed and reported using special equipment at airport weather stations. Wind shear is a phenomenon caused by the interaction between different air masses with varying characteristics, such as warm and cooler air, and topographic features like mountains or coastlines. It can create a weather front, a sharp boundary layer, and can disrupt airflow, leading to local changes in wind speed and direction. Wind shear can be significant and potentially hazardous, especially in aviation, where it can cause abrupt changes in aircraft speed and altitude, making control challenging. It can also affect engine efficiency, leading to increased fuel consumption and reduced performance. Wind shear is an essential condition in weather forecasting, as it can contribute to the intensification of storms and create a rotating column of air, known as a mesocyclone, essential for tornado development. To mitigate risks, various technologies and strategies have been developed, such as Doppler radar systems, onboard systems in aircraft, and protocols in airports and air traffic control agencies. There are two main types of wind shear: vertical and horizontal wind shear [12].

Low-level wind shear is a sudden change in wind speed or direction within the first 2,000 feet above the ground, impacting aviation, weather patterns, and ground-based activities.

Turbulence, caused by the movement of disturbed air, can occur thermally or mechanically and can occur within or outside clouds. The severity of turbulence depends on the airflow's speed or direction intensity. Turbulence is associated with disorderly air movements and can occur in the friction layer, clouds, mountainous areas, and clear air. Factors contributing to these movements include uneven heating of the Earth's surface, atmospheric pressure variations, air currents, and aircraft interaction with air currents.

2.3. Limited visibility

Limited visibility is a critical factor affecting flight activity, affecting safety and efficiency in aviation operations. It is caused by atmospheric conditions such as fog, mist, low clouds, rain, snow, haze, or smoke, which increase the complexity of flight operations and require pilots to rely more on instruments rather than visual cues. The primary concern with limited visibility is the increased risk of collisions, both with other aircraft and ground obstacles. Pilots struggle to maintain proper situational awareness, increasing the likelihood of mid-air collisions and runway incursions during takeoff and landing [13].

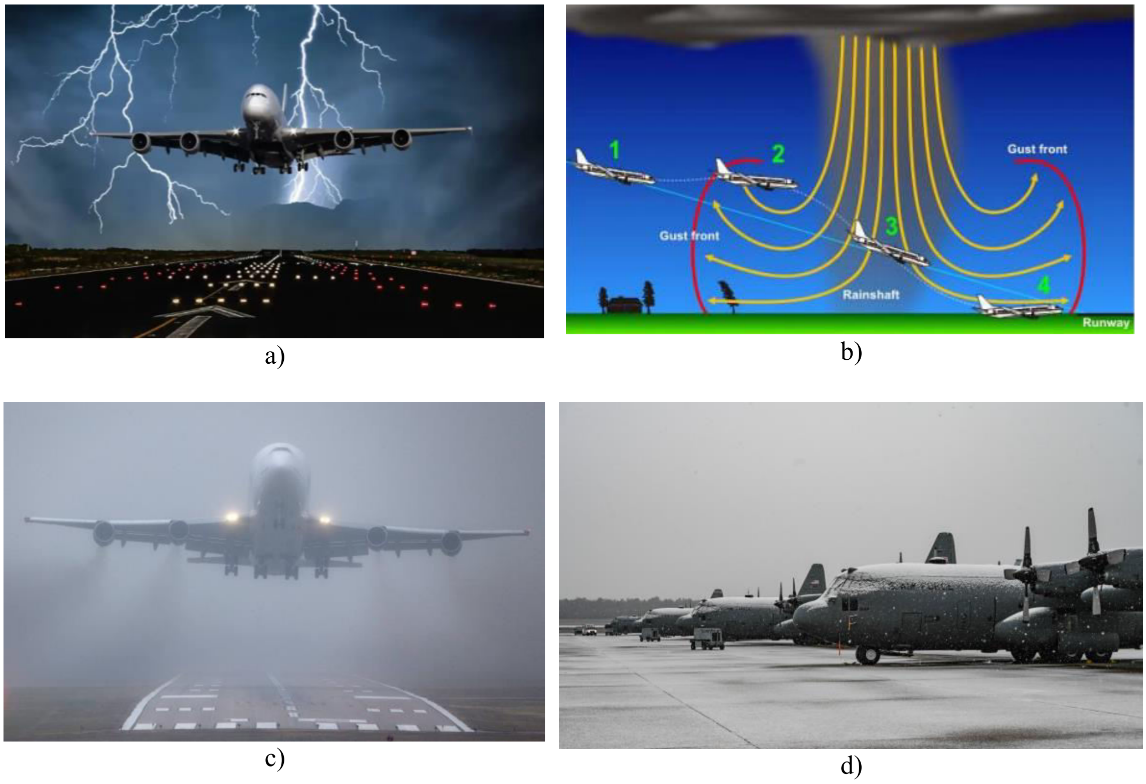


FIG. 2. Weather hazards impacting aeronautical activity.

To mitigate risks associated with limited visibility, aviation authorities and operators implement various strategies and technologies. Advanced weather forecasting systems provide real-time information about current and forecasted weather conditions, enabling pilots to plan alternate routes or adjust departure and arrival times to avoid adverse weather conditions. Aircraft are equipped with sophisticated navigation and communication systems, such as radar, GPS, and instrument landing systems (ILS), which allow pilots to navigate safely in low-visibility conditions and conduct precision approaches and landings even when visibility is severely restricted. Training and proficiency in instrument flying techniques are essential for pilots to effectively manage limited visibility situations and safely operate aircraft under adverse weather conditions. Airports employ ground-based visibility aids, such as runway lighting systems, runway markings, and precision instrument approaches, to assist pilots during takeoff, landing, and taxiing in reduced visibility conditions.

2.4. Snowfall

Snowfall significantly impacts flight activity, affecting all aspects of aviation operations from takeoff to landing. It reduces visibility, alters runway conditions, and increases the risk of aircraft icing.

Pilots face challenges in maintaining situational awareness and navigating safely. Snow accumulation on runways reduces surface friction and increases braking distances, posing hazards during landing and takeoff procedures. Snow and ice buildup on aircraft surfaces disrupt airflow and compromise aerodynamic performance, leading to reduced lift and increased drag. Runway contamination is a primary concern during snowfall, reducing aircraft traction and increasing the likelihood of skidding or hydroplaning during landing and takeoff. Airport operators use snow removal equipment to clear runways and taxiways. Air traffic control personnel face challenges in managing air traffic flow and ensuring safe separation between aircraft. Special procedures, such as increased spacing between aircraft, altered approach and departure routes, and enhanced communication protocols, are implemented to mitigate these risks. Pilots play a crucial role in mitigating snowfall risks by closely monitoring weather conditions, adhering to standard operating procedures, and exercising sound judgment during flight [13].

3. DATABASE, METHODOLOGY AND LIMITATIONS

The study uses ERA5 reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) to investigate hazardous weather phenomena affecting flight activity at major Romanian airports. The dataset, which includes observations from satellites, ground stations, aircraft, and radiosondes, is reliable for long-term climatological analysis due to its temporal continuity, spatial coverage, and ability to provide consistent reconstructions of meteorological conditions over extended periods. Variables such as temperature, pressure, humidity, wind components, and cloud parameters were selected to compute key atmospheric indices and thresholds for identifying and assessing severe weather events. The methodology involved extracting, interpolating, and analyzing specific parameters to characterize the occurrence, frequency, and spatial distribution of thunderstorms, wind shear, limited visibility, and snowfall. The data were processed through vertical interpolation of pressure, height, temperature, dew point, and wind vector components. Thermodynamic indices (LCL, LFC, and EL) were computed using Skew-T diagrams to assess atmospheric instability. The study aims to evaluate the climatology of hazardous weather phenomena affecting aviation in Romania.

Specific threshold values were defined to determine the presence of each hazard, as emphasized in Table 2:

Table 2. Threshold values for proxies defining particular types of hazardous weather.

Hazard type	Threshold values
TSTM (Thunderstorm)	ML CAPE > 150 J kg^{-1} and CP>0.075 mm h^{-1}
LLWS (Low-Level Wind Shear)	0 to 100m AGL vertical wind shear gradient > 5m s^{-1} per 100
SNOW (Snowfall)	Snowfall > 0.5mm h^{-1} LWCE (Liquid Water Content Equivalent)
LIMV (Limited Visibility)	Ceiling height < 60m AGL and low-level cloud cover = 100%

Initially, stricter thresholds were tested, but they underestimated the occurrence of events due to the spatial averaging inherent in ERA5 data; therefore, more relaxed yet physically justified thresholds were adopted. Since the thresholds represent proxies rather than direct observations, the results are subject to uncertainties and must be interpreted probabilistically, acknowledging the limitations of reanalysis datasets in capturing localized, high-intensity events. Reanalysis provides continuous data in time and space but is only an approximation of real atmospheric conditions and may inaccurately estimate thermodynamic instability or vertical wind shear.

Surface meteorological observations, such as SYNOP or METAR reports, have limitations in climatological aspects, including human contributions, spatial coverage limitations, ground variables, short temporal records, and station displacement.

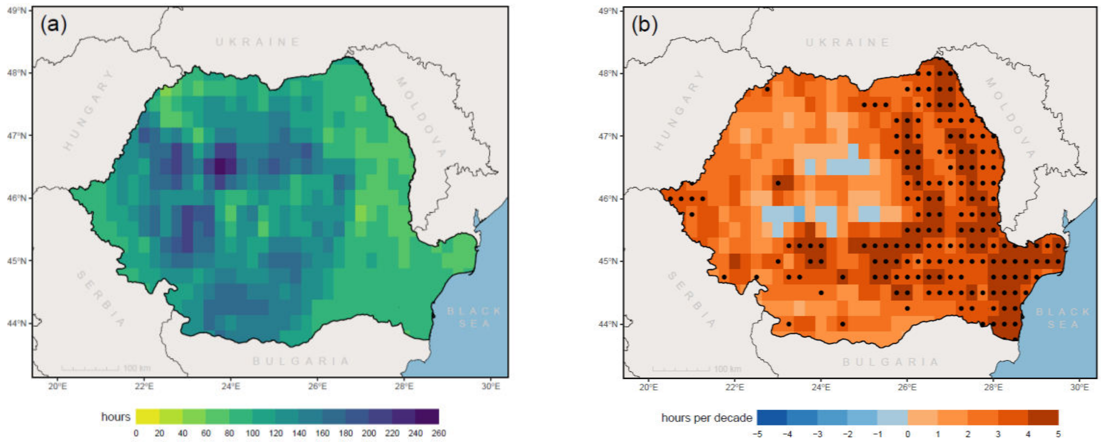
4. RESULTS AND DISCUSS

This study examines the climatological aspects of hazardous weather conditions that can disrupt air traffic, particularly during takeoff and landing. It discusses the spatial distribution of each type of hazard and the year-to-year variability and long-term changes at Romanian airports.

The analysis reveals that precipitating and unstable environments are most frequent during summertime, characterized by strong diurnal heating and evapotranspiration. The peak activity is observed over the western region of Romania, with a significant number of hours with thunderstorms (over 200 hours per year) observed over the Occidental Carpathians Mountains and western part of Muntenia (**FIG. 3a**). Over the eastern part of Romania, Dobrogea, Moldavia, Banat, and the northernmost part, the number of TSTM hours is lower (40 to 100 hours per year). However, the frequency of hours with thunderstorms over 10 years confirms an increasing trend over the eastern area of Romania (**FIG. 3a**).

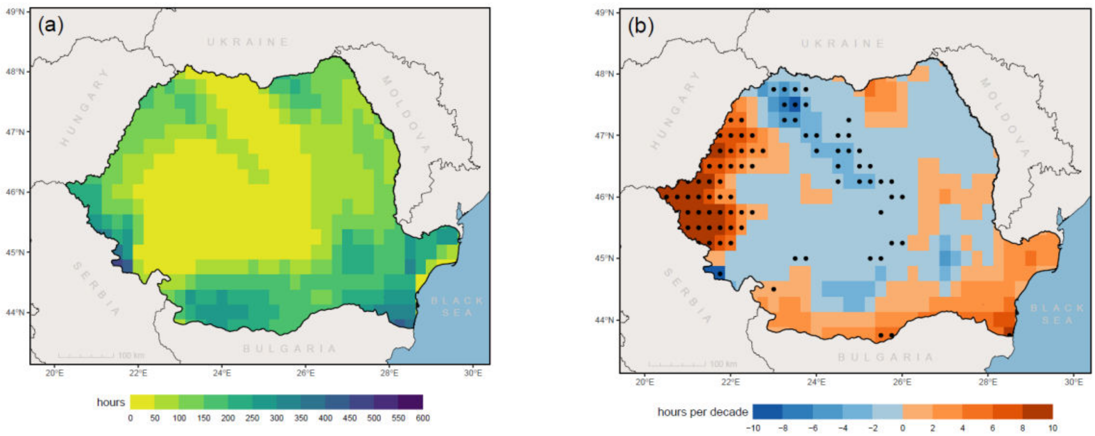
Low-level wind shear (LLWS) events pose a significant threat to Romania's aviation sector, with the southern and western regions experiencing the highest number of LLWS events, with over 300 hours per year (**FIG. 4a**). The eastern part of the country experiences up to 500 hours of LLWS per year, posing significant challenges for flight safety and operations. In the Muntenia region, western part of the country, and Transylvanian Depression, the number of LLWS hours reaches 450 hours per year. Mountainous areas show a less significant number of LLWS hours, but the complex terrain can exacerbate the effects of wind shear. Long-term trends show an increase in LLWS frequency in western Romania, the southern part of Muntenia, Dobrogea, and southern Moldavia, requiring ongoing monitoring and adaptation (**FIG. 4b**). The aviation sector must invest in research to understand the underlying factors driving these trends and develop robust response strategies.

The Eastern Carpathians experience a high frequency of limited visibility hours (LIMV), with ceiling heights below 60m AGL and low-level cloud cover of 100% (**FIG. 5a**). The trend of limited visibility hours in the western part of the country and along Oriental Carpathians is increasing over a 10-year period (**FIG. 5b**).. Accurate predictions and historical data on low-visibility conditions help in planning and mitigating the impacts of reduced visibility on safety and operations.



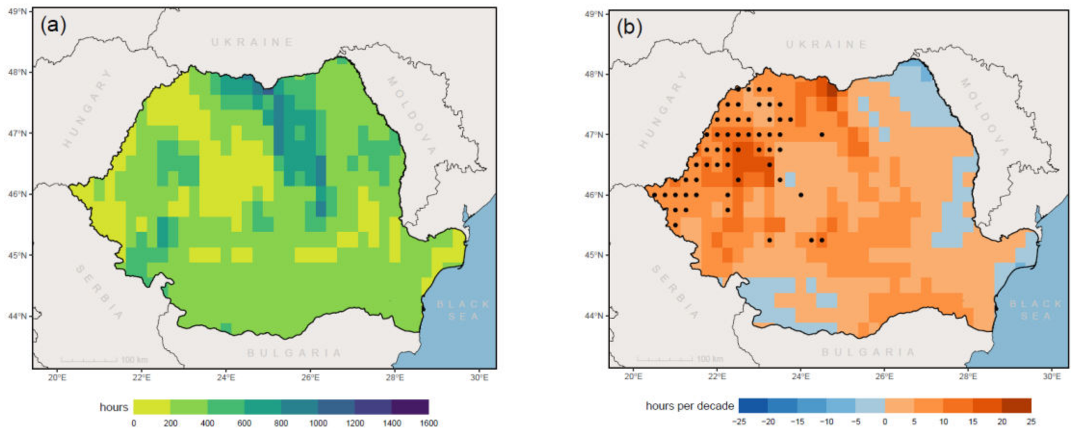
a) b)

FIG. 3. (a) Spatial distribution of the mean annual number of hours with TSTM. (b) Spatial distribution of long-term trends (denoted as a slope of linear regression with values normalised to changes per decade) in hours with TSTM. Points denote statistically significant trend (p-value < 0.05). Based on ERA5 hourly data for the years 1941–2022.



a) b)

FIG. 4. (a) Spatial distribution of the mean annual number of hours with LLWS. (b) Spatial distribution of long-term trends (denoted as a slope of linear regression with values normalised to changes per decade) in hours with LLWS. Points denote statistically significant trend (p-value < 0.05). Based on ERA5 hourly data for the years 1941–2022.



a) b)

FIG. 5. (a) Spatial distribution of the mean annual number of hours with LIMV. (b) Spatial distribution of long-term trends (denoted as a slope of linear regression with values normalised to changes per decade) in hours with LIMV. Points denote statistically significant trend (p-value < 0.05). Based on ERA5 hourly data for the years 1941–2022.

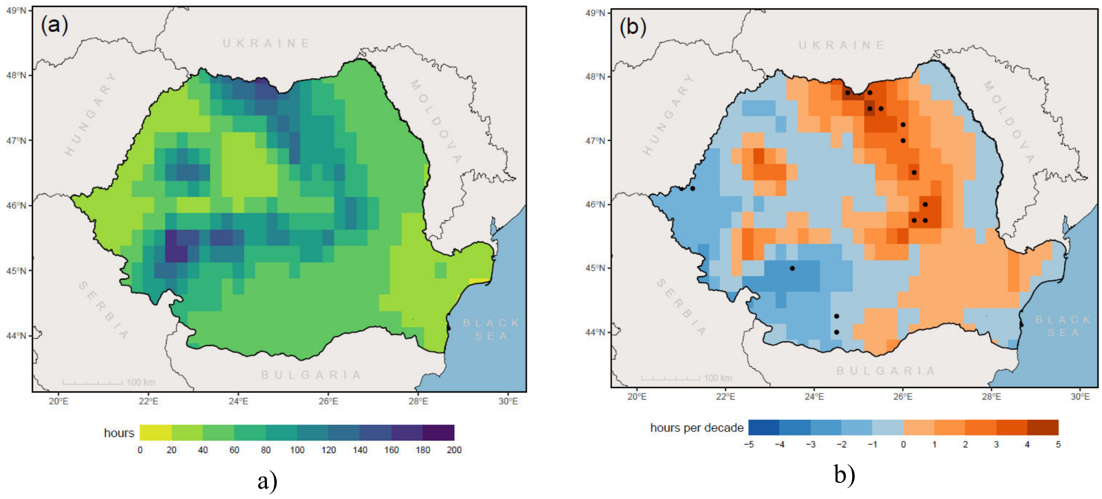


FIG. 6. (a) Spatial distribution of the mean annual number of hours with SNOW. (b) Spatial distribution of long-term trends (denoted as a slope of linear regression with values normalised to changes per decade) in hours with SNOW. Points denote statistically significant trend (p-value < 0.05). Based on ERA5 hourly data for the years 1941–2022.

The number of hours with snow events exceeding 0.5 mm h^{-1} LWCE is larger in mountainous and hilly areas, with over 100 hours per year (**FIG. 6a**). The intracarpathian area, western part of the Occidental Carpathians, and southern and western parts of Muntenia have medium snow hours, with more pronounced orographic lift and cooler temperatures. These regions may be experiencing changes in atmospheric circulation patterns that bring more moisture and cold air, increasing the frequency and intensity of snow events. The trend of SNOW hours per decade is decreasing across the country, with the Eastern Carpathians experiencing a significant increase in snow events per decade, while surrounding areas, including Dobrogea and Muntenia, experience a decline (**FIG. 6b**). This trend may be due to rising temperatures and altered precipitation patterns due to climate change, with precipitation now occurring as rain, reducing the overall number of snow hours. The overall decreasing trend of SNOW hours per decade suggests a broader climatic shift, with urbanization and land-use changes contributing to the heat island effect.

The study reveals that the number of hours with TSTM increases at each airport, with statistically significant increases in Constanţa and Cluj-Napoca airports. LLWS events also increase at Constanţa, Oradea, and Timişoara. These airports are located in areas with increasing convective phenomena and strong winds, indicating atmospheric instability in the Muntenia region, Transylvanian Depression, and Carpathian Mountains. However, at Bucharest, Cluj-Napoca, Oradea, Timişoara, and Sibiu airports, the trend of hours with limited visibility increases. The trend of hours with significant snowfall decreases over the 82-year period of study.

Bucharest Airport serves as a pivotal site for the examination of trends in significant meteorological events, including thunderstorms, low-level wind shear, restricted visibility, and snowfall. Its location inside Romania's varied climatic landscape for a targeted evaluation of the influence of these weather conditions on aviation operations in the area. The distinct local weather patterns in Bucharest, shaped by geography and elevation, offer critical insights into regional variances that impact flight safety and airport administration.

The annual trend of hours with TSTM at Bucharest airport is generally increasing, reaching a maximum of 200 hours per year in 1956.

The trend declines to 50 hours per year after this period (**FIG. 7a**). The trend of hours with LLWS at Bucharest airport is decreasing after 1990, reaching a maximum of over 300 hours per year in 1992 (**FIG. 7b**). The trend of hours with LIMV increases in the first 30 years of study, reaching up to 600 hours per year. In 2013, the maximum value of hours with LIMV reached 800 hours per year (**FIG. 7c**). The number of hours with significant snowfall at Bucharest airport is constant, with a maximum peak in 1969, confirmed by recorded weather data (**FIG. 7d**).

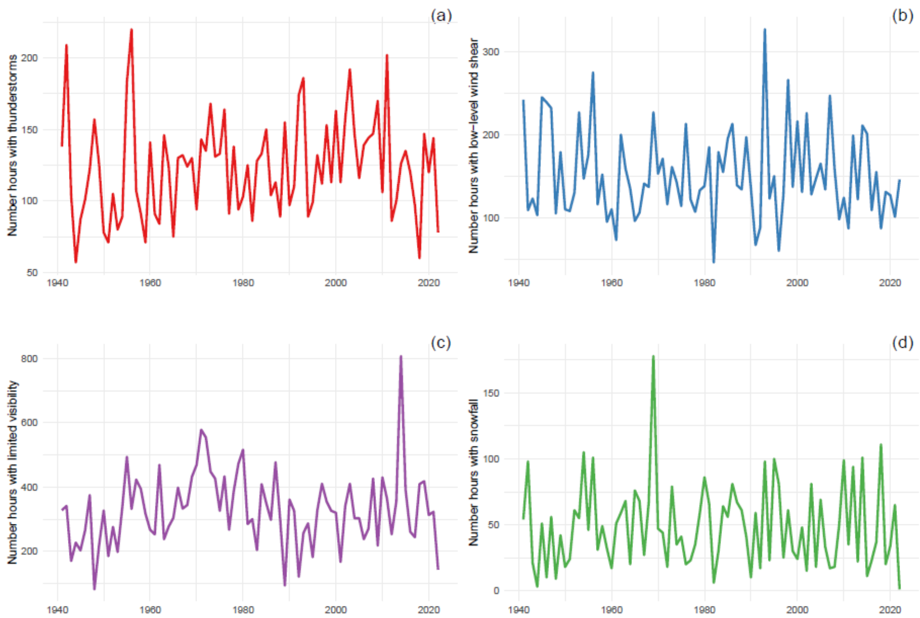


FIG. 7. Annual number of hours with (a) thunderstorms, (b) low-level wind shear, (c) limited visibility, and (d) snowfall between 1941–2022 for Bucharest airport.

CONCLUSIONS

The study reveals significant variability and trends in the climatology of aviation hazards at Romanian airports. Meteorological phenomena such as thunderstorms, low-level wind shear, limited visibility, and snow exhibit distinct patterns across different regions and airports. Thunderstorm occurrence increases in the first half of the study period, followed by a decline post-1990. Low-level wind shear hours increase across the entire study period, while limited visibility trends remain stable across several airports. Snowfall hours exhibit a decreasing trend over the 82-year period, with initial highs dropping to values below 20 hours per year at various airports. Regional differences in hazard frequencies are highlighted, with mountainous regions experiencing higher frequencies of thunderstorms and LLWS. The study recommends enhancing aviation hazard management and operational strategies at Romanian airports, including improved forecasting, advanced warning systems, and strategic infrastructure investments. Further research could focus on detailed characterization of each severe weather event and associated risks, as well as integrating climate change projections for future trends.

AKNOWLEDGMENT

Thank you to my supervisor, PhD Associate Professor Bogdan Antonescu, for providing guidance and feedback throughout this study. I am also deeply grateful to my family, whose constant support and encouragement have meant everything to me.

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CONSIDERATIONS REGARDING ATMOSPHERIC AND ENVIRONMENTAL DATA ACQUISITION WITH QUADCOPTER UAV

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DOI: 10.19062/2247-3173.2025.26.21

Abstract: *The specific applications of atmospheric and environmental data acquisition are found in the following areas: air quality monitoring, climate and meteorological studies, extreme events (volcanic eruptions, fires, and floods), biodiversity, waste and soil pollution, precision agriculture (crop monitoring).*

The paper proposes an applicative approach regarding the monitoring and acquisition of atmospheric and environmental data with the help of open source hardware tools (arduino platform) on board a customized UAV, as a low-cost functional model, with educational and research use.

Keywords: *atmospheric monitoring, UAV, Arduino, temperature sensor, smoke sensor.*

Acronims:

ppm	parts per million	csv	comma-separated values
IDE	Integrated Development Environment	SPI	Serial Peripheral Interface

1. INTRODUCTION

The use of unmanned aircraft for the acquisition of atmospheric and environmental data offers specific approaches to the versatility of these types of aerial vectors together with the technological advantages of the miniaturization of dedicated sensors depending on the specific national regulations applied to the categories of UAV used.

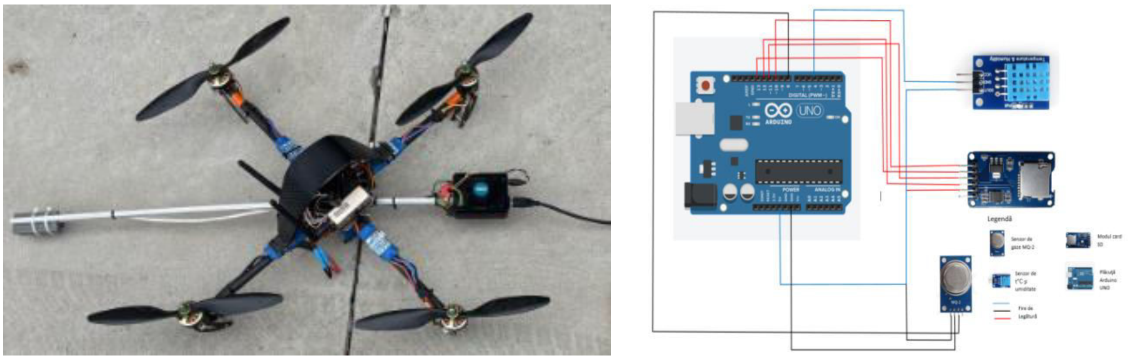
The specific applications of atmospheric and environmental data acquisition are found in the following areas: air quality monitoring, climate and meteorological studies, extreme events (volcanic eruptions, fires, floods), biodiversity, waste and soil pollution, precision agriculture (crop monitoring). [1-5]

The paper proposes an applicative approach to the monitoring and acquisition of atmospheric and environmental data using open source hardware tools (Arduino platform) on board a customized drone, as a low-cost functional model, with educational and research use. The theoretical and applicative aspects developed in the article include a series of references about the tools used in the application stage and obviously an applied approach with the presentation of concrete experimental data on the sampled atmospheric and environmental parameters.

2. RESOURCES

2.1.Hardware

For the acquisition of atmospheric and environmental data we used a quadcopter to which a DHT11 temperature and humidity sensor and an MQ-2 gas sensor were attached. These were integrated into the unmanned aerial platform using an Arduino UNO microcontroller, see Fig. 1. [6-8]



a b

FIG.1 Resources, a. multicopter, b. microcontroler ARDUINO Uno

To initialize the experimental model, I used the Arduino IDE to program the sensor array to deliver data in an easy-to-read and process manner. Humidity is measured in percentage, air temperature and dew point temperature in Celsius degrees, and gases are measured in parts per million (ppm). The Arduino microcontroller is responsible for communicating with the sensors through various protocols, processing the acquired data, and, in my case, storing it on the SD card in csv format. [9]

2.2.Software

The software implementation of the monitoring system was done in the Arduino-specific language, based on C/C++. This code can be divided into several sections: initialization and configuration of components, acquisition of data from sensors, processing and calculation of derived parameters, data storage and display.

a. Initializing and setup elements

This section consists of configuring the libraries used, declaring the pins used in communicating with the hardware components, and initializing global variables. Without the use of libraries, it would not have been possible to run the code below:

```
#include <DHT.h>          // Biblioteca pentru senzorul DHT11
#include <SPI.h>          // Biblioteca pentru comunicarea SPI (necesară pentru SD card)
#include <SD.h>           // Biblioteca pentru modulul SD card
#include <math.h>         // Biblioteca pentru funcții matematice (necesară pentru calculul punctului de rouă)
```

The DHT library facilitates the microcontroller's communication with the temperature and humidity sensor, and the SPI and SD libraries are essential for the optimal functioning of the SD card. The math library provides the mathematical functions necessary for calculating the dew point. We used preprocessing directives to define the pins used in communicating with the hardware components.

This approach allows for easy modification of the hardware configuration without much code modification.

```
#define DHT_PIN 2         // Pinul digital pentru senzorul DHT11
#define DHT_TYPE DHT11    // Tipul senzorului DHT (DHT11)
#define MQ2_PIN A0        // Pinul analog pentru senzorul MQ2
#define SD_CS_PIN 10      // Pinul CS pentru modulul SD card
```

The setup( ) function is important because it provides a robust solution for implementing the SD card, which includes configuring pin 10 as an output and setting it *high*.

```
pinMode(10, OUTPUT);
digitalWrite(10, HIGH);
```

This solves a well-known SD card initialization problem. At the same time, the SD card initialization has been done at a reduced speed to increase the stability of SPI communication.

```
if (!SD.begin(SD_CS_PIN, SPI_HALF_SPEED)) {
  Serial.println("Eroare la inițializarea cardului SD!");
  Serial.println("Programul va continua fără înregistrarea datelor pe card SD.");
  cardSDFunctional = false;
} else {
  Serial.println("Card SD inițializat cu succes.");
  cardSDFunctional = true;
```

An advantage of this code is that it can be used to read data even if an SD card is not used.

b. Data acquisition from sensors

Acquisition of data from sensors is done in the loop() function which is also the main loop of the program. In order not to overload the system and to record data at a certain period, we implemented a timing mechanism based on the millis() function:

```
unsigned long timpCurent = millis();

if (timpCurent - timpAnterior >= interval) {
  timpAnterior = timpCurent;
```

Thus, data recording is done once every 5 seconds. With the help of the call of the readhumidity() and readtemperature() functions, data acquisition from the DHT11 sensor is performed:

```
umiditate = dht.readHumidity();
temperatura = dht.readTemperature();
```

At the same time, we also introduced checks to detect reading errors of the DHT11 sensor.

```
if (isnan(umiditate) || isnan(temperatura)) {
  Serial.println("Eroare la citirea senzorului DHT11!");
  return;
}
```

Information acquisition from the MQ-2 sensor is achieved by reading the value from the corresponding pin.

```
valoareMQ2 = analogRead(MQ2_PIN);
```

3. PARAMETER PROCESSING

3.1. Processing and calculation of parameter

The calculation of the dew point temperature is performed by the function calculaeazaPunctRoua() based on a mathematical formula that uses the temperature measured in degrees Celsius but also the humidity recorded in percentage. The dew point temperature represents the temperature at which water vapor condenses.

```
float calculeazaPunctRoua(float celsius, float umiditate) {
  // Implementarea metodei dewPointFast - mai rapidă și suficient de precisă pentru majoritatea aplicațiilor
  float a = 17.271;
  float b = 237.7;
  float temp = (a * celsius) / (b + celsius) + log(umiditate * 0.01);
  float Td = (b * temp) / (a - temp);
  return Td;
}
```

This implementation uses the *dewPointFast method* which is an efficient and highly optimized method, being faster than other methods of calculating the dew point temperature.

Using a simplified conversion formula, the system converts the analog value read from the MQ2 sensor into ppm units.

```
ppm = valoareMQ2 * 10.0;  // Conversie simplă pentru demonstrație
```

3.2. Storage and display data

The system provides two methods for displaying acquired data: displaying on the Arduino IDE application interface (Serial Monitor) and storing on the SD card. [9]

Displaying data on the serial interface allows for real-time monitoring.

```
// Afișarea datelor pe Serial Monitor
Serial.print("Temperatura: ");
Serial.print(temperatura);
Serial.print(" °C, Umiditate: ");
Serial.print(umiditate);
Serial.print(" %, PPM: ");
Serial.print(ppm);
Serial.print(", Punct de Rouă: ");
Serial.print(punctRoua);
Serial.println(" °C");
```

Data is stored on the SD card only after it has been successfully initialized, using the variable 'cardSDFunctional' to control this action. With this code, the data is saved in CSV format, meaning the values are separated by commas, which facilitates easy data entry into Excel or other special statistical analysis software.

The code implementation includes several optimizations worth mentioning, such as: using the timing mechanism based on ‘millis()’ instead of the ‘delay()’ function allows for a more efficient operation of the system in terms of energy consumption. At the same time, organizing the code into different functions to perform certain operations increases modularity and allows for very easy system changes.

```
// Salvarea datelor pe cardul SD doar dacă acesta funcționează
if (cardSDFunctional) {
  File dataFile = SD.open(numeFisier, FILE_WRITE);

  if (dataFile) {
    // Scriere date în format CSV
    dataFile.print(temperatura);
    dataFile.print(",");
    dataFile.print(umiditate);
    dataFile.print(",");
    dataFile.print(ppm);
    dataFile.print(",");
    dataFile.println(punctRoua);
    dataFile.close();

    Serial.println("Date salvate pe cardul SD.");
  } else {
    Serial.println("Eroare la deschiderea fișierului pentru scriere!");
  }
}
```

4. EVALUATION OF THE EXPERIMENTAL MODEL

4.1 Cost and mass of the atmospheric sensor system

The atmospheric sensor system consisting of an Arduino UNO and the DHT-11 and MQ2 sensors is an economical and efficient choice because the sensors used have a low cost. At the same time, they are recommended for applications that do not require a very high degree of accuracy. [10-15]

Table1. Costs and weight of sensors in the atmospheric monitoring module

Elements	Cost (ron)	Mass (grams)
Arduino UNO	133,24	9
DHT-11 sensor	8,36	2
MQ2 sensor	10,92	8
SD card module	7,14	8
Alluminium stick	50	150
Arduino case	20	40
Senzor case	0,2	25
TOTAL	**229,86**	**242**

4.2. Atmospheric monitoring module power consumption

Estimating the power consumption of this system is essential to know which battery to use and the autonomy it will have. Since this sensor module receives power from the same battery that powers the drone, a battery with a sufficiently large capacity must be chosen so as to meet the needs of each device.

Table 2. Sensor module power

Elements	Power (mA)
Arduino UNO	25-50 (Max)
DHT-11 sensor	2,5 (Max)
MQ2 sensor	180 (Max)
SD card module	20-100 (Max)
TOTAL	**332,5 (Max)**

5. CONCLUSIONS AND FUTURE STUDY

Atmospheric and environmental monitoring through the acquisition of specific data involves the use of calibrated sensors and measurement scenarios adapted to the purpose of experimental tasks. Given the logistical preparation carried out, a series of future stages can be designed as follows: sensor calibration, definition of work scenarios and measurement stages, stages that are the subject of future scientific work.

Educational unmanned aerial platforms constitute a mature technology that can instrument appropriate measurements in experimental scenarios with the delivery of data with medium and high confidence levels.

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