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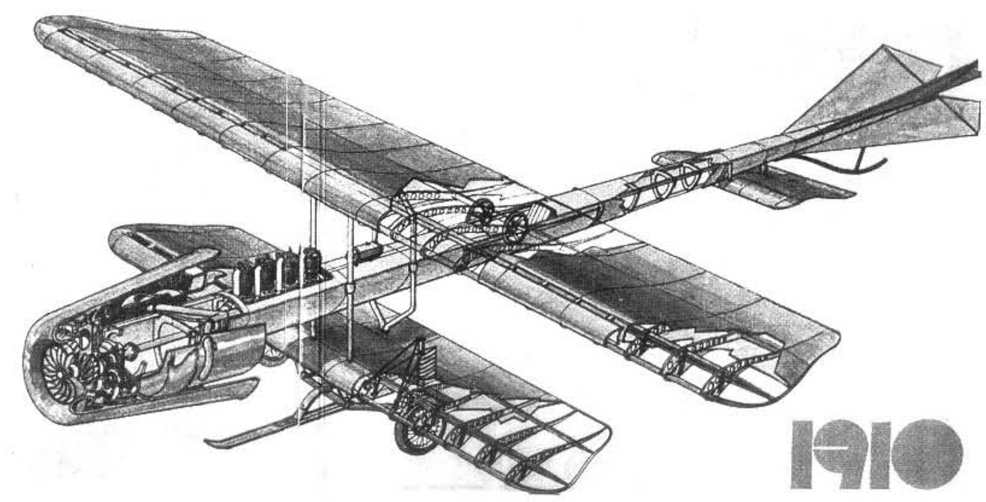

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COMPARATIVE ANALYSIS OF GROUND-BASED AIR DEFENCE SYSTEM CAPABILITIES: JAMMING AND MANEUVERING

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Abstract: *Nowadays, the vertical component of war, continuously subjected to in-depth analyses concerning its development and represented by two different system types – Aerial and Air Defence – is (and will be in the future) the decisive element of victory. Due to the assiduous development of this component, the physiognomy of war will be reshaped, with a higher weight on its vertical dimension, as opposed to the military actions conducted in the other traditional environments: terrestrial or maritime.*

Keywords: *Surface-to-Air Missile System (SAMS), GBAD combat capabilities, jamming and maneuvering*

1. INTRODUCTION

Long Range Surface-to-Air Missile Systems, represents one of the basic pillars of airspace defence. This component of Air Defence was first mentioned in 1931, by the time Dr Gustav Rasmus presented the concept of Surface-to-Air Missile System (SAMS) at a scientific conference. World War II was the main reason to enhance and develop these systems. This development process assured the interoperability support within transport aviation, research, hunting, bombing but also with other categories of forces (army and naval), in order to ensure the airspace protection.

In the paper, we proposed ourself to analyse the SAMS combat capabilities, focusing on determining the possibilities of annihilation in case of an enemy usage of jamming and manoeuvring.

We have chosen this topic because the analysed elements are in accordance with the modern battlefield requirements and, at the same time, it is a material that can arouse the curiosity of the military, especially those who frame the missiles and anti-aircraft artillery.

Kill probabilities study, combined with the efficient exploitation of the technical and tactical characteristics of SAMS, is essential to obtain a high effectiveness against the aerial threat.

The main task of this paper represents the conduction of a study based on detailed analysis of the SAMS' kill probabilities, as well as their calculation, given the use of electronic jamming and manoeuvring by the enemy.

The three chosen systems for this study are $SAMS_1$ that belong to NATO, and $SAMS_2$, and $SAMS_3$ that belong to Russian Federation.

For the comparative analysis of technical and tactical SAMS' performances, the determination of S_1 S_2 and S_3' power index and determining of the aerial enemy kill probabilities in the conditions of use of jamming and manoeuvring, we used the AHP (Analytic Hierarchy Process) method.

By using this method, we can determine which is the most important characteristic (possibility of detection, kill probability, the mobility and possibility of jamming counter measures). After calculating the weights of the features in the Microsoft Excel programming environment, we represented the hierarchical results.

2. DETERMINING THE POSSIBILITIES OF ENEMY AIR TARGET ANNIHILATION BY JAMMING AND MANEUVRING. A CASE STUDY

2.1 Hierarchical analysis of the detection possibility, the kill probability, mobility and the electronic counter-countermeasure capability

In modern conflicts, in addition to the possibilities of research, detection, recognition and tracking of aerial targets, combined with the annihilation probabilities and the possibilities of manoeuvring troops and equipment, an important role belongs to the countermeasures for jamming. In this perspective, the diagram in figure 1 exemplifies the types of jamming used in recent military conflicts.

Active and passive jamming systems block the enemy's signals, as a result they are unable to fire against the target and react to sudden changes in the situation.

As a result of these challenges, some protection measures are required against various types of jamming (active, passive, radiolocation, thermal, television and visual-optical means of detecting and orienting the weapon to the potential enemy. [6]

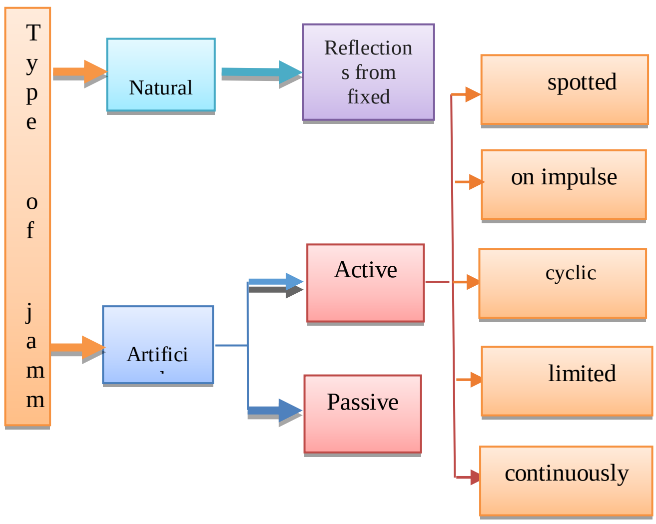

FIG. 1 Jamming classification [6]

In order to highlight the importance of the 4 factors that decisively contribute to fulfilling the mission (the possibilities of research, detection, recognition and pursuit of targets, kill probability, possibilities of troops and equipment manoeuvring and electronic counter-countermeasures) we used a multi-criteria decision-making method, named AHP (Analytic Hierarchy Process).

This method is effective in making a complex decision. It can be useful in setting priorities to choose the most appropriate option.

This is done by reducing complex decisions to a sequence of pairwise comparisons, and then synthesizing the results. Therefore, the AHP concerns both the subjective and the objective aspects of a decision. At the same time, AHP incorporates a useful technique for verifying the consistency of the assessments regarding the decision factor.

Using this method, the weights for each evaluation criterion can be generated according to the decision factor by comparing the criteria in pairs. The overall score for a given option is a weighted sum of the scores for all criteria.

The AHP method involves the following steps:

- the evaluation development of each alternative decision for each criterion, by:
  - development of a pair comparison matrix, type m × m, where m is the number of evaluation considered criteria;
  - the normalization of the resulted matrix;
  - calculating the average value from each row to obtain the corresponding result;
  - calculation and verification of consistency ratio.
- the criteria weights elaboration.
- calculating the weighted average for each alternative decision.

Assuming that *the number of evaluation criteria* is *m* and the number of *evaluated options* is *n*, the steps of the analysis will be described in detail below.

To determine the weights for different criteria, the hierarchical analytical process begins with building a matrix (denoted by *A*) for pair comparison. This is of the type m × m, where *m* represents the number of criteria to be evaluated.

The terms in matrix *A* are constructed in coherent pairs. On the other hand, ranking can generally be done with small inconsistencies, which do not cause serious difficulties for AHP.

The hierarchy of components is achieved by building the matrix, which compares the performance indicators with each other. The performance indicators being detailed by criteria, the pair comparisons are repeated for each of the levels of this hierarchy, and the intensity of importance is evaluated using a Saaty scale. [9]

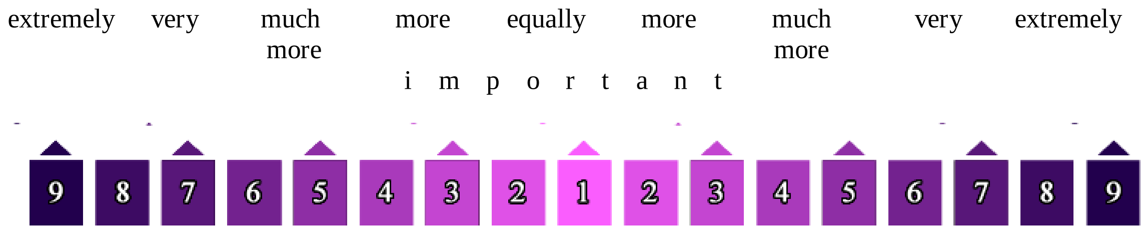

FIG. 2 Saaty scale

This scale is structured on nine levels: basic (1 - equally important; 3 - more important; 5 - much more important; 7 - very important; 9 - extremely important and intermediate (2, 4, 6, 8 - when a compromise is needed) [9]

We applied this method in order to find out what is the most important feature of a Surface-to-Air Missile system. For this I have noted the characteristics which will have to be compared with C_1, C_2, C_3, C_4, where:

- C_1 = possibilities of detection (P_d);
- C_2 = kill probability (K_p);
- C_3 = mobility (M);
- C_4 = electronic counter-countermeasures (E_{CCM})

If one of the chosen criteria is stronger (weaker) than the other, it’s value is set on the chosen scale, to the left (right).

Table 1. Comparison of criteria

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
C_1											■							**C_2**
C_1							■											**C_3**
C_1										■								**C_4**
C_2								■										**C_3**
C_2					■													**C_4**
C_3													■					**C_4**

The next step is to build the matrix corresponding to the pairwise comparisons. It will consist of 4 rows and 4 columns and will be marked with A, and the main diagonal contains only elements with the value of 1, according to the statement that each criterion is as important as itself.

What needs to be done next is to complete the upper triangle corresponding to the matrix. For this, two obvious rules must be followed (minding that when completing the rows of the matrix, we will compare the characteristics C_i with C_{i+p}, where *i* is the line index of the matrix):

a. If the assigned value ($a_{i,i+p} \in \overline{1,9}$) is to the left of 1 (see table 1),this means that C_i is superior to C_{i+p}, so this value is to be filled in the matrix.

b. If the assigned value ($a_{i,i+p} \in \overline{1,9}$) is located on the right side of 1 (see table 1), this means that C_{i+p} is higher than C_i, so that the value $\frac{1}{a_{i,i+p}}$ is completed in the matrix. We have represented below the matrices, fractional and decimal.

$$A = \begin{pmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{2} \\ 3 & 1 & 2 & 5 \\ \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{5} \\ 2 & \frac{1}{5} & 5 & 1 \end{pmatrix} \qquad A \begin{pmatrix} 1 & 0.33 & 3 & 0.5 \\ 3 & 1 & 2 & 5 \\ 0.33 & 0.5 & 1 & 0.2 \\ 2 & 0.2 & 5 & 1 \end{pmatrix}$$

In the following, we will calculate the eigenvector according to Saaty's theory, this being in fact the normalized eigenvector of the matrix. To better understand, it is necessary to recapitulate the notions of eigenvalue and eigenvector, associated with a quadratic matrix.

Therefore, if *X* is a column vector of size *n* different from 0 and *A* is a matrix of type *n x n*, then AX is another column vector Y, of size *n*, resulted from their multiplication, according to the multiplication rule of matrices.

$$A_{n,n} \cdot X_{n,1} = Y_{n,1} \tag{2.1}$$

If the vectors X and Y are collinear, which means the condition $Y = \lambda \cdot X$, is satisfied: then X is called the eigenvector and λ eigenvalue of the matrix A, considering λ a scalar (complex or real, provided that the elements of the matrix are either complex or real).

Therefore, it follows that the equation that characterises eigenvalues and vectors is:

$$A \cdot X = \lambda \cdot X; \tag{2.2}$$

where X is different from zero

The solutions of the equation are represented by the eigenvalues $\lambda_1, \lambda_2, ..., \lambda_n$, and then the corresponding eigenvectors X_1, X_2, …, X_n. Equation 2.2 is written as:

$$(A - \lambda \cdot I_n) \cdot X = O_n, \tag{2.3}$$

where I_n is the unit matrix, and O_n is the null matrix, of type *n x n.*

As mentioned before, X is a nonzero eigenvector, therefore it is clear that the equation (2/3) can be satisfied only if the matrix $A - \lambda \cdot I_n$ has the determinant equal to zero:

$$\det(A - \lambda \cdot I_n) = 0 \tag{2.4}$$

In this way, a *n* degree algebraic equation was obtained, which is called *the characteristic equation of the matrix A*, with the unknown λ. It follows that the solutions the equation (2.4) are the eigenvalues of the matrix.

Then in equation (2.3) the eigenvalues resulted from the calculation are replaced and result the eigenvector values, corresponding to each eigenvalue.

Observation is required:

By replacing the eigenvalues λ_k in (2.3) it is necessary to solve a homogeneous system of equations (it has zero free terms), which has the determinant, obviously, zero (this is the term from the left of the equation (2.3), and λ_k represents one of the solutions of the equation (2.4).

It can be stated that the specified homogeneous system will not have a unique solution, namely the eigenvector X_k cannot be uniquely determined. Moreover, this conclusion could be extracted from the qualitative analysis of the equation (2.2), it obviously being that if X is the solution, therefore the vector kX will also verify equation (2.2), where k is a real or complex scalar (according to the elements of the matrix A).

We`ll consider that the eigenvector, one of the representative sets of homogeneous system solutions mentioned above, is suitable to values of the parameters on which it depends.

Usually, the obtained eigenvectors is normalized.

It is also proven that the solution of the homogeneous system depends on a number of parameters equal to the order of multiplicity of the respective eigenvalue, as a solution of the characteristic equation (2.4).

For example, a simple eigenvalue will correspond to an indefinite simple homogeneous system (its solution will depend on a parameter); a double eigenvalue will correspond to an indefinite double homogeneous system (its solution will depend on two parameters), etc. [8]

So, going back to the matrix above, it can be said that this is now a complete comparative matrix. The next step is to normalize the matrix, and this is done by summing the numbers on each column.

Table 2. Column summation of matrix elements

Criteria	**C_1**	**C_2**	**C_3**	**C_4**
C_1	1.00	0.33	3.00	0.50
C_2	3.00	1.00	2.00	5.00
C_3	0.33	0.50	1.00	0.20
C_4	2.00	0.20	5.00	1.00
Total	6.33	2.03	11.00	6.70

Next, each element in the matrix will be divided by the sum of the column to which it belongs, to obtain its normalized result.

$$a_{ij} \rightarrow \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \forall j = \overline{1,n}; (n = 4) \tag{2.5}$$

The normalized matrix results:

$$A = \begin{pmatrix} 0.16 & 0.16 & 0.27 & 0.07 \\ 0.47 & 0.49 & 0.18 & 0.75 \\ 0.05 & 0.25 & 0.09 & 0.03 \\ 0.32 & 0.1 & 0.45 & 0.15 \end{pmatrix}$$

The eigenvector will be represented by the average value of each line, divided by the number of established criteria (four).

$$w_{ij} = \frac{\sum_{j=1}^{n} a_{ij}}{n}, \forall i = \overline{1,n}; (n = 4) \tag{2.6}$$

According to normalized matrix we will calculate the eigenvector

Table 3. Calculation of the eigenvector

	C_1	**C_2**	**C_3**	**C_4**	**Total**	**Average**
C_1	0.16	0.16	0.27	0.07	0.67	0.167
C_2	0.47	0.49	0.18	0.75	1.89	0.473
C_3	0.05	0.25	0.09	0.03	0.42	0.105
C_4	0.32	0.10	0.45	0.15	1.02	0.254

$$\begin{pmatrix} 0.16 & 0.16 & 0.27 & 0.07 \\ 0.47 & 0.49 & 0.18 & 0.75 \\ 0.05 & 0.25 & 0.09 & 0.03 \\ 0.32 & 0.1 & 0.45 & 0.15 \end{pmatrix} \xrightarrow[\text{average rows}]{} W = \begin{pmatrix} 0.167 \\ 0.473 \\ 0.105 \\ 0.254 \end{pmatrix}$$

Thus, we obtained the value of the corresponding (normalized) vector

$$W_\lambda \begin{pmatrix} 0.17 \\ 0.47 \\ 0.11 \\ 0.25 \end{pmatrix}$$

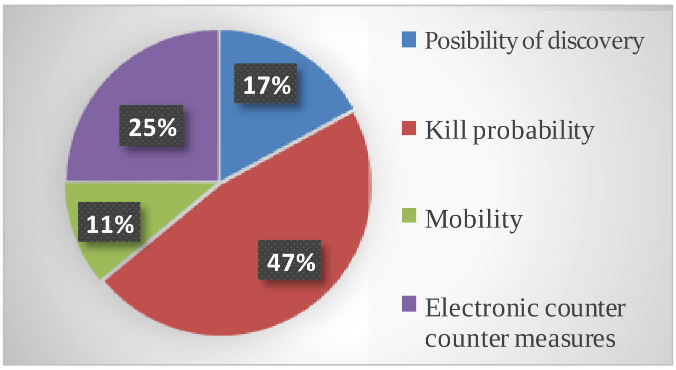

FIG. 3 Criteria subjects to AHP analysis and their weights

From the diagram above it can be seen that the SAMS` kill probabilities C_2 has the largest share, consequently it is the most important feature.

Next, I will analyse regarding on the study consistency, meaning I will appreciate the consistency of the comparison matrix.

It can be stated about the comparative judgment that it has consistency if it respects the principle of transitivity, which is stated as follows: if *X* is more important than *Y*, and it is more important than *Z*, then obviously it follows that *X* is more important than the criterion *Z*.

By transforming these qualitative judgments into quantitative assessments, it results that it can stated, firstly, the consistency of a mutual matrix.

Thus, about a reciprocal matrix $\left(a_{ij} > 0; a_{ij} = \frac{1}{a_{ji}} \right)$ it can be stated that it is consistent if it satisfies the relation:

$a_{jk} \cdot a_{kp} = a_{jp}, \ \forall j,k,p$

Saaty's theorem is being demonstrated:

If the polynomial characteristic of a reciprocal matrix (of type *n x n*) is as follows: $P(\lambda) = \lambda^n - n \cdot \lambda^{n-1}$, it results that the matrix is consistent.

By this method, the eigenvalues of this type of matrix (solutions of the equation $P(\lambda) = 0$ will be zero (multiple root of *n - 1* times) and *n (*single root).

Therefore, the choice of both the eigenvector as a vector of priorities and the maximum eigenvalue is natural. At the same time, the study consistency can be appreciated by the difference $\lambda_{max} - n$. Normally, it should be zero.

However, it is quite unlikely to obtain a consistent comparison matrix from the comparisons between the analysed criteria, therefore, for the purpose of the above definition, the following consistency indicators (Saaty) were stated:

- Consistency index (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2.7}$$

- Random value of the consistency index (IR). It is obtained by randomly generating reciprocal matrices with values $\frac{1}{9}, \frac{1}{8}, \ldots, 1, \ldots, 8, 9$ and calculating the CI consistency index. Its average values are presented in table 5, for matrices of the type 3 x 3,…, 10 x 10.

Table 4 Random values of the consistency index

N	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

- The ratio (rate) of consistency is defined as equal to the ratio between the two indicators listed above:

$$CR = \frac{CI}{RI} \tag{2.8}$$

To find out the value of the consistency ratio, we have to follow the steps below which consists of:

1. Calculation of the consistency measure;
2. Calculation of the consistency index (CI);
3. Calculation of the consistency ratio (CR).

To calculate the *measure of consistency*, we can use the multiplication function of the matrix in Excel = MMULT (). In order to obtain this indicator, it will proceed as follows: multiply successively the values of the column „Total" (from table 4) with the sum of the weights obtained, and the result will be divided by the weight of the corresponding row.

Taking into account the calculation of the eigenvector it will result the *consistency measure*

Table 5 *Calculation of the consistency measure*

	C_1	C_2	C_3	C_4	**Total**	**Average**	**Consistency measure**
C_1	0.16	0.16	0.27	0.07	0.67	0.167	0.91
C_2	0.47	0.49	0.18	0.75	1.89	0.473	1.11
C_3	0.05	0.25	0.09	0.03	0.42	0.105	1.36
C_4	0.32	0.10	0.45	0.15	1.02	0.254	0.71

We are going to find out the values of the *consistency index* and *the consistency ratio*. For this it is necessary to find the maximum eigenvalue λ_{max}, which is calculated by dividing each of the values in the „Total" column by the values in the „ Average" column in table 6, and then the arithmetic average of the results is calculated.

Results:

$$\lambda_{max} = \frac{4{,}011 + 3{,}995 + 4 + 4{,}015}{4} = 4{,}00525$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4{,}00525 - 4}{3} = 0{,}00175$$

$$CR = \frac{CI}{RI} = \frac{0.00175}{0{,}9} \cong 0{,}00194 < 0{,}1$$

Table 6. *Calculation of the consistency index / ratio*

	C_1	C_2	C_3	C_4	Total	Average	Consistency measure
C_1	0.16	0.16	0.27	0.07	0.67	0.167	0.91
C_2	0.47	0.49	0.18	0.75	1.89	0.473	1.11
C_3	0.05	0.25	0.09	0.03	0.42	0.105	1.36
C_4	0.32	0.10	0.45	0.15	1.02	0.254	0.71
						CI	0.00175
						RI	0.9
						CR	**0.00194**

Analysis of this type is considered consistent if and only if $CR < 0.1$. Any higher value requires a re-examination of the made comparisons. As in our case the CR is less than 0.1, it is not necessary to re-examine the made comparisons.

2.2 Calculation of the power index of SAMs S_1 S_2 and S_3

Next, we will develop the previous study by determining *the power index* of the SAM S_1 S_2 and S_3.

The three SAMS power index calculation consists of the necessity of evaluation by requirements and capabilities of the $SAMS_1$ compared to the performance of $SAMS_2$ and S_3.

In the first phase, for this index determination, we will proceed as in the case of the multicriteria analysis method AHP (we choose the criteria for comparison and we calculate their weights, following the necessary steps).

In this perspective, I will not choose other criteria, or other weights, but I will also use those used in this chapter, where, by calculating their weights, I determined the importance of each criterion in the process of fighting against an aerial threat.

In order to achieve the criteria homogeneity (which can be described both quantitatively and qualitatively), we have built a performance scale with five levels (Table 7).

Table 7 *Presentation of criteria, weights and performance evaluation*

Performance criteria	Weights	$SAMS_1$	$SAMS_2$	$SAMS_3$
Possibilities of detection (P_d)	0,167	≈ 160 km	≈ 300 km	≈ 400 km
Kill probabilities (K_p)	0,473	≈ 0,8-0,9	≈ 0,8-0,91	≈ 0,8-0,93
Mobility (M)	0,105	50-60 km/h	40-60 km/h	25-60 km/h
Electronic counter-countermeasures (E_{CCM})	0,254	high value	moderate	high value

Table 8 *Performance scale*

Level of performance	Scaling
Not applicable	0.0
Limited	0.25
Accepted	0.5
Significant	0.75
Remarkable	1

The next step to determine the power index of SAMS is represented by the application the calculation formula:

$$WPI = P_d\, w_1 + k_p\, w_2 + M\, w_3 + E_{CCM}\, w_4 \qquad (2.9)$$

The evaluation, integration of indicators / performance criteria of missile systems are presented in table 9.

Table 9 *The calculation of their power index*

Indicators (Performance criteria)	**Weights (W_i)**	**$SAMS_1$**	**$SAMS_2$**	**$SAMS_3$**
Possibilities of detection (Pd)	0,167	0,5	0,5	0,75
Kill probabilities (Kp)	0,473	0,75	0,75	0,75
Mobility (M)	0,105	1	0,75	0,75
Electronic counter-countermeasures (E_{CCM})	0,254	1	0,75	1
Weapon power index (WPI)		0,79725	0,7075	0,81

Following the performed analysis, according to the chosen criteria (possibility of detection, annihilation probabilities, mobility, possibility of jamming protection), it can be seen that the $SAMS_1$ has a second power index compared to the other systems, but if we make a parallel between the necessary working times regarding the maintenance works of the three systems, it can be stated that the S_1 version ranks above the level of the two Russian systems S_2 and S_3.

The $SAMS_2$ and S_3 subsystems, because they are built by Russian standards, they are not built with high-performance equipment for automatic testing, diagnosis, technique and fault signalling, which leads to increased service life maintenance.

CONCLUSIONS

The evaluation of SAMS information is very important for the military personnel assigned to use the missile weapon and anti-aircraft artillery.

At the same time, putting into the practice this knowledge on the battlefield results an increased effectiveness against aerial threat.

Taking into account the report of the last decades regarding the evolution of Air Defence systems, it can be said that they have been considerably developed.

The implementations brought to the systems contributed on the one hand to increased capabilities of SAMS, and on the other hand to improved manoeuvre force capabilities.

The comparative analysis of SAMS, technical and tactical performances, was based on: evaluation of the chosen criteria (WPI, IPA, P_d, K_p, M, J_{cm}), calculation of their weights and their ranking according to importance.

This study was performed with multicriteria analysis of decision making, the AHP (Analytic Hierarchy Process) method.

After completing these steps, we have calculated the power index of the SAMS. The detailed study describes the notions used by this method of analysis, as well as the steps taken to calculate the weights of the chosen criteria. After following the steps, which consisted of calculations performed in the Microsoft Excel programming, we represented the results hierarchically.

According to the calculations made, we came to the conclusion that the possibility of destroying an air defence system has the greatest weight in the process of fighting an enemy target, and the power index and, at the same time, the chances of destroying aerial targets under the conditions of usage of jamming and manoeuvring on the S_1 are the second place compared to all three systems.

In conclusion, following the presented information, it can be stated that the SAMS have had a significant evolution in several directions (technological, structural and action-based) and along with their evolution gradually increasing their importance, becoming an indispensable element in the battlefield.

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MANEUVERABILITY, ONE OF THE MOST IMPORTANT FEATURES OF AIR DEFENCE SYSTEMS

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Abstract: *The basic Surface-to-Air Missile System (SAMS) mission is to combat and destroy the aerial threats on the close and direct ways of access to the defended anti-aircraft objectives, before they fulfil their mission. The main features of Air Defence Systems will aim to increase the effectiveness, Electronic Counter-Counter Measures (ECCM), short reaction time, mobility and stability in work during the day or at night regardless of the weather conditions.*

Keywords: *Long Range Air Defence system forces and means manoeuvring Surface-to-Air Missile System (SAMS).*

1. INTRODUCTION

Integrated Air Defence (AD) involves the engagement of high-performance air platforms, with or without pilots, and technologically advanced aerodynamic and ballistic missiles.

The complex operational environment will include actions in the air, on water and on land carried out by different categories of forces and weapons or joint and coalition forces.

The integrated Air Defence mission will include regional defence, local defence and self-protection, being able to respond quickly to air and missile threats and use combined forces and means.

Area defence is specific to theatres of operations and can be defined as the action of each air defence and anti-missile system to ensure the protection of any other means of combat during military operations. The protected area may include elements to the level of military target groups in a conflict area.

An example of regional defence can be the Aegis system, with the mission of defence against air attacks and potential air threats (*„Anti Air Warfare"/ AAW*) **[Nr.6]**.

Aegis BMD-equipped vessels can transmit their target detection information to the Ground Based Midcourse Defense system and, if needed, engage potential threats using the Standard Missile 3 (SM-3) mid-course interceptors and the Extended Range Block IV (SM-2 Block IV) or Standard Extended Range Active Missile (SM-6) terminal-phase interceptors.**[Nr.21]**

This example includes the requirements for Aegis warships to protect aircraft carriers and other ships in a maritime combat group against any air attack.

Local defense or objectives defense is represented by the mission to protect targets and / or property in the immediate area from air attacks.

This may mean the protection of military or civilian means or smaller populated centres.

An example of a local defense system is the PATRIOT PAC-3 missile system. The local defense also includes self-protection for the own troops and for the combat disposition and its subsystems **[Nr.8]**.

When these strategies are used in combination, the result is a layered defence system in which the systems act successively to eliminate the threat.

Systems that work together can be brought together in a systems architecture and, as such, will act on the same concept of operations (CONOPS). The purpose is to achieve a combat system that destroys the target before it can fulfill its established mission or achieve success by neutralizing or accidentally destroying targets of interest to those defending against their attack.

In this paper we propose to simulate some of the Surface-to-Air Missile (SAM) system manoeuvre of forces and means, as well as to calculate the total time required to execute.

2. THE BASIC ARCHITECTURE OF LONG RANGE AIR DEFENSE SYSTEM

The Long Range SAM system is a set of sensors and components, incorporated regarding action and function through a fire control centre (FDC) into a combat structure which is capable to provide AD with ground-to-air means.

This system is intended to prevent surprise and to take immediate, firm and decisive action to destroy the aggressor, even from the border area, omnidirectional, in the full range of heights in terms of using radio electronic countermeasures.

The main components of the system are:

- C4ISR subsystem which stands for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance is the basic element to perform the specific functions of battle management;
- Sensor subsystem: 3D firing and search radars (if appropriate);
- Launching subsystem: launchers with related equipment and ammunition;
- Subsystem of vehicles and transport;
- Logistical support.

2.1 Typology of systems in the AD environement

High-altitude Surface-to-Air Missile (HSAM) systems can be classified according to capabilities, as follows:

1. Surface-to-Air: PATRIOT PAC-2;

The PAC-2 missile has a range of about 160 km. This AD system has four missiles per launcher. Missiles are stored and launched from reinforced aluminum canisters at a fixed angle. Launchers are mounted on trailers or based on 8x8 high mobility chassis. Launchers are self-contained units, fitted with their own powerplants and fuel. During operation these units are unmanned. The launchers are towed by tractor trucks. The mobile version is based on the Man Kat 1, 8x8 high mobility vehicle.

It takes 30 minutes to prepare the system for firing. A battery of launchers and associated support vehicles can change position up to several times a day.**[Nr 19]**

2. *Surface-to-Air with anti-missile capabilities*: PATRIOT PAC-3 (3rd configuration), Surface-to-Air Missile Platform/Terrain, the system uses a network of sophisticated radars and sensors (SAMP/T), ASTER 30, HQ-9, S-300, S-400;

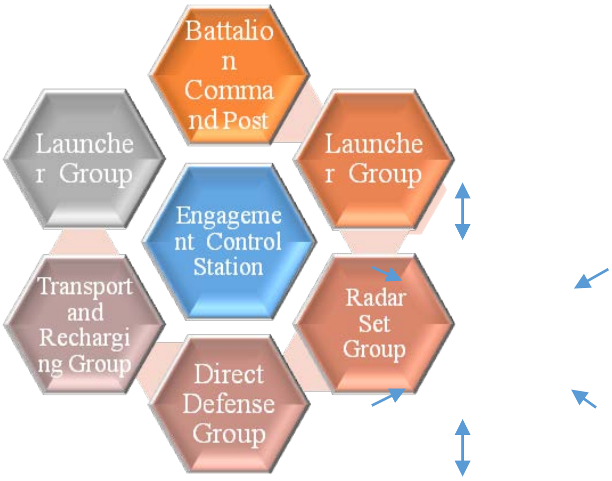

FIG. 1 The basic architecture of a GBAD system

The AN/MPQ-53 and 65 Radars Set from the PATRIOT structure are passive, electronically scanned array radars equipped with IFF(Identification friend or foe), electronic counter-countermeasure (ECCM), and track via missile (TVM) guidance subsystems.

TVM refers to a missile guidancemethod which combines features of semi active radar terminal homming (SARH) and radio command guidance.

The main difference between these two radars is the addition of a second traveling wave tube(TWT)**[Nr.18],** Fig.2, which gives the − 65 radar (PAC-3) increased search, detection, and tracking capability.

Between the two radars, -53 RS supports only PAC-2 units, while the -65 one supports both PAC-2 and PAC-3 units.

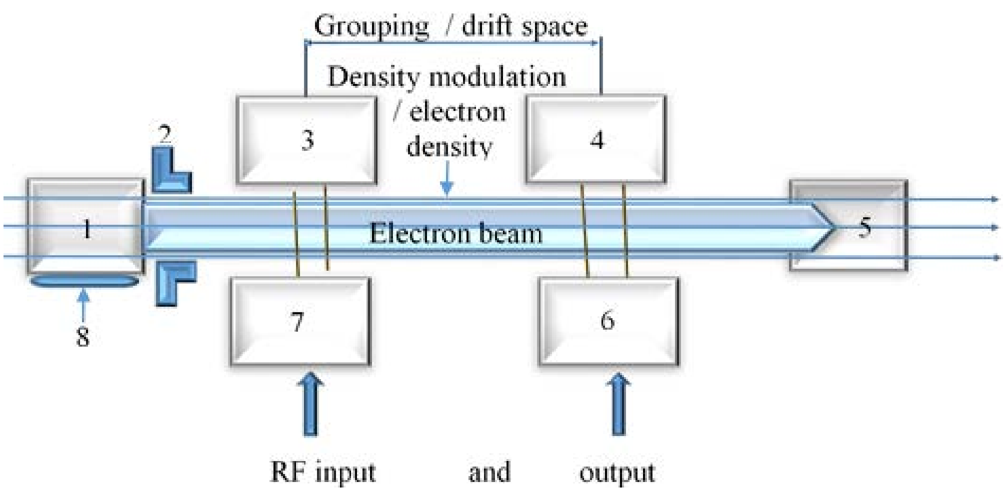

FIG. 2 Cutaway view of a helix TWT. surse [Nr.5]
(1) Filament /Heater(2) Anode; (3, 4) Resonant cavities; (5) Collector;
(6) Microwave input; (7) Microwave output; (8) Cathode

The radar antenna array consists of over 5,000 elements that "deflect" the radar beam many times per second. The radar antenna array also contains an IFF interrogator subsystem, a TVM array, and at least one "sidelobe canceller" (SLC), which is a small array designed to decrease interference that might affect the radar.

1. Anti-missile with anti-aircraft capabilities: The Medium Extended Air Defense System (MEADS), DAVID'S SLING, ARROW 2;

The ability to operate at a high level of flexibility ranks the MEADS type systems among the top performing systems, and the "plug and fight" type structure and combat characteristics allow the system to be adapted to a wide range of operations and missions specific to the forms of contemporary struggle. At the same time, the ratio between the firepower of MEADS, extremely high, and the human resource serving the system, relatively low, describes an equation whose solution is efficiency, characterized by the perfect balance between the resources involved, the results obtained and the costs.

The system has subordinated and coordinated structures and subsystems that enable the detection, tracking and engagement of hostile threats. The mode of deployment and combat is established by the command and control structures, those responsible for combat management.

A specific and extremely useful property of these systems is that which allows the command and control of combat elements (launcher, missile) to be taken over and coordinated by another combat subunit, arranged nearby, thus ensuring time for the structure engaged in combat to be able to execute the maneuver of forces and means.

This compatibility with neighboring AD systems gives MEADS systems the ability to conduct autonomous military actions adaptable to the operational environment. Thus, for the minimum provision of the assigned airspace area, a single multifunctional radar, a command center of tactical actions and a launcher with 12 missiles of the PAC-3 MSE type can be used. That elements can be transported and introduced into the area of combat actions with C-5 Galaxy aircraft (in one transport) or C-130 Hercules (in five transport stages).

DAVID'S SLING system is modular, scalable, and flexible to tailor-fit the area and topology to be defended. The Battle Management Center uses information from the multi-mission radar array and infrastructure resources to build an accurate, detailed Air Situation Picture. When interception is required, the planned course is communicated to the launcher via a dedicated data link and the interceptor can be retargeted in real time to eliminate the threat successfully**[Nr 21].**

2. Anti-missile: ARROW3, Theater High Altitude AreaDefense (THAAD).

The THAAD terminal (formerly theatre) is an easily transportable defensive weapon system to protect against hostile incoming threats such as tactical and theatre ballistic missiles at ranges of 200 km and altitudes of up to 150 km.

The system provides the upper tier of a ‘layered defensive shield’ to protect high-value strategic or tactical sites such as airfields or populations centres. The THAAD missile intercepts exo-atmospheric and endo-atmospheric threats.

The sites would also be protected with lower and medium-tier defensive shield systems such as the Patriot PAC-3, which intercepts hostile incoming missiles at 20 to 100 times lower altitudes.**[Nr 20]**

2.2 Calculation of manoeuvrability

„Nothing is harder than the art of manoeuvring. The difficulty from this point of view, is to make the most direct way in a twisted one, and to change the misfortune into the advantage "- Sun Tzu, The Art of War.

The manoeuvrability represents the unit's ability to respond quickly and timely to requests generated by changes in the enemy's mode of action, the consequences of its attack on the unit and the target to be defended, and the need for AD of other troops and objectives. [Nr. 8]

The manoeuvre is a summary of the planned, organized, coordinated and executed actions, in order to:

– repel the enemy's air attack;

– carry out decisive attacks against the structures of the aerial enemy, deployed on the ground or at sea;
– defend against air attacks and research of own objectives;
– the destruction of the tactical, operative and strategic air landing of the enemy;
– prohibit the supply and evacuation of enemy surrounded forces or carrying out violent actions.

In addition to these basic purposes, the manoeuvre will aim at:
– removing their own troops from the air, land or sea enemy attacks;
– restoration of the (combat, strategic and / or operative) district, as a result of the damages caused by the enemy;
– restoration and keeping in the battle and operation of air means;
– surprising the air enemy and the prevention of the surprise by him;
– carrying out actions to demoralize the potential opponent.

Influencing factors:
– general status (war, crisis, peace);
– airspace control index;
– weather conditions, season, as well as relief conditions;
– the technical-tactical characteristics of the fighting forces involved;
– the level of troops and headquarter training;
– the level of logistical support.

Technical factors:
– the gathering time of the equipment;
– framing the fighting team;
– the level of staff training;
– the endowment level of the combat component with means of transport.

Tactical factors:
– intervention in certain districts;
– forces deployment in order to realise the established districts;
– the establishment of new fighting forces or their removal from enemy blows;
– moving to defence in a new district or strengthening the defence;
– change of disposal districts;
– restoration of operational capacity;
– setting up reserves.

When the maneuver is performed in order to ensure the continuity of AD of the troops (objectives), the movement of units (subunits) in the composition of the large Air Defense unit begins when the enemy has reached an alignment located at a distance to allow units (subunits) to timely time from the combat district (shooting positions), or with the target directly defended.

The marching procedures are shown in the Fig. 3:

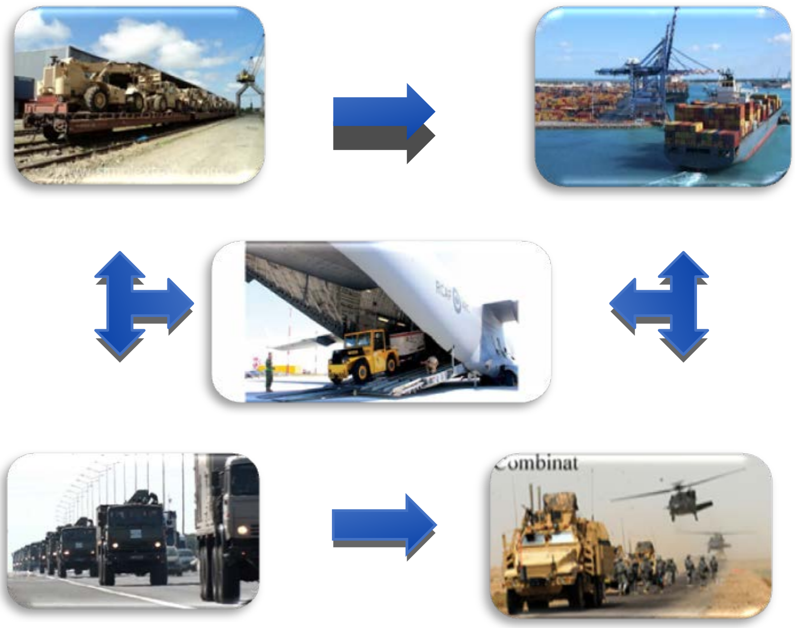

FIG.3 The marching procedures [Nr. 8]

SAM units and subunits can perform manoeuvring forces and means, as well as firing manoeuvre. During the operation, the maneuver of forces and means is performed to strengthen the Air Defense of some troops orobjectives, as well as to change the AD efforts from one direction to another.

During the manoeuvres of forces and means, it is necessary to ensure the continuity of radiolocation research of airspace, as well as the use of combat possibilities of SAM units at maximum capacity, while removing their troops from enemy blows.

The fire maneuver consists of the simultaneous or successive concentration of SAM fire on the most important air targets. It shall be carried out in accordance with the intensity of combat operations, the procedures used by the enemy air force to strike groups of troops and targets, their maneuvering against air strikes, the amount of ammunition and SAM available and the mode of cooperation with other AD. fighter aviation. The fire maneuver, by successive concentration of fire from one air target to another, is called fire transport. [Nr. 5]

The maneuver of forces and means is organized by the officers designated to ensure air security based on the decision of the operative group commander, taking into account: the general concept of conducting the defense operation; the situation and the operative district of the operative grouping; the availability of the communication means necessary for the organized movement of the AD troops performing the maneuver; ensuring the conduct of the fight with the air enemy; level of logistical support.

The maneuver of AD forces and means is materialized in the Air Defense Plan, on variants of action as well as in the successive action orders (combat dispositions) of the officer in charge of AD, given during the defense operation.

Table 1 presents the main characteristics of the missile subunits that influence the efficiency of the maneuver performed to participate in the battle with the air landing during transport and landing.

Table 1 - Estimated technical-tactical characteristics of SAM ssubunits

Nr. crt.	**SAM**	**Details**				
		Gathering time [min]	Deployment and preparing for shooting[min]	Total [min]	March speed [km/h]	Interval between launches [sec]
1.	PATRIOT PAC-3	≈50	≈30	≈80	≈50-60	≈3

For example, we will illustrate the simulation of the forces and means manoeuvre by a battery of SAM. In order to execute it, we chose the PATRIOT PAC-3 missile system.

We set out to determine the total time required to execute the manoeuvre with a subunit of this type. The manoeuvre of forces and means with the PATRIOT Surface-to-Air Missile battery will be performed both on land and in air, on the following itinerary:

FIG. 4 March itinerary

Table 2 – Technical data on the components of the missile battery that will be deployed

Patriot components	**Gauge characteristics of transport means**				**Transport means**
	Lenght: [m]	Width: [m]	Height: [m]	Weight:[t]	
Engagement Control Station (ECS)	10,29	2,50	3,38	31,8	Truck M927-5 ton 6x6
Radar Set	14,72	2,78	3,54	30,3	Truck M983-10 ton 8x8
Antena Mast Group(AMG)	7,6	2,50	2,85	24,8	Truck M942-5 ton 6x6
Launchers (4 x 16 missiles)	10,12	2,70	2,48	37,8	Truck M983-10 ton 8x8
Electric Power Plant (EPP)	10	2,7	2,8	33,7	Truck M927-5 ton 6x6

The manoeuvre of forces and means will be carried out in a tactical exercise. In this perspective, the air transport will be performed with C-17 Globemaster aircraft, considering that the military transport aircraft (C-27 J Spartan or C-130 Hercules) are required to perform other missions.

In Table 3 there are presented some comparative data on the transport possibilities of the three aircraft mentioned above.

Table 3 – The aircrafts transport capacity

Gauge data, UM / Typeof plane	**C-27 J Spartan**	**C-130 Hercules**	**C-17 Globemaster**
Lenght: [m]	7,8	12,2	26
Width: [m]	3,29	2,69	5,48
Height: [m]	2,23	2,74	3,76
Capacity of transport: [t]	11,4	10, 3	76

Initial situation:

Four C-17 Globemaster aircraft are required to carry out the air transport of the equipment of a PATRIOT PAC-3 SAM battery. The arrangement of the subunit equipment will be done as follows:

-Commamd Post and Electric Power Plant (total weight = 66,2 t) in the first aircraft;

-Radar Set and Antena Mast Group (total weight = 55,8 t) in the second aircraft;

-Two launchers with 4 missiles each (total weight = 76 t) in the third aircraft;

-The others two launchers with the same weight in the fourth aircraft.

Taking into account that the movement on wheels between Military Base and Air Base1 (AB_1) respectively Air Base 2 (AB_2) and new combat district is done with an average speed of 60 km / h, the resulting ratio between march speed and distance travelled is reflected in time T_2 and T_6.

Knowing that the C-17 Globemaster aircraft flies at an average speed of 830 km / h, and the distance in a straight line between $AB_1$and $AB_2$is 270 km, it results, by calculation, that the approximate flight time (T_4) will be 20 minutes, plus the time required for the take-off procedure (5-7 minutes) and the landing one (5-7 minutes). Therefore, it takes about 30 minutes to perform the manoeuvre in the air.

FIG. 5 Flight and road itinerary

To calculate the total maneuvre time it is necessary to determine the fractions of time for every operation:

-time for gathering and preparing for march (T_1);

-time to march on the road from the gathering area to plane boarding area(T_2);

-boarding time(T_3);

-flight time to the deployment area to which is added the landing and take off time(T_4);

-landing time from the plane(T_5);

-time to march to the deployment area(T_6);

-puttimg into service time(T_7);

-total manoeuvring time(T_{TM}).

$$T_{TM} = T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 \tag{2.1}$$

The values of the time fractions necessary for the SAM forces and means manoeuvring, against the air landing, are presented in Fig. 6.

With the development of decisive aviation actions, most armies are conducting studies and forecasting for the modernization of AD, the introduction of new types of weapons and military equipment, the modernization of existing ones and the improvement of tactical procedures and concepts of use in combat and operation, starting from the principle of maintaining a high level of combat capability of SAM units.

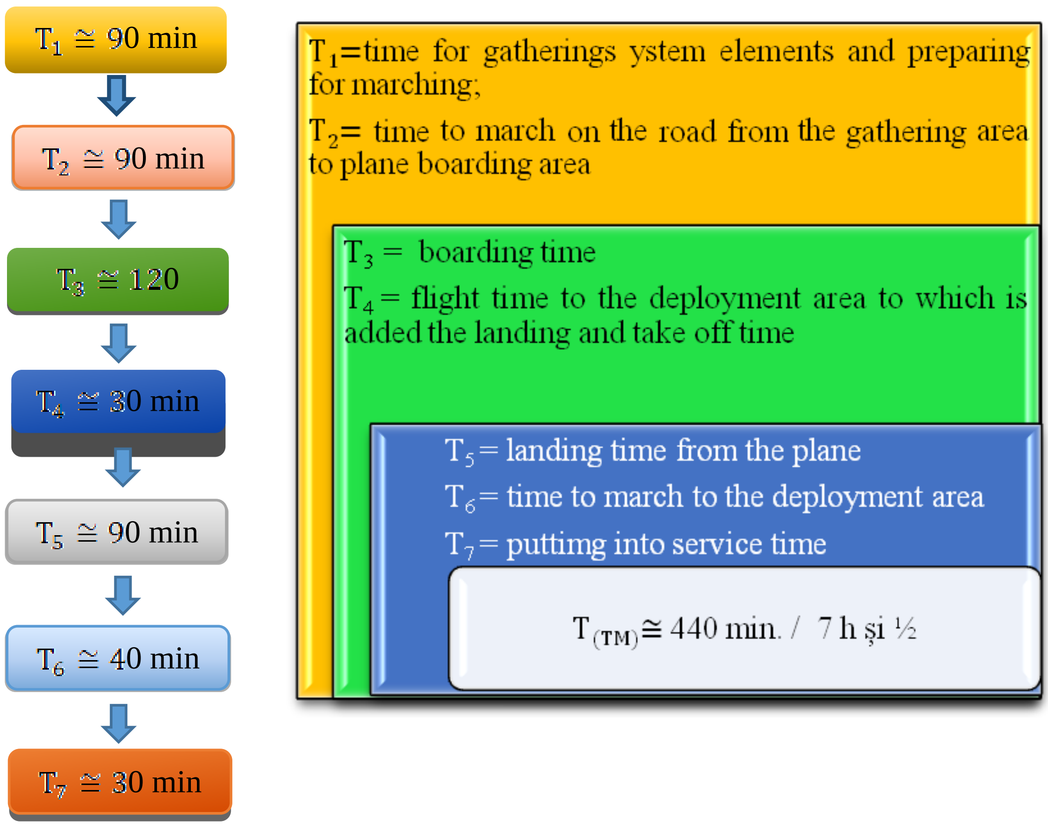

FIG. 6 Calculation of total manoeuvring time

3. CONCLUSIONS

It has been considered that the lines of evolution of an air defence system must meet the following conditions of efficiency:

- to be organized and led in a unitary conception, since peacetime, and to include the entire area of responsibility;
- to ensure the research, the opportune discovery and the continuous pursuit of the opponent's means so as to avoid surprise;
- to have the capacity to carry out combat actions against the air adversary in all probable directions of his action, in the space corresponding to the area of responsibility;
- to be permanently ready to fight with all forces and means;
- to achieve a shorter reaction time than available and to be stable in operation, even in complex conditions;

- to be made, constructively, on an advanced technology, with possibilities for modernization in perspective;
- to ensure the use to the maximum capabilities of the fighting technique, to allow the efficient cooperation between the component elements, as well as the other fighting systems in the area;
- to allow the standardization of the means of AD and their constitution in efficient mixed structures;
- to ensure compatibility and interoperability with other modern air response systems;
- to be able to act both in integrated and independent systems. [Nr. 5]

The prefigured AD systems for the future are designed to meet the following more important requirements:

- the possibility to fight against a wide range of aerial targets (from unmanned aerial vehicles to Long-Range Ballistic Missiles);
- discovery of aerial targets from a distance at least double from the range of the means of fire they serve;
- engagement in the fight with aerial targets at altitudes between 2000-30,000 m, with a probability of destruction of 80%, below 2000 m will act the specialized means for fighting at low altitudes;
- engagement in the fight against aerial targets that fly at altitudes between 2000-30000 m, with a kill probability equal to 0,8 (80%);until 2000 m will act the specialized means for fighting at low altitudes;
- short time to change firing positions;
- permanent airspace research;
- system operation time at least 20-30 years, with the possibility of successive update.

There are two dominant main trends in the development of SAM systems, namely: the creation of new systems for counteracting shocks and research from the air or from outer space; modernization of existing systems and endowment with high-efficiency missiles.

Taking into account the defensive nature of the AD, the triggering of impact systems must be ensured as soon as possible depending on the permanent threat situation. In this perspective, the researched airspace must be much larger than the defended area.

It is estimated that in the case of a SAM system, the search of airspace must comprise an almost double distance from the range of the missiles. In principle, airspace surveillance is based on the area of defense established on the basis of tactical considerations.

In the field, the limitations determined by the coverage angle and the influence of the blindspot of the long-range radar means shall be taken into account.

To discover targets that fly at low altitudes, studies have been conducted to increase the effectiveness of certain radiolocation antennas (folding arm or telescopic).

Studies in this field are still ongoing and aim to build radio stations, which have the ability to determine the shapes of air targets and even their dimensions, which would lead to a more accurate assessment of the aerial enemy and the adoption of measures effective in combating these threats.

The improvement of the IFF equipment is constantly increasing, thus obtaining the possibility of efficient correlation on the actions of SAM systems with the actions of its own aviation troops, under the conditions of the enemy's electronic countermeasures or a complex air situation.

Regarding the development of SAM, military specialists consider the following:

- the continuous information technology improvement and the wide use of microprocessors that will increase the accuracy of the combat components;

– creating smaller, simpler and more secure means for the automatic discovery, identification and tracking of targets;
– an optimal conception regarding the weight of the combat components, with programmed proximity warhead, which allows the optimal determination of the explosion moment.
– the realization of some means smaller, simpler and more secure for automatic detection, identification and tracking of targets;

It can be concluded that improvements to AD systems are an important direction towards automating activities and increasing effectiveness in the fight against aerial threats.

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EFFECTS OF FATIGUE ON AERONAUTICAL PERFORMANCE

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Abstract: *Events occurring in aviation affect the entire activity of a company. The contribution to the occurrence of an event is both routine and fatigue that can have negative preponderant effects. Identifying the factors favoring the occurrence of an event brings a progress in the development of programs to maximize flight safety. The study of routine and fatigue factors raises the level of importance and awareness on aviation events. Each member of the company must actively participate in the compliance of working procedures to increase the degree of safety at work. This level can only be reached when we establish and maintain strict rules, eliminate chaos and stress, minimize the pressure of tasks to create an environment proper to development.*

The study addresses all aeronautical personnel to increase the understanding of the effects of fatigue and how they contribute to the rate of occurrence of events.

Keywords: *routine, aviation event, safety, chaos, procedures*

1. INTRODUCTION

The purpose and necessity of this study is to identify, minimize and correct how aerospace activity is affected by fatigue and routine.

A study published by EASA[1] (European Union Aviation Safety Agency) shows that in 2020 a number of 323 people died in air accidents, compared to 1972, when 2365 people died (Fig. 1).

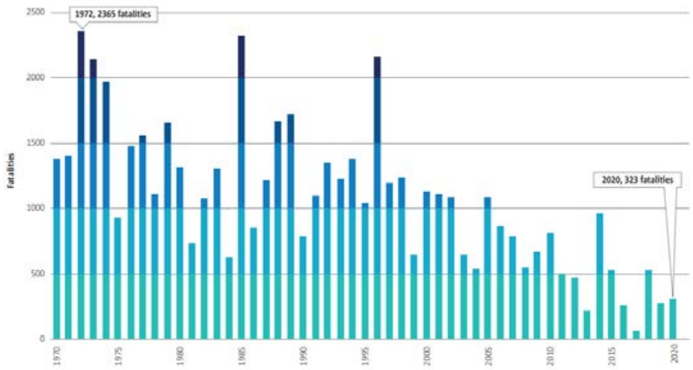
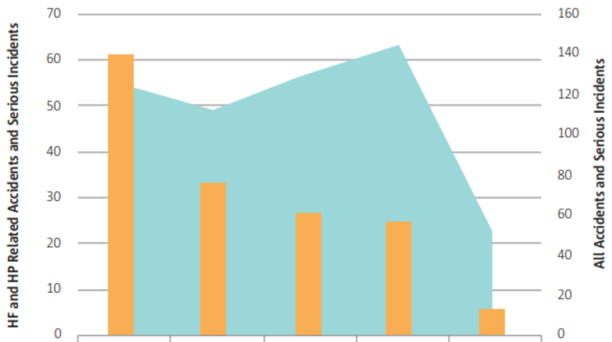


FIG.1 EASA report on the number of deceased persons between 1970 and 2020

The death rate from airborne causes is steadily decreasing due to the increase in the level of aeronautical safety. This level is reached if education on the line of safety reaches the first places in any company. A company without a developed safety system attracts accidents, lack of trust and sanctions from the authorities but also from users.



	2016	2017	2018	2019	2020
Accidents and Serious Incidents	126	114	131	145	50
HF/HP Accidents and Serious Incidents	61	33	27	24	5

FIG 2 The rate of occurrence of the human factor in aeronautical events

Another EASA report (EASA_asR_2021), Annual Safety Review 2021 (p. 47) on performance and the human factor shows that a quarter of commercial transport aviation accidents identify as the cause the human factor or links to the human factor.

The graph is made over a period of 5 years and a very high occurrence rate is observed in 2016 decreasing towards 2020, with the mention that all the data were analyzed only after the publication of the final report, therefore in 2020 the occurrence rate is very low.

Some of the human factors that contribute to the occurrence of an event are: lack of communication (example: a simple quarrel between crew members), complacency, lack of knowledge (many accidents occurred due to lack of knowledge of the procedures), distraction, lack of teamwork, fatigue, stress but also the pressure of executing the mission (a mission canceled for reasons of undue fatigue creates great problems for some pilots).

The basic idea is to highlight how aeronautical personnel are affected by their activity depending on their level of fatigue and routine. Although sometimes routine is a positive factor because repetition increases safety, in combination with fatigue it can become a triggering factor for a catastrophe.

2. THE MASK OF FATIGUE AND ROUTINE

Many times, we say that we can do one thing because we have done it 100 times. This is the trap of routine. Many times, we say that we can drive another 10 km that we have a little more to go home after driving 700 km and then an accident happens. This is the mask of fatigue. But what happens when we combine the 2. Often the results are not positive. But what happens when these 2 elements appear in the aeronautical environment? We are still looking at it from the point of view of aviation safety.

Aeronautical safety is the state in which the risk of injury to people or damage to material property is reduced and maintained at an acceptable level through a continuous process of hazard identification and risk management.

The concept of safety starts from the beginning of the last century when technical and technological deficiencies were identified in civil aviation and aimed at investigating, improving and education on safety.

At the beginning of the 7th decade, aeronautical safety was directed towards the human factor, especially the human-machine relationship, considering that the car fully complies with the rules imposed by man, so the problem is in the way of conceiving i.e., the human factor.

Since the 90s, the concept of safety has been viewed as a combination of several factors such as organizational, human and technical[2].

3. CIRCADIAN RHYTHM

Fatigue is not felt only in the military or aeronautical environment. The analysis begins with the study of circadian rhythm[3] and its effects on the human body. We will analyze the effects of insufficient sleep, acute or chronic sleep deprivation, willful or forced, and the appearance of a change in the cyclicality of the rhythm caused by the crossing of several time zones. Unfortunately, many people who work in this environment resort to illegal methods such as medicines or alcohol to combat the effects of disrupting this cycle.

Within a period of 24 hours, the human body goes through several states. The route of these states (sleep, fatigue, alert) is known as the circadian cycle and follows a set of constant parameters such as body temperature, endocrine functions or hormones. Evolving over time, this cycle has remained constant on mammals, so including humans, and is quite resistant to change. Most people have adapted to a 24-hour cycle[4], that is, the human body feels when it needs sleep, food or rest even if it were locked in a darkroom. Scientists tried to understand what sleep represents, but no one has come up with a clear conclusion of what it represents. The recovery or sleep period is 8 hours in a cycle of 24 to maintain active cognitive functions.

Newborns need a lot of sleep, especially in short periods, but by the age of one year they begin to develop a continuous sleep especially at night. From one year to 10 years, children need, in addition to nightly sleep, a half of light sleep during the day. Adolescents and young adults give up daytime sleep but recover at night with 1-1.5 hours of extra sleep. The constant lack of this hour causes the imbalance of the circadian cycle, which leads to fatigue. The triggering factor for sleep is melatonin. This substance is naturally produced by the body at the time of preparing the body for rest. Many times, due to multiple tasks or exhaustion we resort to artificial solutions for resting the body such as melatonin pills. They have a positive effect in the short term because the human body will fall asleep ordered and not through a natural secretion of melatonin and in the medium and long term negative effects due to the fact that the body no longer produces the same amount of melatonin in its natural state.

4. EFFECTS OF INSUFFICIENT SLEEP

In the case of a prolonged flight through several time zones, prolonged shifts or chronic fatigue[5], they contribute to insufficient or uneasy sleep. Unfortunately, these elements begin to become frequent in aeronautical activities where tasks are continuous and difficult. In case, instead of rest, we spend a long time on social networks, we have 2 affected organs (eyes and brain) that are subject to prolonged stress. In other words, instead of giving the body a state of rest we bring it an extra fatigue. Over a long period of time, a disorder of the circadian cycle and the out of synchronization of the organism regarding the state of natural rest occurs.

In the case of military missions, the degree of fatigue tends to increase compared to the civilian environment and the reason is that combat missions have priority. The military is not only confronted with the hostile external environment, but they must also face the internal environment that becomes hostile due to fatigue, stress, panic attacks, fear or fear that can become dangerous.

After a 10-hour transport mission, a civilian pilot has enough time to rest and recover in a beneficial environment (hotel, recovery center) but an operational military pilot often recovers in a hostile, difficult or stressful environment for a longer period.

Let's look at the actuality of the war in Ukraine (fig 3). How can soldiers rest after a mission in enemy territory under the conditions in which they can be attacked at any time.

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FIG. 3 AzovStal soldiers

The soldiers of the Azov Battalion (Azovstal platform, Mariopol, Ukraine) were in a continuous struggle both externally and internally. Acute stress, hunger, insufficient rest were at very high levels. Their circadian cycle has been disrupted and the recovery period will be long. The level of stress resistance of a military man depends on his level of preparedness. A well-trained military man will cope with stress more easily compared to a civilian caught in a fight.

The AZOV battalion had between 3000 and 5000 soldiers trained for the special operations forces, but their role was complicated because they were surrounded by the Russians and among them were civilians, members of the families

4.1 Fatigue

Fatigue poses a huge challenge to the military environment and degrades crew performance[6]. The effects of fatigue are proportionally related to the body's response capacity so the probability of an error increases.

The effects of fatigue are visible in: decision-making capacity, communication skills, memory loss, accuracy of movements, the ability of logical analysis, oxygenation of the body.

According to Skybrary (2015) when a person is tired, the chances of errors appearing increase especially if they fly in difficult conditions such as flying, instrumental flight or use in combat.

Fatigue leads to the occurrence of late response for crew members or traffic controllers, and the occurrence of a special situation amplifies the error in making the decision.

According to Brandon (2000) the crash of the KAL aircraft (Korean Airline) on August 6, 1997 was the result of a series of errors committed by the crew, in particular the lack of attention due to fatigue.

4.2 Flight time limitation analysis

An EASA (European Union Aviation Safety Agency) report – provides an analysis of the effects of fatigue and recommendations on how to combat them. The report includes the impact of fatigue on the crew for certain periods of work:

a) Working time more than 13 hours mainly during the day;
b) Working time of more than 11 hours in little-known climate, both day and night;
c) Working time in different areas (sectors), more than 6;
d) Unspecified program.

The research was based on 3 sources:

- 15 000 online questionnaires to aircrew;
- Analysis on 260 000 flight hours;
- 381 crew members from 24 different airlines.

From the online questionnaires it emerged that tasks longer than 10 hours and the unspecified schedule have the highest weight in increasing fatigue. All 381 crew members volunteered to participate in the study. The information collected and analyzed refers to fatigue, drowsiness and mental exertion over a period of 14 consecutive days. Objective metrics were recorded in a rest log using an online app.

The study on flight hours showed an increase in the level of fatigue measured on the KSS' scale (Karolina Sleepiness Scale) at the time of transition from cruise flight to the descent phase (when the aircraft starts the landing procedure) at night, with no significant results for periods of less than or greater than 10 hours.

Consequently, in order to reduce the level of fatigue[8][9], airlines have considered limiting shifts below 10 hours at night, especially for pilots, in order to grant recovery time.

5. BOWTIE MODEL ANALYSIS OF THE AVIATION CATASTROPHE OF JANUARY 26, 2020

On January 26, 2020, at 9:45 a.m. PST (Pacific Standard Time), a Sikorsky SK76B helicopter crashed on a field in Calabasas, California. The NTSB (National Transportation Safety Board) states that the probable cause of the crash in which 9 people died (the pilot, Kobe Bryant, his daughter and 6 other people) was the pilot's decision to continue flying in severe weather conditions, favoring the appearance of disorientation and loss of control.

A human factor that contributed to the catastrophe was the self-induced pressure to continue flying to take the VIP to its destination. The pilot, Ara Zoboyan was forbidden by the controllers to enter the cloud formation, he reported that he was climbing over the ceiling but crashed on a hill.

In analyzing this case we will use the Bowtie method[10] from the Safety System Management. Although it is not used internationally, about 10% of small aircraft operators consider this model to be the best for auditing an aviation event.

The model is based on going through 5 stages, each analyzing a part of the event and how to implement the solutions.

Step 1: Initial causes

The causes of an aviation event can be due to pilot distraction, malfunction of an airport service, bad weather conditions or human error.

In the analyzed case we can consider the main cause of the event spatial disorientation and loss of awareness of the situation, hence the human factor. Spatial disorientation occurs due to several factors such as fatigue or stress, combined with the fact that the pilot was not ready for the IFR flight and asked for an SVFR authorization to continue the mission.

Stage 2: Previous Events

In the case of the Bowtie analysis, these are the causative actions that occurred just before the event, such as: the pilot did not hear the approval of the takeoff or did not see the stop signal.

In our case, the previous event was the controller's request to board and the pilot's confirmation that he was in a boarding flight even though the aircraft was in a descent flight.

Step 3: Determine the direct consequences after impact

In the analyzed case, the main consequence is the loss of human life, after which the destruction of the aircraft and other goods.

Step 4: Overall impact on the disaster

In addition to the loss of human life in any aviation event, there are other consequences such as the reputation of the firm, the loss of trust implicitly the loss of money. In many cases, after a major event, aeronautical firms go into insolvency due to accumulated debts. The quality of services also has a direct impact on passengers.

Step 5: Implementation

After identifying the causes, we can implement methods to minimize the risks. In the analyzed case, the main event was spatial disorientation, so we can force the air operators to train the personnel in order to combat disorientation.

Another cause is the lack of weather radar or education on the priority of a mission: safe landing or VIP transport. The pressure on the pilot to execute the mission was very high because there was a very important person on board the helicopter.

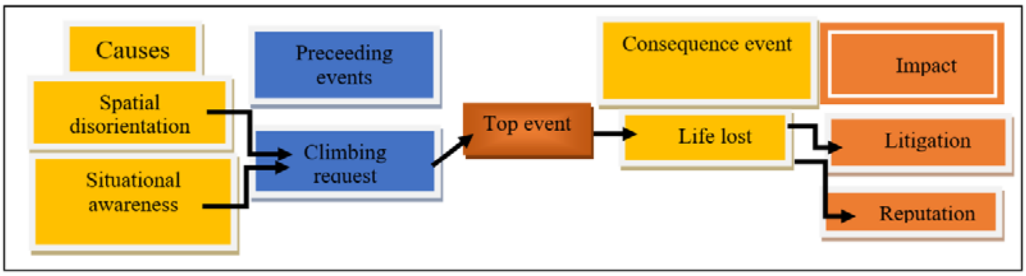

FIG. 4 Bowtie model in the analysis of the aviation catastrophe of January 26, 2020

6. RECOMMENDATIONS, CONCLUSIONS AND IMPLEMENTATION

1. Although companies avoid stating in the safety recommendations, a sleep break of a few minutes, before the descent procedure decreases the level of fatigue;
2. It is recommended to introduce night shifts in shifts. This would help operators devise effective measures to combat fatigue;
3. Informing operational staff of the possibility of fatigue and errors;
4. Increasing the level of attention for air traffic operators when starting the landing phase;

5. Changing the descent strategy especially during night shifts that start earlier than 1:59 and end after 6:00, at which point the state of fatigue is at its highest level.

Ensuring that crew members have sufficient rest time is the responsibility of the operator and crew. Current regulations describe the need for operators to provide opportunities for rest and recovery. As this is essential for the effective management of this risk, EASA will work with national civil aviation authorities as well as industry stakeholders to actively promote the provision and use of rest facilities at or near airports to facilitate the start of the service at night and minimize fatigue.

All indications of analysis lead to the recommendation of "controlled rest", that is, a period "outside of pregnancy" during which the body can relax. Research has shown that short, controlled rest is the most effective strategy to alleviate fatigue during flight.

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DESIGN AND CODE OPTIMIZATION WHEN WORKING WITH TIME-CRITICAL DATA

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Abstract: *FPGA modeling techniques for DUT's are currently the state-of-the-art in the testing and verification industry for ASIC designs and with a growing interest in smart house solutions, a quick time to market is a benefit for any company. The system presented in this paper consists of an FPGA-based multifunctional digital clock with a temperature sensor connected to a Microblaze CPU and a control and monitoring unit consisting of a software running on a Raspberry PI 3B with an enhanced version of Linux with PreemptRT patch. The paper presents the design and testing of the system and also an analysis of the optimizations considered for the proposed system.*

Keywords: *FPGA, DUT, RaspberryPi, Linux, PreemptRT, Microblaze, Smart house.*

1. INTRODUCTION

In today's world, the interest over quality of life is becoming more and more important. This interest is placing pressure on technology companies to develop more and more efficient solutions for home automation. The current solutions, involve a growing number of sensors, actuators and CPU-s to automate a house[1] , Embedded systems have a major importance in this due to low power consumption and high configurability.

When it comes to the home comfort, probably the most important factor is the temperature. In this case, home automation solutions take this factor very seriously by offering ways to monitor the ambient temperature and control the methods of generating heat or air flow. The sensors used to monitor the environment parameters like temperature, humidity or gasses, can be most of the time hidden in typical household electronic devices, mostly due to esthetics, like digital clocks. The modern digital clock can hold a variety of sensors and can display the values but can also contain a Bluetooth, WiFi or RF transmitter to send the data to central units for processing. While the array of sensors located in different parts of the building provide the monitoring aspect, these central units handle data collection and control aspects, by collecting the data from the connected sensors and taking appropriate measures to improve the conditions by controlling devices in the house like valves, actuators or pumps.

Since the creation of the RaspberryPi single core platform in 2012, development of home automation applications has grown exponentially due to the low cost, modularity, open design and high processing power offered by the processors used, capable of running Operating Systems. The RaspberryPi boards are taking the place of the central units while also being capable of holding sensors on their own.

In [1], the authors propose and interesting collection of aspects that are not present in the state-of-the-art of home automation or are simply issues still not addressed by solution developers. These aspects are: Control mode, communication, scalability and power consumption.

In this paper, the proposed system tries to offer a partial solution to these issues by implementing a monitoring system that offers an additional use for the gadget by adding the clock aspect, designed using a FPGA with different peripherals, and using Verilog and VHDL languages to create a running, stand alone architecture used to access the data on the peripherals. Using a Raspberry Pi[4] board as the central unit, the data from the monitoring station is processed using a software application written in C, running on a real time version of Linux, making use of the OS built in functions like the scheduler and memory management.

2. DESIGN AND HARDWARE IMPLEMENTATION

The proposed system is composed of a modern digital clock and a central processing unit. The clock system is implemented on a Digilent Nexys 3 FPGA board to which is connected the MCP 9808 temperature sensor. The display used is a VMOD TFT from Digilent, with a 480×272 native resolution, connected to the VHDCI FPGA port. The central processing unit is represented by a Raspberry Pi 3B board containing a 64-bit Broadcom BCM2837 CPU.

The architecture on the FPGA[5] is mainly composed of a Microblaze CPU, connected via AXI bus to an I2C[9] master module for the temperature sensor, a time control module used to control the values for the clock itself and a serial control module for the communication.

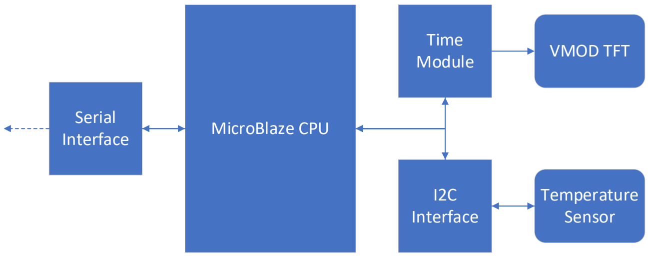

FIG. 1 Block diagram of the FPGA Architecture.

The Microblaze processor is running its own application which is capable of taking commands over the serial interface and acting on them, either to write or to read registers via the AXI Bus. In fact, the software is capable to read the temperature from the temperature sensor and set the time and date on the time control module.

The RaspberryPi is connected to the FPGA using a USB to MicroUSB cable. The Raspberry Pi[2] is running a modified version of Linux, enhanced with the Preempt-RT[10] patch for real time applications. On the operating system, the control application runs a series of BIST type tasks to verify the correct functionality of the peripherals and then launches threads for data collection, processing and control.

For the proposed system, as the controlled device, a LED has been attached to the Raspberry Pi pins which in this case will be active when the temperature from the sensor passes a certain threshold. Other peripherals may be added like a buzzer for the clock alarm which is not a part of the smart house concept so it will not be controlled externally but is an integral part of the clock. On the other hand, the alarm can be set as needed by the control unit.

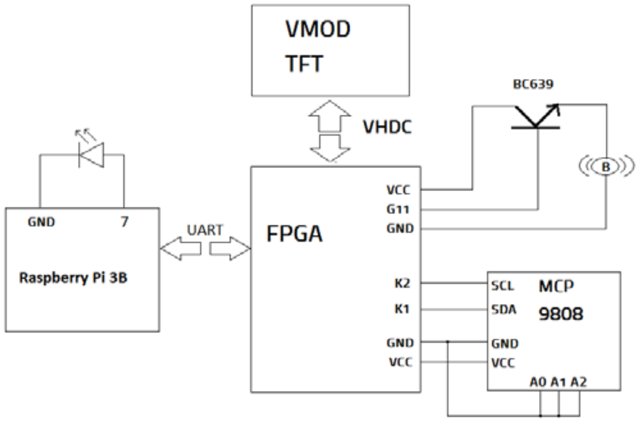

FIG. 2 General diagram for the proposed system.

3. SOFTWARE IMPLEMENTATION

The software running on the MicroBlaze processor is minimized to be as fast as possible, acting like a switch between the peripherals and the control unit. The serial interface is scanned and data is present from the control unit, the decoded instruction is compared against the set of instructions contained. For simplification purposes, the instruction is delivered as a lower-case letter. This is to separate the instructions from the numeric values transmitted to the time module in order to set the clock, the alarm or the current date. There are different letters used for every action, including setting or getting a time value. In this case, a similar module may contain 26 instructions and is capable of expanding with another 26 instructions if upper-case letters are also used.

```
read = read_uart_lock();
if (read == 'a') {
    a = read_uart_lock();
    ceas[0] = a;
}
if (read == 'z') {
    a = ceas[0];
    write_uart_u(a);
}
if (read == 's') {
    b = read_uart_lock();
    ceas[1] = b;
}
```

FIG. 3 Example of Microblaze code

The hardware must always have the values at hand in case of a processor access. In this case, all sensor modules must be implemented using interface registers. Only by accessing these registers, the processor communicates with the modules and must not be permitted to act on the internal values of the modules. In Fig. 3, the read variable receives the value from UART as an instruction. In this example, letter “a” is used to signal that the control unit is requesting to set the value of the hour value on the clock. The software understands the instruction and waits for the numeric value from the control unit after which it is written to the access register of the time module. In case the control unit requests the current time, for synchronization porpoises for example, the letter “z” is used to get the value from the access registers and sent to the control unit. The table of instructions continues for every parameter that the control unit can access.

The software written for the FPGA MicroBlaze processor[7] contains 2 functions, both related to the communication over UART. The read function is blocking the flow and waits for data inside the function. This is the most efficient way to address the instructions sent by the control unit since the processor does not have any other duty. The function is used every time the processor is done with an instruction and waits for the next one, or based on a set instruction, it waits for the numeric value.

The main function contains the instruction table inside an infinite loop but before this, on startup, the software sets the default time and date on the clock screen as 11.00 25.10.2020, and the alarm as 9.00. This process can also be considered a BIST since on startup, a visual inspection can be done by an observer.

In the case of the application running on the control unit, the software is more complex, having to deal with all the sensors and control devices. The smart house[3] general idea is that data is periodically read from the sensors, processed, and based on the processing result, a control action is, or not, taken. In this case, we can determine 3 phases of the process:

-Data collection (DC)

-Data processing (DP)

-Control action (CA)

When dealing with cause-and-effect actions where action A leads to action B, and most importantly, action A must occur periodically, parallelism is considered the best course of action since there is no way to determine when action B is finalized or if there are any actions after B.

In the case of processors, parallelism is represented by the use of application threads[6]. Using threads for each action is crucial for a correct functionality of the entire system. Of course, the main disadvantage of using threads is when a large number of threads is created and can stall the processor. This is the system designer attribution, to check the optimal time between launching two thread series.

FIG. 4 Thread series example.

In Fig. 4, the collected data from the second thread series generates a control action, but in the same time, the periodical data collection is launched for a new series. In this case the scheduler controls what is occupying the processor at a certain time. In this way, the processor will complete both tasks.

The software running on the control unit for the proposed system contains the main function which starts up with a BIST portion of code which is taking advantage of the built-in WiFi capability of the Raspberry Pi. Once the device itself starts up, it searches for an internet connection over LAN or wireless and if successful, sets its internal clock and date from the internet. Taking advantage of this, the first thing the control unit will do is to set the time and date on the clock using the SET instructions and requests the temperature as a first value to verify the connectivity. In the same time, the thread that handles the control device (Thread 3) is started for a visual inspection by an observer. After the BIST is finished, the first thread is started as the main thread for the application.

Thread 1 handles the serial communication with the sensor. At a specified interval, the thread launches a request for the temperature value and once received, the value is passed through a queue to the second thread. Thread 1 is the Data collection thread and is controlling the timing of when data is requested from the monitoring device.

Thread 2 receives data from the queue and comparing it against a hardcoded threshold value. Based on the result of the comparison, thread 3 is either launched or not. If launched, thread 3 will send a PWM signal lasting 5 seconds, to the LED with a frequency of 1 second. The process is repeated until the temperature from the sensor is below the threshold value.

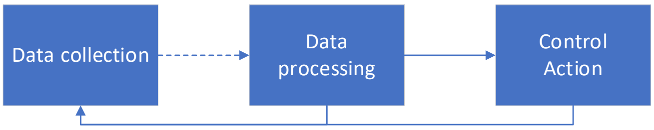

FIG. 5 Thread series for the proposed system

It is still unclear the optimal thread series process and how is should occur or how many threads can run at one point in time until the processor stalls.

4. EFFICIENCY IMPROVEMENT

Scenario 1: Data collection thread is running in an infinite loop and the related data processing thread is launched when the data is available. This is similar to the diagram in Fig. 4. For every monitoring device (MD) there must be a thread series. This kind of architecture may be used when:

-there is a small number of monitoring devices

-the time between requesting data from the devices is bigger.

The only potential benefit in this case is an ease of scalability since for every new device a thread series is added to the code, but the issues with this architecture are substantial. In first place, a minimum number of threads are running on the CPU equal to the number of MDs connected. Furthermore, accessing the same communication medium by 2 different threads may result in an access conflict. Lastly, if the data collection threads launch their own data processing thread, in a worst-case scenario, the load on the CPU would be close to 2x the number of MDs. In the case of a small control unit with limited computing power, this is an issue.

Scenario 2: One way to ease the load on the CPU is to have a general data processing thread. The initial load is the number of MDs +1. The communication between the DC and DP may be done by queue. DC threads are pushing data in the queue and DP thread will treat each data and launch the appropriate CA thread. In a worst-case scenario, the load would be 2x MDs +1, in the case of all existing CA threads are launching close to the same time, depending on the length of all CA threads and the processing speed in the DC thread. The benefit of implementing such an architecture is having more control over the back-end of the application, but this complicates the scalability having to add the DC and CA threads for a new MD while complicating the CA to integrate the new function. Also, the queue may contain the data from the DC thread but having multiple DC threads, the main DP will not know the source DC. A signaling system must also be implemented complicating even more the scalability. This scenario is represented in Fig. 5.

Scenario 3: To improve on the benefits from Scenario 2 to ease the load would be to also control the front end of the application.

The software will launch a master DP thread that will, in turn, control the moment each DC thread is launched. In this way, the issue of the source of the data is solved if the DP launches one DP thread at a time, collects the data. It and then launches a new DC thread and at the same time, launching a response CA thread. Having this kind of control is very beneficial for the load aspect since the initial load is of one single thread and the worst-case scenario is three threads. This scenario is most optimal for central units with low processing power, but still maintaining scalability. Since each MD is requested data in a serial mode, there is no possible overlap on the communication devices and no heavy load on the CPU. The drawback of this architecture is actually what draws in the benefits. The request on each MD being done in a serial manner, with a large number of MDs, the time between accessing the same MD rises but the issues presented, from [1] of scalability, communication and control are solved but the architecture may not be efficient on a large scale.

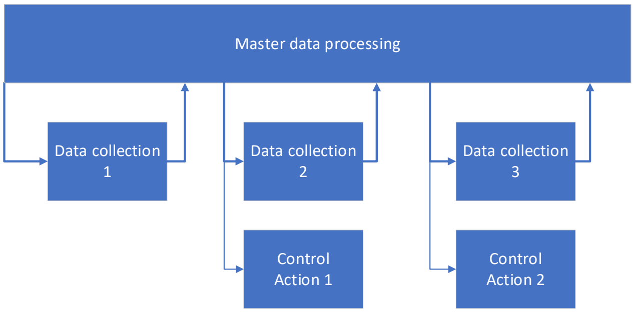

FIG. 6. Thread series for scenario 3 architecture

Scenario 4: The remaining efficiency issue may be resolved by a combination of the first and third scenarios. Implementing a single Master thread that controls all thread series.

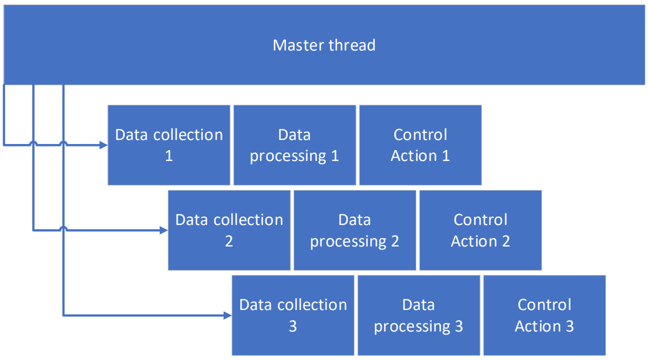

FIG. 7 Thread series for scenario 4 architecture

Analyzing this scenario, CPU load in a worst case scenario is the number of MDs +1, being the Master thread. This value of load is much higher than scenario 3 but still lower than the other scenarios, thus solving the issue of balancing efficiency against the possibility of stalling the CPU. Having control directly from the Master thread, each thread series can be launched to avoid same communication channel overlap. Scalability is solved by retaining the simplified variant of implementing the 3 threads[8] as independent functions and only modifying the master thread to allocate each new MD a time slot to be launched in. In addition, a more important MD may receive more time slots in a specified time than less important MDs.

5. EXPERIMENTAL RESULTS

As mentioned in this paper, an experimental design has been created to test these hypotheses. The main focus is to test the timing difference between Scenario 2 and 4 since these versions of the architectures can be considered the most un-optimized and optimized versions.

Starting with the architecture proposed at scenario 2, where threads 1 and 2 are launched at the start of the application and only thread 3 is conditioned we get the time values presented in Table 1.

Table 1. Average execution time for scenario 2

T1 exec. Time + 5s	T2 Q empty + 2s	T2 temp < th.	T2 temp > th.	T3 exec. Time + 5s	T1 start to T3 start
13551 us	64 us	2 us	636 us	496 us	1947662 – 936386 us

While these are the values under normal functionality, some anomalies have been observed.

1. In some cases, the time reported from start to finish for T3 is reported as being under 1 second. This is practically impossible since T3 has an average functionality time of 5000496 us. The cause is because in special cases, “T1 start to T3 start” is smaller than T3 start to T3 finish. In these cases, a second T3 is launched before the first T3 is finished.

2. The large values of time reported for “T1 start to T3 start” are due to T1 and T2 not being synchronized.

For the implementation of the architecture for scenario 4, a more simplified technique is applied as mentioned, by writing the independent threads as stand-alone functions. In this scenario, only the Master thread is launched in a loop and every 6 seconds, T1 is started. T2 is launched only when the data is received by T1. In this manner, the memory is freed and the synchronization issue between T1 and T2 is solved. In addition, a more precise time line can be observed thus preventing an unnecessary overlap of two T3 threads.

The time values obtained from the test run can be observed in table 2.

Table 2. Average execution time for scenario 4

T1 exec. Time	T2 Q empty	T2 temp < th.	T2 temp > th.	T3 exec. Time + 5s	T1 start to T3 start
11080 us	N/A	21 us	559 us	367 us	18319 - 9658 us

First observation is that there is no execution time for when the Queue is empty between T2 and T1 since T1 launches T2 only when there is a value available in the Queue. Secondly, most of the values are significantly smaller since the threads do not have internal delays and are terminated once the tasks are done. A massive increase in efficiency can be seen in the “T1 start to T3 start” value since there is a synchronization. No anomalies have been observed during the test.

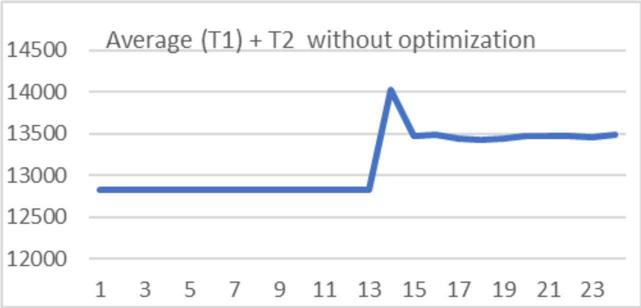

FIG.8 Timing values on unoptimized architecture.

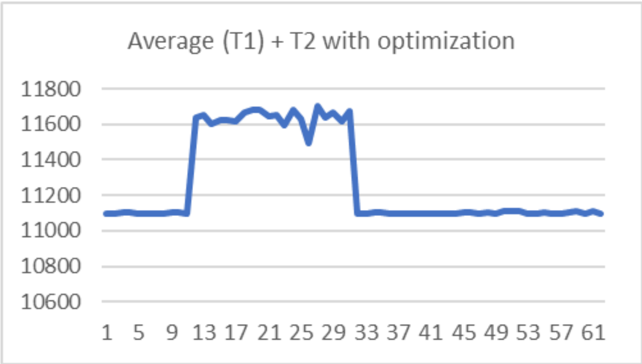

FIG.9 Timing values on optimized architecture.

Charts 1 and 2 contain the timing values collected during running. In both cases, the higher values coincide with the moments where high temperature values are received. Timing analysis suggests a decrease in general timing even when T3 is launched by 2 ms.

6. CONCLUSIONS

From this paper, we can conclude a well-defined architecture for a smart-house system and an efficient software for the control unit that is acceptable for different levels of processing power regardless of how many sensors or control devices are present. This presented software architecture solves all of the objectives planned.

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HANDLING DYNAMIC NONLINEARITIES IN UAV AUTOMATIC FLIGHT CONTROL SYSTEMS

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Abstract: *The linear or the nonlinear feature of systems being modelled or designed is a core property we should be familiar with before taking up any system design or analysis-related task. The dynamic model-based closed loop control design is widely used in control engineering when dynamic or static nonlinearities are considered to be present in the closed loop control system. This paper addresses both dynamical and static nonlinearities modelled and handled in the closed loop control system.*

Keywords: *nonlinearity, static nonlinearity, dynamical nonlinearity, nonlinear systems, nonlinear system analysis and modelling.*

1. INTRODUCTION

The nonlinear feature of control systems is a crucial issue in control engineering when to handle nonlinearities and select design methods for closed loop control system. It is well-known from mathematics that the ideal linear function of the form of $y = f(x) = ax + b$ rarely can appear as a pure linear function; moreover, represents a simple function from among those existing and mathematical analysis.

The linearity, and the strong wish to linearize in the nonlinear world at any price, at any loss of originality of the system dynamics is known from many centuries and decades. Taylor B. in 1715 introduced his method called (first order) Taylor-series expansion to linearize any nonlinear (polynomials, power functions, logarithm function, exponential function, trigonometric functions, (square) root, geometric series, binomial series, hyperbolic functions etc.) function. This method often called as tangent linearization of the given nonlinear function at the given equilibrium point set previously.

In flight dynamics several nonlinear functions (e.g. basic formulas of the International Standard Atmosphere, like $T(h)$, $p(h)$, or $\rho(h)$) are used to express different nonlinear relationships between physical values. It is well-known from flight mechanics, that both longitudinal and lateral/directional motion equations involve different coefficients of forces and moments being in nonlinear dependency with speed, Reynold's number etc. Moreover, many coefficients (e.g. $C_L(\alpha)$, $C_D(v)$ etc.) are nonlinear functions of several independents.

Thus, any aircraft model, among those of the UAV's models are derived as a nonlinear being linearized at some equilibrium flight regime we consider for the linearization.

Besides dynamic nonlinearities being handled in any closed loop control design there are several types of static nonlinearities should be considered and handled.

Static nonlinearities (e.g. dead zone (delay), saturation, hysteresis, relay etc.) are integral parts of devices used to build up closed loop control systems.

Existence of the static nonlinearities might be unavoidable in closed loop control systems, like it happens in case of hydraulic actuator remotely controlled by electro-magnetic valve having dead zone in control rod position, and having saturation in the cylinder of the actuator.

Next example when the dead-zone plus saturation static nonlinearity is used is 2D electro-mechanical gyroscope supplemented with potentiometer to harvest electrical signal of the rotational speed. The potentiometer itself often has a dead zone to eliminated unwanted signals from sources other than the rotational motion, like high frequency vibrations. The maximum of the rate (saturation) is defined by the aircraft flight characteristics.

This paper will address both static and dynamical nonlinearities of the small UAV automatic flight control systems, and will highlight methods serving nonlinear control system analysis and design purposes.

2. RELATED WORKS AND PRELIMINARIES

The early and pioneer work of A. Isidori (editions of 1985, 1989, and 1995) gives thorough and rigorous mathematical background of both SISO and MIMO nonlinear feedback systems dealing with system analysis and closed loop system design [5].

The linear and nonlinear systems are discussed in [2, 3, 4, 12, 13]. In [15] and [16] linearization of the nonlinear systems is presented.

In [14] a human-in-loop problem is subjected to thorough analysis, how the LTI system output nonlinearity effects the entire system performance.

The describing function method and its inversion serves nonlinear system analysis since many decades. References of [6, 7, 8, 9, 10], and [11] deal with nonlinear control system analysis using describing functions.

In [17] and [18] gives sufficient help in computer-aided design and analysis of nonlinear systems using MATLAB® and Simulink®. In [19] mathematical backgrounds of the topic addressed in this paper are discussed going into deep details.

Finally, [1] derives nonlinear dynamical aircraft models used in design and analysis of the automatic flight control systems.

3. NONLINEARITIES OF UAV AUTOMATIC FLIGHT CONTROL SYSTEMS

The automatic flight control systems have several different nonlinearities being static or dynamic. Static nonlinearities such as the dead zone, saturation, relay, inverse relay, hysteresis etc. are integral parts of any device (e.g. amplifiers, valves, actuators, induction motors, gears etc.).

Dynamic nonlinearities represent functions differing from the unique linear function. They might have different mathematical forms like trigonometric functions and their inverses, logarithm functions, exponential functions, powers of different orders excluding the first order, different types of the root function etc.

3.1 Dynamic nonlinearities of closed loop automatic flight control systems. There are several powerful linearization techniques well-known from mathematics, and widely applied and used in the engineering practice [19].

As an example, let us linearize a nonlinear function of the natural logarithm function given by the following equation [15, 16, 19]:

$$f(x) = \ln(x). \qquad (1)$$

It is evident that the arbitrary mathematical function of $f(x)$ centered at $x^* = x$ has no discontinuity at this equilibrium point and is differentiable infinite n times at this point. Thus, the Taylor series of the function given by Equation 1 as follows:

$$f(x) = f(x)|_{x=x^*} + f^{'}(x)|_{x=x^*}(x - x^*) + \frac{1}{2}f^{''}(x)|_{x=x^*}(x - x^*)^2 + \cdots + \frac{1}{n!}f^{n}(x)\Big|_{x=x^*}(x - x^*)^n = f(x)|_{x=x^*} + \frac{1}{n!}\sum_{n=0}^{\infty} f^{n}(x)|_{x=x^*}(x - x^*)^n = f(x)|_{x=x^*} + f^{'}(x)|_{x=x^*}(x - x^*) + H.O.T. \tag{2}$$

The first-order approximation of the Taylor series, when sum of the higher order terms meet condition of

$$\sum_{n=2}^{\infty} H.O.T \cong 0 \tag{3}$$

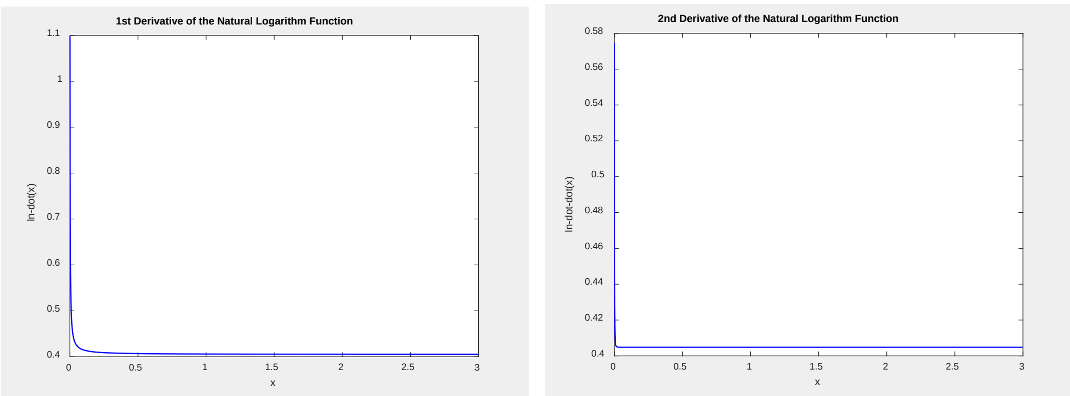
and it leads to the linear approximated function as given below:

$$f_{appr}(x) \cong f(x)|_{x=x^*} + f^{'}(x)|_{x=x^*}(x - x^*) \tag{4}$$

Taking multiple derivatives of the natural logarithm function:

$$f(x) = \ln(x);\quad f^{'}(x) = x^{-1};\quad f^{''}(x) = -x^{-2};\quad f^{'''}(x) = 2x^{-3};\quad f^{''''}(x) = -6x^{-4} \cdots \tag{5}$$

The first two derivatives of the function $f(x) = \ln(x)$ are depicted in Fig. 1. [17, 18].



(a) (b)

FIG. 1 Derivatives of the natural logarithm function $f(x) = \ln(x)$.

Let us consider for the linearization the following equilibrium point at $x = x^* = 1{,}5$. Thus, the linearized function we seek will have a form as follows:

$$f_{appr}(x) \cong f(x)|_{x=x^*} + f^{'}(x)|_{x=x^*}(x - x^*) = 0{,}408793 + \frac{1}{1{,}5}(x - 1{,}5) = -0{,}591207 + 0{,}666666 \cdot x \tag{6}$$

The natural logarithm function and the approximated liner tangential to this function at $x = x^* = 1{,}5$ equilibrium (E) can be seen in Fig. 2. [17, 18].

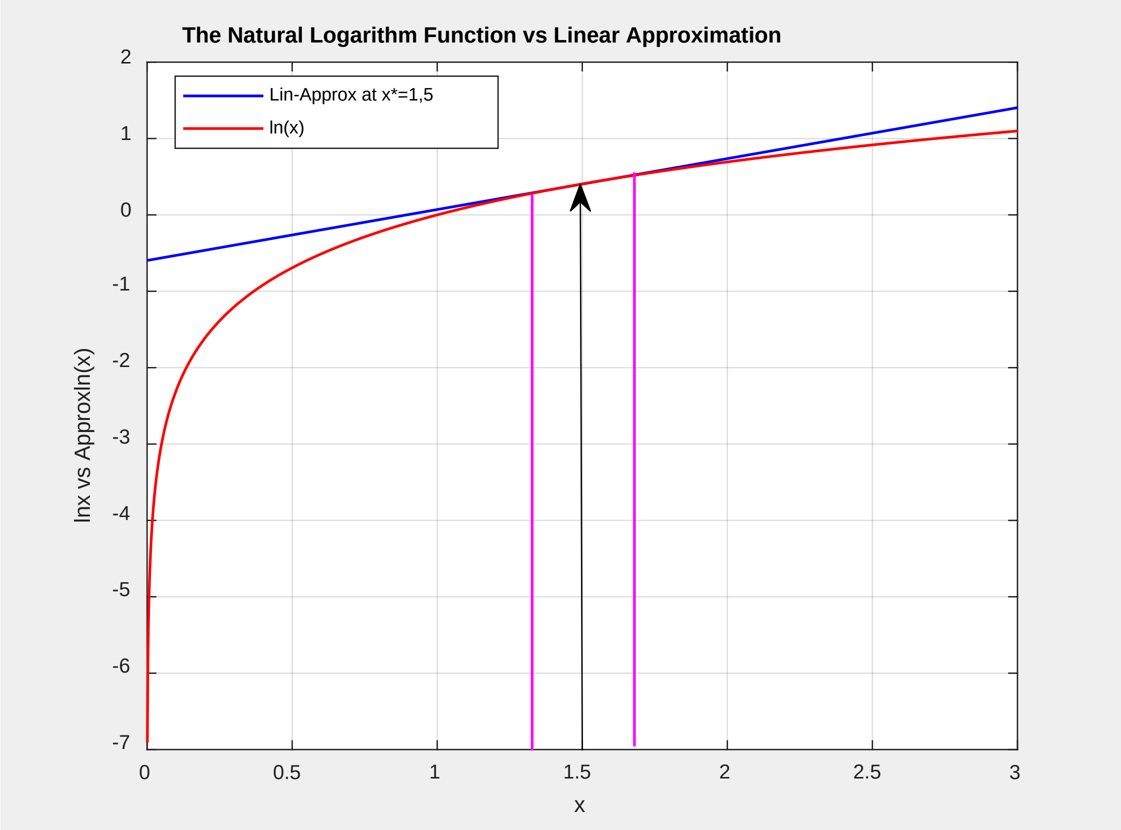


FIG. 2 The natural logarithm function $f(x) = \ln(x)$ and its first order approximation.

The first order linear approximation performs the best at the $x = x^* = 1{,}5$ equilibrium (E) point as a tangential to the natural logarithm function, elsewhere has error due to increase of the sum of the neglected higher order terms (H.O.T.). Errors of the approximation (linearization) calculated for edge points of the range $\Delta x^* = \pm 0{,}15$ are tabulated in Table 1.

Table 1 Approximation error

	x		
	1,35	$x = x^* = 1{,}5$	1,65
Arbitrary function $f(x) = ln(x)$	0,300105	0,408793	0,500775
Linearized function $f_{appr}(x)$	0,308792	0,408793	0,508792
Error of the linearization, $e = f_{appr}(x) - f(x)$	0,008687 ($\approx$ 0,8%)	0	0,008017 ($\approx$ 0,8%)

Leaning on data of Table 1 one can state that although for wide range of x around the equilibrium point (E) the error of the linearization is small, and the linearized (approximated) function is suitable for further applications. As to leave the equilibrium point E for larger values of x as the error of the approximation increases.

Note that error of the linearization is an important issue and set prior the first-order approximation of the arbitrary function $f(x) = ln(x)$.

In other words, knowing the maximums of the error e bounds, the range of x at which the arbitrary function $f(x)$ can be replaced by the linear function $f_{appr}(x)$ can be set.

In engineering sciences (i.e. electrical, mechanical, mechatronics etc.) the decaying exponential function is widely applied.

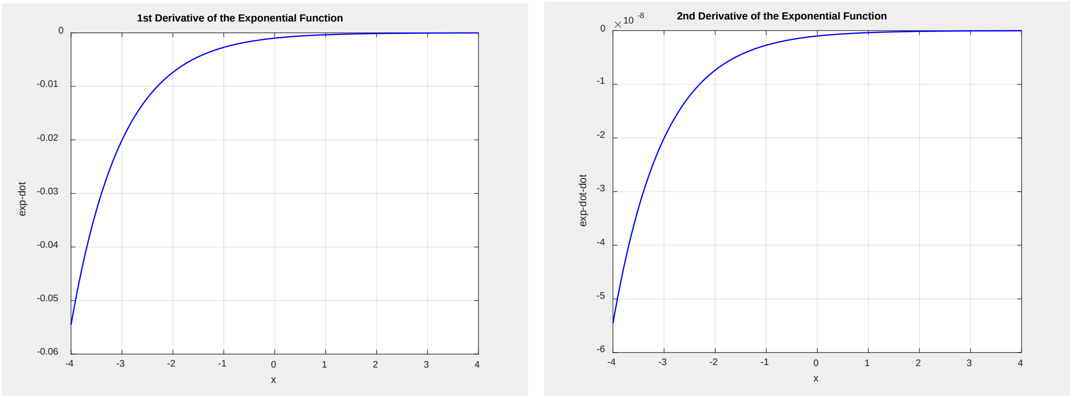
For further studies let us consider the following decaying exponential function expression [16, 19]:

$$f(x) = \mathrm{e}^{-x} \tag{7}$$

Taking multiple derivatives of the exponential function [19]:

$$f(x) = e^{-x};\quad f^{'}(x) = -e^{-x};\quad f^{''}(x) = e^{-x};\quad f^{'''}(x) = -e^{-x},\qquad f^{''''}(x) = e^{-x}\quad \ldots \tag{8}$$

The first two derivatives of the function $f(x) = e^{-x}$ are depicted in Fig. 3. [17, 18].



(a) (b)

FIG. 3 Derivatives of the natural logarithm function $f(x) = \mathrm{e}^{-x}$.

Let us consider for the linearization the following equilibrium point at $x = x^* = 0$, when:

$$f(o) = \mathrm{e}^{-0} = 1;\; f^{'}(0) = -\mathrm{e}^{-0} = -1 \tag{9}$$

Thus, the linearized function we seek will have a form as follows:

$$f_{appr}(x) \cong f(x)|_{x=x^*} + f^{'}(x)|_{x=x^*}(x - x^*) = 1 - x \tag{10}$$

The decaying exponential function and the approximated linear tangential to this function at $x = x^* = 0$ equilibrium (E) can be seen in Fig. 4. [17, 18].

The first order linear approximation performs the best at the $x = x^* = 0$ equilibrium (E) point as a tangential to the natural logarithm function, elsewhere has error due to increase of the sum of the neglected higher order terms (H.O.T.). Errors of the approximation (linearization) calculated for edge points of the range $\Delta x^* = \pm 0{,}1$ are tabulated in Table 2.

From Table 2 it is evident that change in x for $\pm 10\%$ will lead to the error of $(\approx 0{,}5\%)$ and $(\approx 0{,}7\%)$, which are acceptable. In case or larger changes in x, the approximation error will increase permanently.

If any accuracy criteria are set, knowing the maximums of the error e bounds, the range of x at which the arbitrary function e^{-x} can be replaced by the linear function $(1 - x)$ can be set.

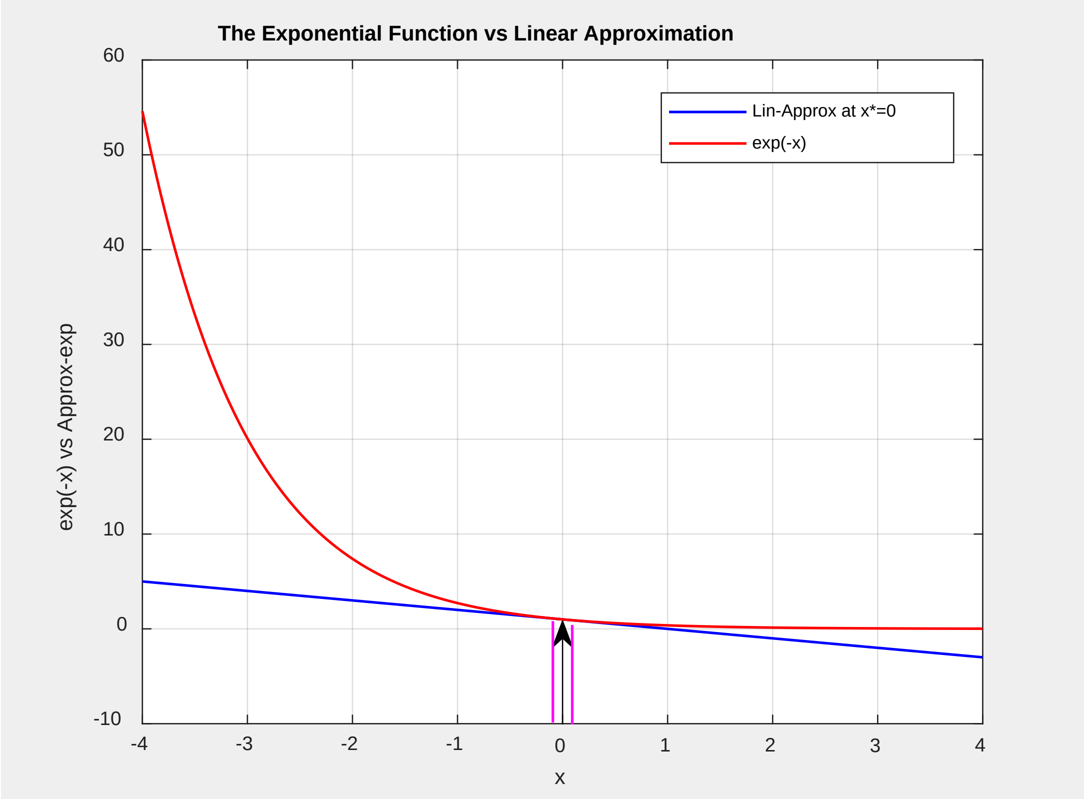


FIG. 4 The decaying exponential function $f(x) = \mathrm{e}^{-x}$ and its first order approximation.

Table 2 Approximation error

	x		
	0,9	$x^* = 0$	1,1
Arbitrary function $f(x) = e^{-x}$	-1,10517	1	0,907556
Linearized function $f_{appr}(x)$	-1,1	1	0,9
Error of the linearization, $e = f(x) - f_{appr}(x)$	0,00517 (≈ 0,5%)	0	0,007556 (≈ 0,7%)

Using mathematical procedure explained above to linearize the exponential function $f(x) = \mathrm{e}^{x}$ one can lean on following derivatives of this function [16, 19]:

$$f(x) = e^{x}; \quad f'(x) = e^{x}; \quad f''(x) = e^{x}; \quad f'''(x) = e^{x}, \quad f''''(x) = e^{x} \quad ... \tag{11}$$

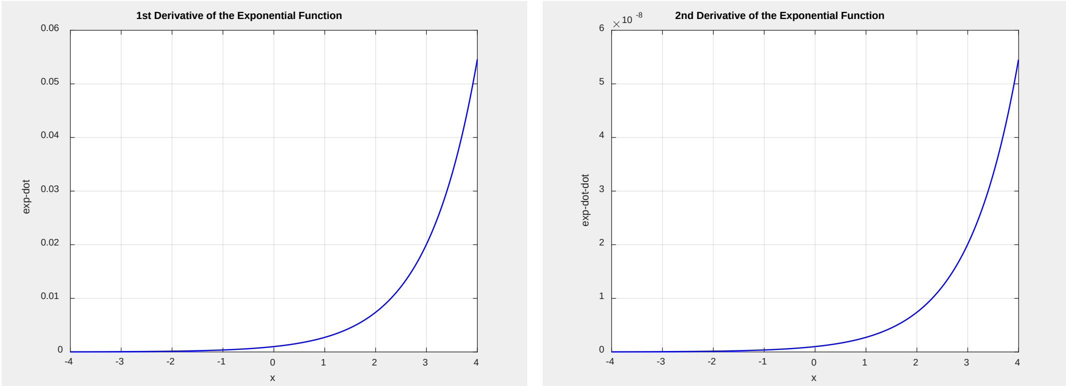
The first two derivatives of the Equation 11 can be seen in Fig. 5. [17, 18].

If to consider for the linearization the following equilibrium point at $x = x^* = 0$:

$$f(o) = e^{0} = 1; \; f'(0) = \mathrm{e}^{0} = 1 \tag{12}$$

Thus, the linearized function we seek will have a form as follows below

$$f_{appr}(x) \cong f(x)|_{x=x^*} + f'(x)|_{x=x^*}(x - x^*) = 1 + x \tag{13}$$



(a) (b)

FIG. 5 Derivatives of the natural logarithm function $f(x) = \mathrm{e}^x$.

The exponential function and the approximated linear tangential to this function at $x = x^* = 0$ equilibrium (E) can be seen in Fig. 6. [17, 18].

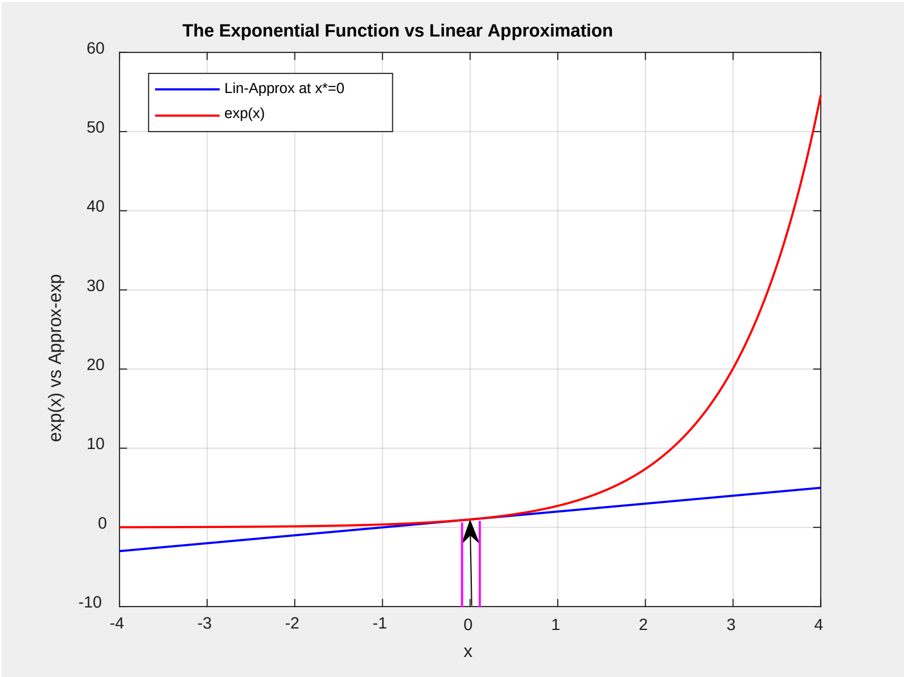


FIG. 6 The exponential function $f(x) = \mathrm{e}^x$ and its first order approximation.

The first order linear approximation performs the best at the $x = x^* = 0$ equilibrium (E) point as a tangential to the natural logarithm function, elsewhere has error due to increase of the sum of the neglected higher order terms (H.O.T.). Errors of the approximation (linearization) calculated for edge points of the range $\Delta x^* = \pm 0{,}1$ are tabulated in Table 3.

Table 3 Approximation error

	x		
	-0,1	$x^* = 0$	0,1
Arbitrary function $f(x) = e^x$	0,903933	1	1,10517
Linearized function $f_{appr}(x)$	0,9	1	1,1
Error of the linearization, $e = f(x) - f_{appr}(x)$	0,003933 ($\approx$ 0,39%)	0	0,00517 ($\approx$ 0,51%)

From Table 3 it is evident that the linearization at the given equilibrium x^*accurate to model the nonlinearity at the newly selected equilibrium with its range defined. Nevertheless, it is easy to agree on that the wider the range selected for x the bigger the error of the approximation will occur.

For further studies and for engineering applications one can apply and use Table 4 for the linearization of the representative nonlinear functions:

Table 4 Representative arbitrary functions and their derivatives

Arbitrary function $f(x)$	First derivative	First-order linear approximation, $f_{appr}\ (x)$
$x^n, \mathbb{R}/\{0\}, n \in \mathbb{Z}$	$n \cdot x^{n-1}$	$2x$, for $n = 2,\ x^* = 0$
$\sqrt{x}$	$\frac{1}{2\sqrt{x}}$	$\frac{1}{2} + \frac{1}{2}x$, for $x^* = 1$
$\frac{1}{x}, \mathbb{R}/\{0\}$	$-\frac{1}{x^2}$	$2 - x$, for $x^* = 1$
a^x	$a^x \cdot lna$	$1 + ln2 \cdot x$, for $a = 2,\ x^* = 0$
$log_a x$	$\frac{1}{x \cdot lna}$	$\frac{1}{ln10} \cdot (x - 1)$, for $a = 10,\ x^* = 1$
$sinx$	$cosx$	x, for $x^* = 0$
$cosx$	$-sinx$	$1 - x$, for $x^* = 0$
$tanx$	$\frac{1}{cos^2 x}$	$1 + \frac{1}{\left(\frac{\sqrt{2}}{2}\right)^2}(x - \frac{\pi}{4})$, for $x^* = \pi/4$
$ctanx$	$-\frac{1}{sin^2 x}$	$1 - \frac{1}{\left(\frac{\sqrt{2}}{2}\right)^2}(x - \frac{\pi}{4})$, for $x^* = \pi/4$

In inverse problem formulation, any pre-defined error of the accuracy of the linearization can be used for finding the acceptable range of the independent x.

Using the method of the Taylor series expansion dynamic nonlinearities can be handled and linearized modelling the Taylor series with its first-order approximation, when the sum of the H.O.T. is very small compared with the first linear term of the series.

Thus, the H.O.T. representing the error of the linearization (approximation) and it can be omitted without any loss of originality of the arbitrary nonlinear function.

3.2 Time invariant static nonlinearities of UAV closed loop control systems. It is easy to agree that any technical device being involved to solve control problems in the UAVs automatic flight control systems have several static nonlinearities both in its feedforward and feedback paths.

The feedforward path is of controller, amplifier, valves, actuators, famous mostly about their static nonlinearities like dead-zone plus saturation. In case of presence of multiple static nonlinearities, it is supposed that all static nonlinearities can be converted into a single block of the static nonlinearities.

The feedback path sensors often have nonlinearities, in other words, rate limiters introduced by the designers, to limit maneuverability of the UAV, which is extremely important to avoid aggressive UAV maneuvers. If multiple nonlinearities are in the feedback path, it is supposed that they can be blocked into a single unit of the static nonlinearity (Fig. 7).

When to discuss any nonlinear system analysis it is supposed that the linear system dynamics can be decoupled from the static nonlinearities, and all nonlinearities can be unified in one block, as it shown in Fig. 7.

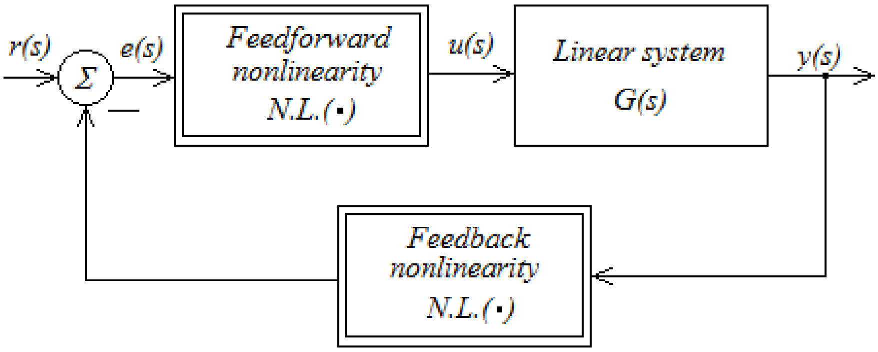


FIG. 7 Decoupling linear dynamics and static nonlinearities.

To model the static nonlinearity, and to find conditions for any limit cycle of the nonlinear closed loop control system describing functions are used widely [5, 6, 7, 8, 9, 10, 11, 12, 13, 15], and the interested reader should refer to.

4. CONCLUSIONS, OUTLOOK AND FUTURE WORK

The linear system is a rare phenomenon in control engineering practice. Although dynamics of the plant to be controlled is a nonlinear awaiting its linearization. This paper mostly focuses on the linearization method called Taylor series expansion. Few functions used the most widely have been linearized and shown that at a properly selected equilibrium points the can be substituted with linear (linearized) functions with tolerable errors.

Errors calculated for the linearization introduced are small for the pre-determined range of the independent. Any increase of the range bounds we linearize over will lead to increase of the linearization error.

In the practice, linearization often starts with definition of the error describing the inaccuracy allowed when to approximate any arbitrary mathematical function with its linear tangential substitution.

Future work will address the nonlinear closed loop control system analysis using describing function methodology to determine closed loop stability and existence of limit cycle generated by the time invariant static nonlinearities. Second field being discussed is a pilot induced oscillation (PIO) of the UAV, when a less-skilled and less-trained amateur operator flies the UAV.

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CONSIDERATIONS REGARDING JET ENGINE COMBUSTOR PARAMETERS

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Abstract: *The thermo-gas dynamics of fuel combustion in the combustor of aircraft engines involves thermochemical activity and combustion dynamics, but also the geometric volume of the combustion process. Research around the topic provides clues regarding the fluctuations of the combustor's performance depending on the fuels used and the kinetics of the gas mixture determined by the internal geometry of the combustor, clues that can help initiate numerical approaches regarding the optimization of the mixture and combustion temperatures. The article proposes an approach to the combustion process in jet engines both from the perspective of the fuels used and from the perspective of combustion thermo-gas dynamics through numerical analyzes designed to highlight the relevant parameters and performances of the jet engine combustor.*

Keywords: *combustion thermodynamics, combustor, GasTurb, numerical analysis.*

Nomenclature:

T_3	*inlet combustor temperature*	T_4	*inlet turbine temperature*
V_c	*combustor volume*	p_3	*inlet pressure combustor*
q_v, q_s	*thermal loading*	r	*radius*
C_3 , C_4,	*combustor speeds*	ζ_c	*burn efficiency*
α	*air exceed*	θ	*gradient heat*
Q_g	*heat of burning gases*	δ	*thermal distribution*
σ_c	*pressure loss*	*JP*	*jet petrol (JP-1, JP-4, JP-10)*
BDE	*burner design efficiency*	*BPR*	*burner pressure ratio*
TSFC	*true specific fuel consumption*	*W*	*flow gases*
P	*total pressure*	*T*	*total temperature*
ρ	*Air density*	p_{lf}	*pressure loss factor*
Q_{grr}	*heat release rate*	V_f	*fuel volume*
m	*air mass*	A_c	*max. surface section of the combustor*
k_1, k_2	*experimental factors*		

1. INTRODUCTION

This paper reveals a concept of analysis of the combustion phenomenon both through thermochemical approaches and through thermo-gas dynamic-related considerations, approaches instrumented through the use of software solutions necessary for the stages of geometric parameterization and numerical analysis. The addressed problem provides clues regarding the modification of the combustor performances depending on the fuels used and the kinetics of the mixture gases determined by the internal geometry of the combustor, clues that can initiate numerical approaches regarding the optimization of the mixture and combustion temperatures. The analytical approaches presented provide logical educational and research benchmarks using software tools based on commercial numerical codes.

The approach focuses on a comparative analysis of the combustion kinetics performances and their influence on the overall performance of the propulsion system, using a series of aviation fuels in fixed volume enclosures similar to jet engines. The analysis cases comprise numerical approaches with the GasTurb tool for the ground operation of a classic turbojet engine.

2. ABOUT COMBUSTION TERMODYNAMICS

2.1. About the combustion process. Combustion thermodynamics

An optimal process of the combustion process of a fuel in the first phase is necessary to connect it with the combustion agent (air or O_2) and in the second phase to produce the ignition. Depending on the state of aggregation of the fuel and the combustion agent, two types of combustion are distinguished: homogeneous combustion, when the two phases have the same state of aggregation, so it is characteristic of gaseous fuels (combustion takes place in volume, in the fuel mixture and oxidant) and heterogeneous combustion, when the two phases are in different states of aggregation, being characteristic of solid and liquid fuels (the combustion process takes place at the contact surface between fuel and oxidant). [1].

The burning process of any fuel is preceded by the stage called ignition. This can be achieved under the following conditions: the existence of a certain local proportion between fuel and oxidizer (stoichiometric ratio) and the existence of an energy source for heating the fuel up to its ignition temperature. The quantitative assessment of the combustion process of a fuel is carried out by calculating the combustion, which determines: the amount of air required for combustion; the amount and composition of combustion products; combustion temperature. Specialists in the field of aviation propulsion systems pay special attention to combustion management (combustion control and monitoring) by minimizing the coefficient of excess air to ensure complete combustion (α=1.15÷1.4). This coefficient is determined indirectly, using the analysis of the composition of combustion gases carried out with gas analyzers.

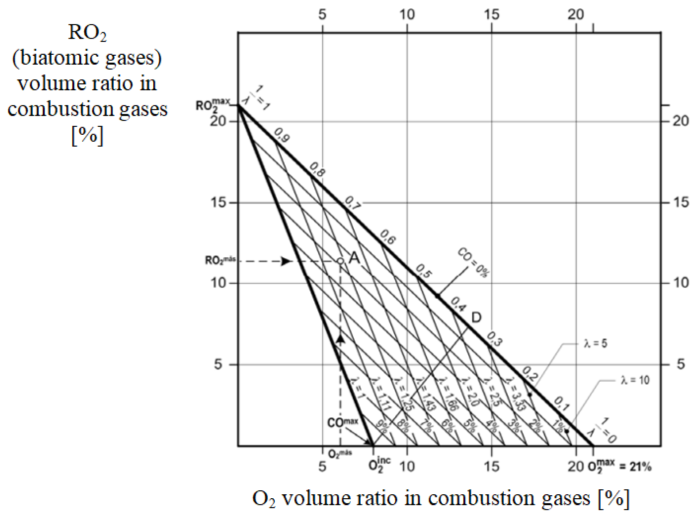

FIG. 1 Oswald diagram (combustion triangle), [2].

Combustion control is done using the Oswald diagram (combustion triangle) specific to each fuel, in Fig.1 we have the combustion triangle for solid fuel (CO_{2max}). The rapid ignition of a fuel depends on the contact surface between the fuel and the oxygen in the air; partial pressure of oxygen in air; the (auto)-ignition temperature of the fuel relative to the local one. [1].

2.2. The fundamental requirements and performances of the combustor

a. Combustor requirements

The combustor is the defined volume for managing the stoichiometric combustion process at maximum performance at a maximum mixture velocity for a combustor of minimum dimensions and mass (Fig. 2). Due to the short time in which the gases remain in the combustor, a precise control of the flame front regarding its shape and frequency is required [3, 4, 5, 6].

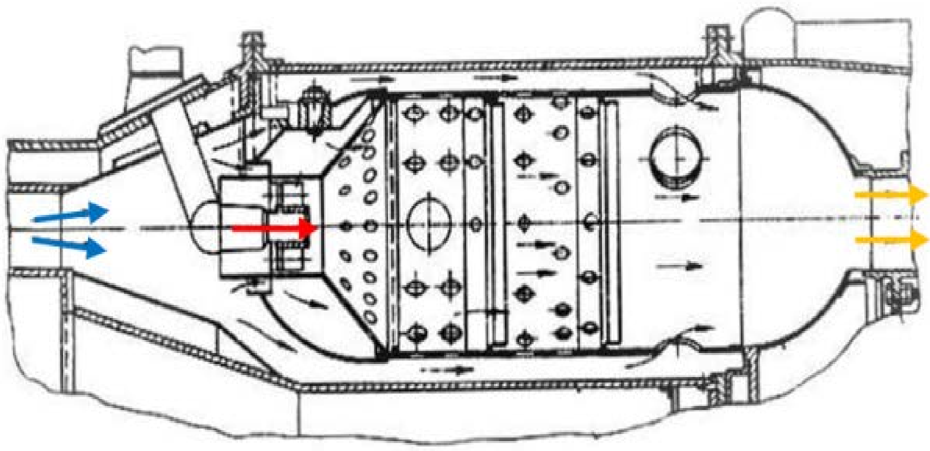

FIG. 2 The combustor. Mix gases circuit, [7].

The general requirements of the combustor are focused on simple manufacturing technology; an exploitation process at minimal costs; optimized mechanical strength and high reliability. The specific requirements of the combustor are: ensuring a stable combustion process at a maximum efficiency (0.94÷0.97), ensuring minimum pressure losses (total pressure losses max. 0.95-0.98); achieving a uniform maximum temperature distribution and uniform kinematic parameters at the turbine inlet section, defined by the degree of unevenness of the distribution $\delta<0.2$ (equation 1); a high thermal load and a high operating resource, (equations 2 and 3).

- the degree of non-uniformity of the thermal distribution:

$$\delta_c = \frac{T^*_{3max} - T^*_{3min}}{T^*_{3max}} \tag{1}$$

- the thermal load is defined as a function of the volume of the combustion chamber (qv) or in relation to the cross section (q_s):

$$q_v = \frac{Q_g}{V_c \cdot p^*_3} \tag{2}$$

$$q_s = \frac{Q_g}{S_c \cdot p^*_3} \tag{3}$$

where Q_g – heat of the combustion gases;
V_c – combustor volume;
S_c – surface of the transversal section;
p^*_3 – inlet gases pressure of the combustor
for q_v=5000÷10000 kJ/m^{3}bar.

b. The basic performance of the combustion chamber

The fundamental performances of the combustor are: total pressure loss (caused by the processes of friction, heating and mixing of combustion gases), combustion efficiency, combustion stability limits, degree of fluid heating or combustion intensity, [15]:

- The loss in total pressure takes place according to the following pattern (Fig.3):

$$\sigma_c^* = f\left(C_3, C_4, \frac{T_4^*}{T_3^*}\right) \tag{4}$$

or pressure loss due to friction [15], turbulence and combustion temperature increase, is defined by PLF (pressure loss factor), has the form:

$$p_{lf} = \frac{\Delta p_o}{\frac{m^2}{2\rho_1 A_c^2}} = k_1 + k_2\left(\frac{T_4}{T_3} - 1\right) \tag{5}$$

where m-air mass
A_c –max. section of combustor,
C_3, C_4 -inlet and outlet speed of the combustor,
T_3, T_4 –inlet and outlet temperature of the combustor,
k_1, k_2 – experimental factors (could and hot test process)

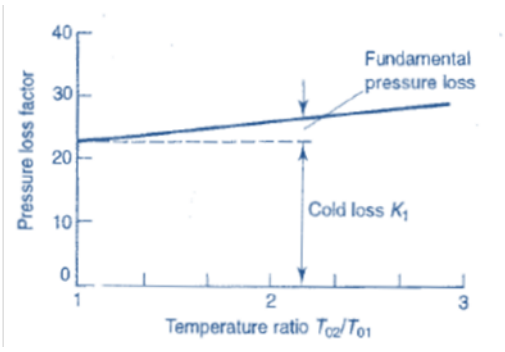

FIG. 3 Pressure loss variation, [15].

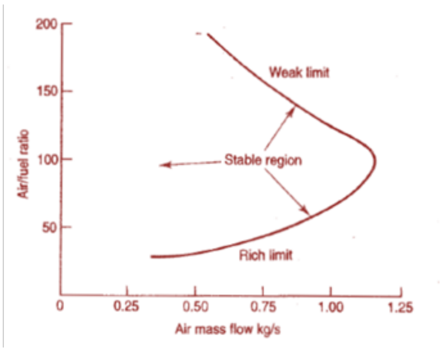

FIG. 4 Stability limtis of combustion, [15].

-combustion efficiency is a function:

$$\zeta_c = f(p_3, T_3, \alpha, C_3) \tag{6}$$

where p_3 –pressure inlet gases of the combustor,
α –air exceed.

-stability limits of combustion, see Fig. 4,
-fluid heat gradient, is a function:

$$\theta_c = f(C_3, C_4) \tag{7}$$

or combustion intensity:

$$I_c = \frac{Q_{grr}}{V_f \cdot P} \tag{8}$$

where Q_{grr}*- heat loss rate,*
Vf- fuel volume,
P-total pressure

3. METHODOLOGY AND INSTRUMENTS USED IN THE ANALYSIS

The scope of these numerical analyzes is focused on highlighting the influence of the combustion parameters on the global performance of the propulsion system and the main objective is to quantify the performance of the propellant according to the combustion parameters and the type of fuel used with the help of the GasTurb software tool, [8, 9]. The analysis methodology comprises numerical linear analyzes for a single duty cycle.

GasTurb software offers three levels of numerical analysis with varying degrees of detail: basic thermodynamic analyses, performance analyzes for the study of gas turbine cycles, and numerical analyzes for preliminary engine design.

GasTurb software offers a number of numerical analysis approaches, the most relevant are:

-*the design of the operating cycle*, which is based on a series of predefined jet engines for global performance studies or for certain constructive elements (device, intake, compressor, combustor, turbine, exhaust device), using both the parameters atmospheric (temperature T_1, pressure p_1, humidity), local operating parameters (flow rates, pressures, temperatures) as well as constructive parameters (efficiency, revolutions, angles, coefficients);

-*parametric design*, provides a complete picture of the analyzed engine design concept, by choosing two parameters (atmospheric, operational, constructive) that can generate numerical results and relevant 2D graphic diagrams;

-*parametric optimization analysis*, can be used to calculate the best duty cycle relative to certain variables and analysis limits.

-*the analysis of the influence of small effects*, is used to highlight the mutual influence of the operating parameters within the operating cycles of the analyzed aerojet engine.

-*Monte Carlo analysis*, this type of numerical simulation uses the selection of input parameters of randomly distributed cycles (with specified standard deviation), having results with Gaussian distribution.

4. ANALYSIS OF COMBUSTOR PERFORMANCES

a. Input data

The analysis is for a single operation cycle of a theoretical scenario, which uses the initial parameters from Table 1 for 7 types of fuels having the calorific values from Table 2.

Table 1.Analysis parameters

Parameter	Value	Parameter	Value
Altitude	0 m	Mach number	0
T_1 (total temperature)	280 ^oK	Ambient pressure	100 kPa
Inlet flow	32 kg/s	Pressure ratio	12
T_3 (burner exit)	1450 ^oK	Burner design efficiency	0,99
Burner pressure ratio	0,97	Burner part-load constant	1,6

Table 2. Fuels and corresponding calorific values

Fuel	Calorific value	Fuel	Calorific value
JP-4	43,323 MJ/kg	H	118,429 MJ/kg
JP-10	42,075 MJ/Kg	Diesel	42,743 MJ/kg
Bioethanol	36,000 MJ/Kg	Propane	50,000 MJ/kg
Natural gas	49,736 MJ/Kg		

b. Output data.

In the initial simulation conditions imposed on a jet engine (Tables 1 and 2) the use of the 7 types of fuels generates a series of results highlighted in figures 5÷7.

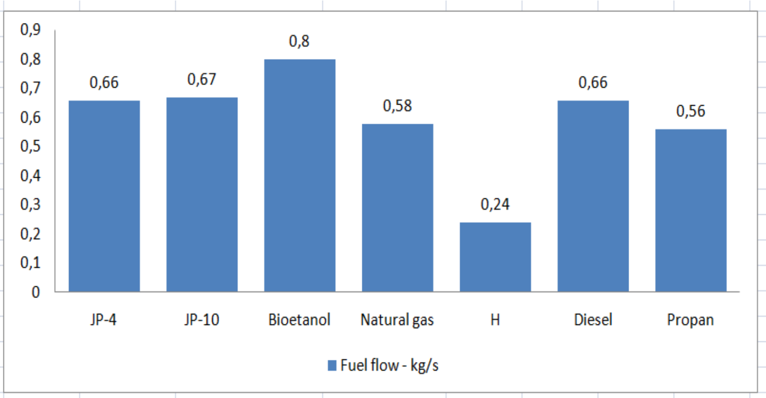

FIG. 5 Fuels flow proprieties

By using the types of fuels with the values of the flow properties in Fig. 5, the values of the nominal traction forces are according to Fig.6 and the specific consumption resulted (Fig. 7).

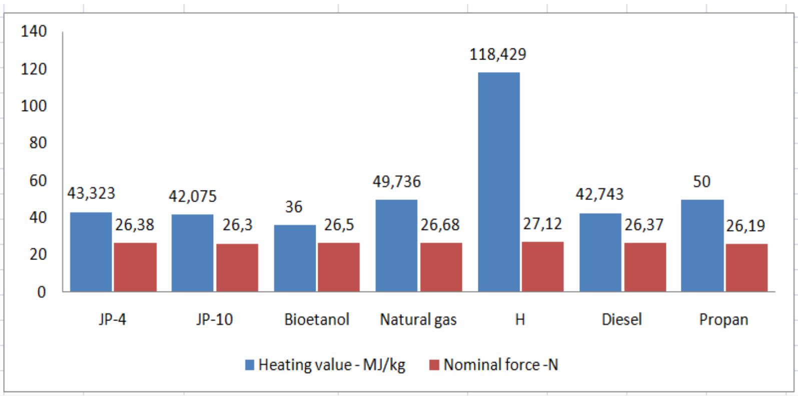

FIG. 6 Traction performance depending fuels

We observe a small value of the flow properties for hydrogen (Fig. 3) at a high value of the specific heat and the nominal traction force (Fig. 4) with a low specific consumption (Fig. 7).

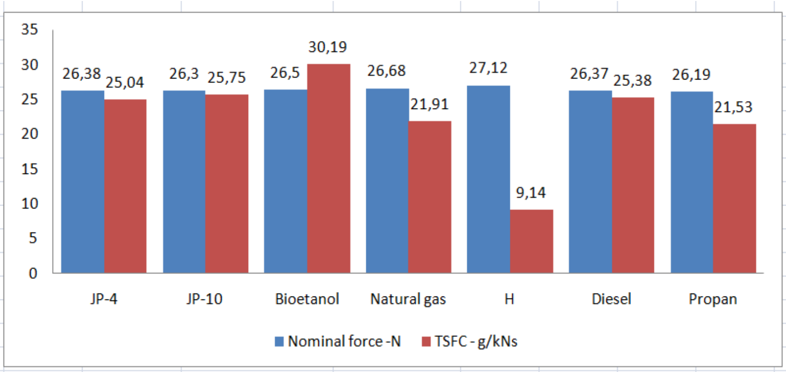

FIG. 7 Traction performance depending specific consuption

The fuel types selected for analysis generate the temperature-entropy thermodynamic diagram having similar shapes (see Fig. 8), however a comparative analysis reveals a range of refined thermo-kinetic results, with the initial analysis data recorded in Table 1. A temperature jump is observed in front of the combustion chamber inlet section (3-3.1) from 613 oK to 1450 oK (red arrow) and a slight cooling (4-4.1) in the vicinity of the outlet section (blue arrow).

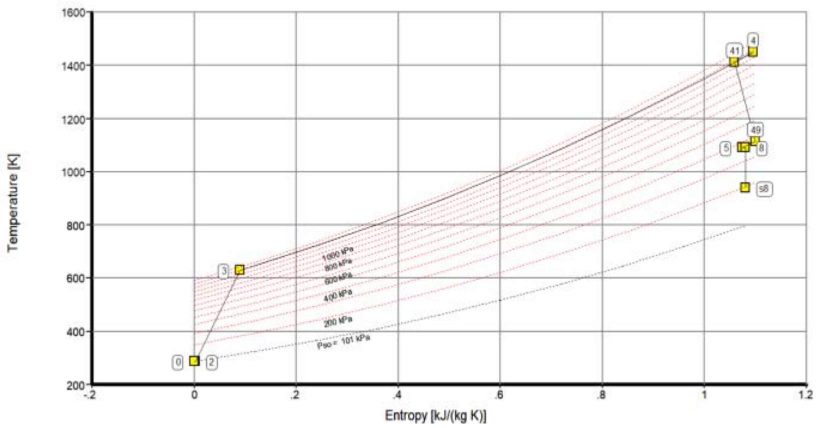

FIG. 8 Thermodynamic diagram (for JP-4 fuel)

The comparative thermo-kinetic results in the jet engine sections have the numerical values from figures 9÷11, they provide indications regarding the operation of the combustion chamber depending on the fuel used.

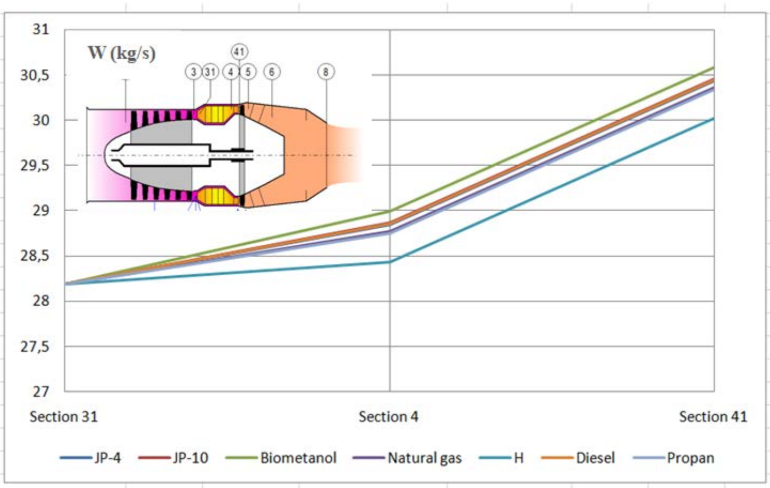

FIG. 9 Comparative diagram for flow gases W (kg/s) in combustor sections

Having identical numerical values for the gas flow at the inlet to the combustion chamber (see Fig. 9), the density and calorific values of the fuels determine different kinetic behaviors, with an increase in the flow of the fuel mixture in the various sections of the combustor, with extreme values for biofuel and hydrogen.

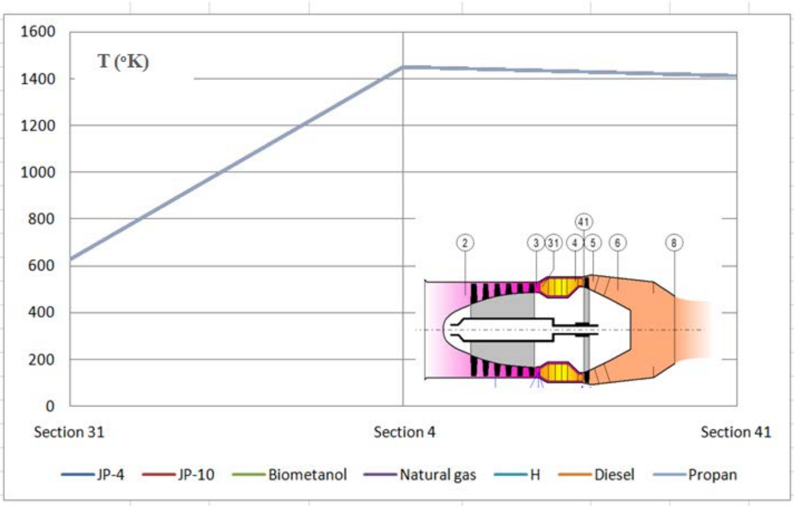

FIG. 10 Comparative diagram for the total temperature T (^{o}K) of gases in combustor sections

According to Fig. 10, the variation of the total temperature values is similar for all the fuels used, with a slight cooling of the gas mixture towards the combustor exit (section 4.1).

The fuels used in the numerical analysis generated similar downward variations of the total pressure in the combustor, with quasi-constant values on the exit section of the combustor (4-4.1), see Fig. 11.

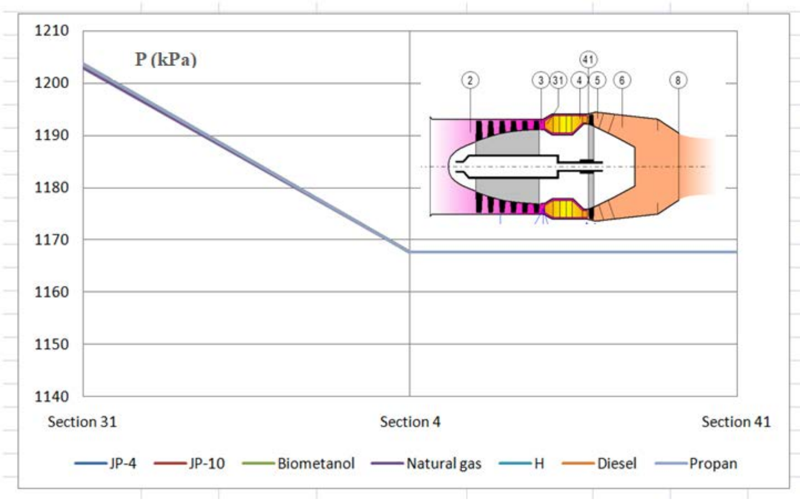

FIG. 11 Comparative diagram for the total pressure P (kPa) of gases in combustor sections

CONCLUSIONS

The combustors of jet engines are the constructive elements with the highest degree of thermal load, which implies a refined thermodynamic design and optimization that can lead to numerical results that are the basis of future experimental research on test benches and verification of parameters and constructive performances.

The article proposed a comparative approach using numerical simulations for a range of fuels used in the aerospace industry in general and jet engines in particular. Although the software tool generated a series of relevant results (thermo-kinetic and traction) regarding the thermodynamic behavior of fuels, the numerical instrumentation was limited to a theoretical model of an aerojet engine that only used the design method of a thermodynamic cycle of operation. Although we have different values of nominal thrusts, the generated results revealed quasi-similar thermodynamic behaviors of the fuels used, which implies future numerical analyzes based on multiple initial data or the use of similar software tools (e.g. GTPsim, Gas Turbine Simulation Program, Mathworks-Turbojet Engine Simulation), [10, 11, 12].

The continuation of research efforts on the performance of combustion chambers of jet engines are focused on parametric numerical analyzes and optimization with the help of GasTurb considering the consideration of valid input data for aerojet engines in use (e.g. Pratt Withney F100 on the F16 Fighting Falcon aircraft). , [13, 14].

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THE CHILD WITH SPECIAL EDUCATIONAL NEEDS (SEN): A HISTORY OF SOCIAL PERCEPTION

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Abstract: *The complexity of situations in the educational sphere generated by the presence of people at risk, in vulnerable situations is currently one of the priorities of governments worldwide. Historical periods show us that their social perception and acceptance was not at all favorable, on the contrary, attitudes ranged from hostility to extermination programs.*

History shows us that the separation of people with disabilities from others was determined by the fear of contamination and also by the desire to escape responsibility regarding those who were a burden to society and considered useless.

Keywords: *vulnerable situations, acceptance, Special Educational Needs, disabilities*

1. INTRODUCTION

The complexity of situations in the educational sphere generated by the presence of people at risk, in vulnerable situations is currently one of the priorities of governments worldwide. Historical periods show us that their perception and acceptance was not at all favorable, on the contrary, attitudes were from hostility to extermination solutions.

History shows us that the separation of people with disabilities from others was determined by the fear of contamination and also by the desire to escape responsibility to those who were a burden to society and considered useless.

2. BRIEF HISTORY OF THE SOCIAL PERCEPTIONS REGARDING CHILDREN WITH SPECIAL NEEDS IN DIFFERENT PERIODS AND CULTURES

One of the authors who manages to capture special education in the world until 1970 is Traian Vrășmaș, from whom I have taken, in this research, some very valuable information. (Vrăşmaș T. , 2010)

According to the author, the attitude of the society towards people with disabilities, as well as towards other people in difficulty, has been, over time, one of rejection, devaluation, isolation, segregation.

In ancient times, if we were to think of Sparta, children with disabilities were physically exterminated or exposed in cages; the same in Aztec society. In the Middle Ages these people were accused of witchcraft, cursing or paying for the sins of their parents. Regarding the attitude of modern society towards children with disabilities, a group of authors (Descamp si col., 1981, apud. Vrașmaș T., 2001, p. 9) highlights mainly 4 types of reactions: extermination, segregation, grant of reduced citizenship and recognition of equal rights.

Christians have been referring to disabilities since the Old Testament, where non-discrimination is mentioned, with the Lord wishing "not to speak evil of the deaf, nor before the blind to put a hindrance." (Leviticus 19:14)

And yet, even among Christians, disability, although tolerated and encouraged an attitude of the citizens full of understanding towards it, was perceived as a divine punishment:

"And if you will not hearken unto the voice of the Lord thy God, and force thyself to fulfill all his commandments and decrees," [.] 'Let the Lord beat you with foolishness, blindness, and with numbness of heart." (Book of Deuteronomy (15: 11 and 28: 15-29)).

The cruel attitude towards children with disabilities is well known in antiquity, with Greek laws encouraging the killing of babies who up to 7 days did not prove normal development.

In Greece and Rome, any minor problem turned a healthy person into one with a disability and was later marginalised.

The concern to help people with physical disabilities dates back to ancient times. A first mention of a prosthesis is in the ancient poem Rig-Veda, a poem written between 3500-1800 BC, in which is presented the story of a queen, Vishpala, an ally of Ashins, the spirit of the horsemen-gods, who loses his leg in battle and is given an iron prosthesis, returning to battle.

In the Middle Ages there is a new change of social and moral conceptions, the ideas of charity and mercy propagated by Christianity make people with disabilities to be cared for in asylums organized by the Church (Arcan and Ciumăgeanu, 1980, p. 34). Epilepsy was considered to have demonic causes, demonic mastery being considered the primary etiology for mental illness as well.

In the fifteenth century, millions of people (mostly women) were killed in Europe on charges of witchcraft. Many were women with disabilities or mothers of children with disabilities. The mentally ill and the mentally deficient were regarded by Luther and Calvin as sons of the devil, as possessed by Satan, and "In order to get the devil out of them, inhumane treatments were applied to them - they were put in chains and scourged in a barbaric way. Because they were considered to be related to the devil, they were hunted with dog packs on the domains of some magnates, and the conditions for sheltering in hospice remained hellish." (Arcan şi Ciumăgeanu, 1980, p. 34)

In the 17^{th} century, "the fools bound in their cells served, like the animals in the menagerie, for the amusement of the visiting public". (Semelaigne, apud. Arcan and Ciumăgeanu, 1980, p.35).

The empirical beginnings in the direction of protecting these people, who have been joined by timid attempts at education, are due to the Enlightenment period, when asylums and hospitals appear.

The first opening to the possibility that even children who learn harder to deserve educational attention is found in Comenius, in Didactica Magna (chapter IX): "The heavier and less endowed someone is from nature, the more he needs help, in order to free himself from his limitations and stupidity." (Comenius, apud Vrăşmaş, p. 10)

The first to carry out specialized education is considered Gabriel Itard, who tried to humanize that "enfant sauvage" called Victor, discovered at Aveyron, France (1799) whose tutelage he obtained. In the history of pedagogy, these "wild" child is considered the first mentally deficient for which it was demonstrated, according to the authors Arcan and Ciumăgenu (1980) that education is possible. The teaching-learning techniques used by Itard were later taken over and developed by Seguin, who influenced the progress of "treatment" for people with mental disabilities in special institutions (nursing homes, hospitals).

"Chronologically, the term idiotism was used by J. Esquirol in the eighteenth century, and in 1846 E. Sequin introduced notions of the degrees of mental deficiency: idiot, imbecile, mentally backward or retarded." (Arcan şi Ciumăgeanu, 1980).

The orientation of children with disabilities towards special institutions, within which special boarding schools are differentiated and developed more, was a fundamental feature also in the twentieth century.

Between the two world wars, the first timid attempts to overcome the model of separate schools are identified, by establishing special classes, inside the usual schools. This is the case of the "refresher classes" in France, or of the special classes built in our country, for "abnormally educable children", based on the Education Act of 1924:

"For the late-minded children, for those touched by contagious diseases or by physical and intellectual infirmities, which do not make them incapable of receiving primary education, special classes or schools will be established." (Art.16, Education Law of 1924)

A radical form of separation, better said extermination, was known to mankind during the period of the Third Reich, when about 300000 people were killed, considered "subhuman". (Wolfensberger, 1981)

The "segregationist" orientation in special education will continue and will be amplified after the Second World War, when the structures of separate education are strengthened and multiplied, increasing the number of children excluded from the usual living and education environments.

International organizations (UN, WHO, EDF) claim that 10% of the population has disabilities. In many countries it is recognized that, out of the entire school population, about 15-20% have school learning difficulties.

Inclusive education has become a movement at international level, aiming to create an education system in which all children learn together, and are treated equally, regardless of conditions, background, health status, gender, ethnicity.

"A nation can be judged by how it treats its most disadvantaged and vulnerable members. While it's hard to repair the harm already done to children with disabilities, states should take steps more quickly to stop the discrimination that is clouding the lives of these children and theirs. As the report points out, now is the best time to transform the care and treatment of children with disabilities from public shame to the extent of human progress..." (Calivis, 2005)

The concepts used today for the Special Educational Requirements want to replace those concepts that had negative connotations and with the help of which children were considered deformed, infirm, retarded.

The current conceptualization of children with special needs has replaced the negative labeling of the past who saw children with disabilities as crippled, infirm, less fortunate or mentally retarded.

With all the efforts made, we are still faced with the lack of access to education for all children with Special Ducational Requirements (SEN), in violation of a fundamental right for all, enshrined in the Universal Declaration of Human Rights, and protected by various international conventions, which is a very serious problem.

"Everyone has the right to education. Education must be free of charge, at least as regards elementary and general education. Technical and vocational education must be available to everyone, and higher education must also be equal, accessible to all, on the basis of merit. Education must aim at the full development of the human personality and the strengthening of respect for human rights and fundamental freedoms." (UN, Universal Declaration of Human Rights, 1948).

In most countries, there is a dramatic difference between the educational opportunities offered for children with disabilities and those provided for those without disabilities. It is impossible to achieve the goal of Education for All unless a complete change in the situation is achieved. A significant number of children and young people with disabilities are largely excluded from educational opportunities for primary and secondary education.

Education is widely recognized as a means of developing human capital, improving economic performance and increasing people's capacities and choices.

Exclusion, poverty and disability are interlinked. Exclusion and marginalization reduce opportunities for people with disabilities to contribute productively to domestic work and community work, and also increase the risk of falling into poverty.

Attitudinal as well as physical barriers, such as lack of proper transport, physical inaccessibility, and lack of learning opportunities, can affect access to education and employment opportunities, while also reducing the chances of income consolidation as well as social participation.

"The combination of poverty and disability is a frightening one. Any of them can cause the appearance of the other, and their presence in the association has an enormous capacity to destroy the lives of people with disabilities, and to impose burdens on their families that are too hard to bear." (Acton, 1983)

As we can see, poverty and disability are inextricably interconnected. People with disabilities are poorer as a group than the other population in general, and people living in poverty are more likely than others to be disabled.

In order to better understand the current moment of inclusion of children with SEN, it is recommended to present the evolution of the Romanian educational system that has gone through the turbulent periods, which have left consequences. We must not forget that until 1989 Romania was a country that lived in a totalitarian regime, which preferred to ignore the reality of children with disabilities / disabilities at that time.

Children with disabilities represented, in Romania, "the most controversial category of children protected according to Law 3/1970" (Zamfir, 1995: 140). During the communist period, the admission of these children in an institution was considered the most appropriate way of care and, eventually, their schooling, because it was considered that they needed an environment adapted to the special requirements.

Under this law, children were divided into "recoverable," "partially-recoverable," and "unrecoverable."

Those who received the employment of "recoverable" children were oriented to special schools that corresponded to the deficiency to which they belonged (special schools for the hearing, visionary or motorized), and those with mild mental deficiency, to schools-helpers. At the end of the gymnasium, they attended special vocational schools that offered them a professional qualification.

The "partially-recoverable" children were hospitalized in dormitories-school and carried out elementary school education.

The "unrecoverable" children, that is, diagnosed with severe mental disabilities or associated deficiencies, were admitted to the dormitories-hospital, where they received only care, the staff of these institutions having medical training.

The year 1990 meant the beginning of some transformations that our country felt on all levels after the revolution of 1989; then everyone was hopeful of embarking on a new path when the whole people were trying hard to adapt to changes for which they were not yet prepared. The revolution was the signal that the changes were imminent, but the steps that will follow will be difficult, mentalities that have persisted for decades will have to be removed, everything that had been built until then had to be transformed, without having a model that would adapt to what had defined Romania until that moment.

Social interventions will be needed to cover the shortcomings of the general education system, to which will be added intense efforts to change social perception. The period of communism had formed some "models" that now had to be adapted and transformed. The Romanian educational system up to the 89th moment was based on a rigid system, which centered on performance, which it promoted, and whose results, why not admit it, had formed some internationally recognized personalities. The role of the individual was belittled, the achievements were of the party and the individual, especially if it did not "optimally" serve its causes, it was not taken into account.

If we did not present these realities from which the Romanian educational system started, it would be very difficult to understand how inclusive education appeared and what steps inclusive education took in Romania. We can imagine that if even today, 31 years after the revolution, although there was a rigorous concern for legislative regulations and changing the perception of the pedagogical act, the practices of inclusion encounter difficulties, the mentality is very difficult to change, the empathy of all the factors involved is very difficult to achieve, the more the course of the communist era of the system of acceptance of children with disabilities is more dramatic.

After 1990, the measures of child protection, recognition of its value and uniqueness had a good evolution more in the social sphere (from which they "profited", unfortunately some parents, being with their children only for material benefits), but the educational system did not move as quickly and efficiently.

For Eastern Europe, the direction and level that Romania has reached in the sphere of protection of the rights of the child is to be commended, thinking about the starting point, the extemporaneously poor and limited conditions from which it started. We could even say that, in 1990, the zero moment for the change towards inclusive education, the situation of children in Romania was, if not the worst, one of the worst in Europe.

Romania has demonstrated that it has mastered, at least at the level of theory, the principles of inclusive education, which recognized equal opportunities for all children, trying to apply these principles in legislative terms, in practice, proposing innovative projects, carried out by people with a soul, professionals who understood that all children have the same rights regarding access to education and social life.

Goffman is the one who has demonstrated that "total institutions" exercise social control over the individual, create his dependence, do not respect the right to privacy, because absolutely all activities are carried out in this space, they cannot take any initiative without being allowed to do so, he is humiliated being "violated the boundaries of the self". The result of this research was that it set in motion the process of deinstitutionalization and people at risk began to benefit from support services. (Gofman, 2004, p. 52)

The numerous researches aimed at educating children with SEN wanted to highlight the fact that special education, by being "special" itself, stigmatizes, violates the rights of the child and goes against the values of democracy. (Skrtic, 2005)

CONCLUSIONS

Recent years have intensified actions to ensure that all children, regardless of disability, could be included in mainstream education. This cannot change without changing school policy, which would remove any form of discrimination, accept differences between children as uniqueness, and thereby be all the more valuable, promote respect and tolerance among all participants.

For this to be possible, you need to have prepared communities that accept diversity (Watson, 2009), to have human resources to work with children who have SEN, to have services appropriate to their special needs, to be able to cooperate closely with parents.

"*... in the orchard we like to have trees that bear fruit sooner or later [...] all these fruits are good; none is to be thrown away. why not accept more keen or slower minds in schools, then? why wouldn't we help them? we lose time but gain satisfaction and respect*..." Comenius

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RESILIENCE: A MILITARY CONCEPT

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Abstract: *In recent years, resilience, as a concept, has become an important topic in the military. What exactly is resilience and why is it important? The purpose of this article is to present the value and implications of resilience when applied to the military as a system. A systemic approach to resilience at the strategic level has gnoseological and epistemological potential as a topic for research. The capacity of a system to recover after strong stress involves approaching the system as a living organism featuring a capacity for autopoiesis.*

Keywords: *resilience, military concept*

1. INTRODUCTION

Defining resilience represents a challenge because of the numerous domains where this concept has meaning and relevance. The definitions from the literature might suggest that this concept was adapted to an increased number of research fields in order to answer the scientific development which describes a new reality with new attributes. From a military point of view, the nature of threats development and the complexity of military actions justifies the interest for this concept and a better understanding of its particularities.

As the majority of scientific and philosophical terms which have their roots in the two antique cultures, Greek and Latin, etymologically „*resilience*" also comes from the latin „*salio*" which means „*to spring, ricoche*" while „*re-*" meaning „*back*", *resalio* meaning „*to spring back after an impact with an obstacle*".

The Romanian dictionaries explain that the word *resilience* is a technical term regarding materials technology [1], however, this concept was given a psychological meaning as in Newton's Third Law: action and reaction.

The beginnings of resilience research are marked by three major founding contributions: Emmy Werner and Ruth Smith's longitudinal study [2], research on various populations at risk, undertaken by Michael Rutter [3] and the "Competence" project, coordinated by Norman Garmezy [4].

In 1939-1945, American psychologists Werner and Smith [5] achieved significant results in the recovery of a group of children with disabilities emphasizing the importance of the resilience. But as a concept, "*resilience*" appears for the first time in John Bowlby's research on the affective attachment [6], [7], [8].

From a psychological point of view, resilience is defined as an ability to recover psychic functions after a strong stress of different causes: catastrophe, war, trauma, difficult living conditions, loss of work, and other similar situations. The way some people manage to overcome difficult times more easily than others represents one of the research topics in psychology. Personality skills and characteristics developed after overcoming the difficult living conditions that made some individuals become better professional, stronger, who find better solutions to the problems of life; do not victimize themselves, trust them, have confidence in them, active social life. They are optimistic, they have friends, and a vision of perspective on their lives. These individuals allow themselves to have negative feelings of anger, sadness, anger, disappointment, loss, etc. but do not get overwhelmed by them. They manage to control their emotions and transform those experiences into life lessons and move on, stronger.

Resilience has been translated from English Resilience to Romanian in some contexts by resistance, including by the Ministry of Foreign Affairs (translation of the statement made to the NATO summit in Warsaw July 2016) [9] which subordinates to an initial stage, the Euro-Atlantic Center for resilience. Resilience, unlike resistance, represents the ability to overcome and dominate unfavorable stimuli. If we took as an example (starting from the definition in the explanatory dictionary of the Romanian language), a ball that strikes a wall and ricochet without changing its shape, on the ball did not act a large enough to break, therefore, it is resistant to shocks of a certain intensity. But if we talk about a person, following a difficult experience (example: emotional shock), that person has learned a lesson, has developed, evolved stronger, resilient in the face of similar stimuli. Or it can be "broken" like a ball, resulting in trauma, anger, depression, etc. Resilience does not involve the return to form before the action of the shock, and in the case of a system, if it retains its function, the role. Starting from the premise that there is no perfect system, perfect person, resilience is defined by the direct proportionality with the intensity of the shock it is subjected to. Resilience involves resistance but does not define the same process or the same quality or ability.

In the specialized literature, resilience is regarded both as a process, a phenomenon, and as a quality. Resilience most often implies a process in which, not only the individual or system concerned, participates. For example, when a person goes through an extreme situation, he can exert his influence over the environment, family, friends and economic situation. Resilience, most of the time, represents a consequence of a process attended by several factors. Resilience as a result can be positive or negative from an ethical point of view.

2. RESILIENCE IN THE MILITARY

The environment in which military actions take place can most often be characterized by volatility, insecurity, complexity and ambiguity. These characteristics can lead to: physical and mental exhaustion, reduction of rest time and caloric deprivation. The very short time needed to respond to many of the possible threats involves a high level of availability to respond, in time. Also the ability to cope with a hostile, stressful environment for maintaining optimal cognitive capacity. This ability is named, resilience. The ability to overcome, as effectively as possible, the negative aspects of stress caused by the obstacles encountered represents a complex process that is based not only on the individual physiological and mental qualities but is influenced by factors such as the environment, level, and quality of training.

From a military point of view, the US has given the most interest to this concept, which is also due to the complexity in which they define their resilience:

„*The ability of an architecture to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions. Resilience may leverage cross-domain or alternative government, commercial, or international capabilities*." [10]

The definition given by the US Department of Defense although explicit, uses general terms as a result in the following definition given by FM 3-01 U.S. Army Air and Missile Defense Operations: „*Resilience is the quality of the defense to maintain continuity of operations regardless of changes in or unanticipated tactics by enemy air or losses of critical air and missile defense components*."[11], it can be seen that the definition only particularizes what was already defined by a higher level publication, preserving the basic idea of the unitary concept, although, in the first definition, the concept is regarded as a skill and in the second as a quality.

In the same manual, resilience as a key factor in maintaining anti-aircraft defense, involves the optimal choice, principle, or principles of creating an integrated fire system. This decision must be made by the commanders under the conditions of a very good understanding of all the capabilities of the systems that are part of the forces package as well as the types of threats. The decision-making process based on analyzing the risks and vulnerabilities of their own fire system, will have to be taken into account during the planning process and the reply mode, if a subsystem is no longer in the initial operating parameters (such as mutual support, e.g.).

The way of using the armed principles struggle, from the perspective of resilience, implying an unitary effort, going to the strategic level until the conjugated use of the power tools of a state. Thus, the condition of the military power of its own.

In this regard, starting with 2010 (the strategic concept for the defense and security of the members of the North Atlantic Alliance "Active Commitment, Modern Defense", adopted on the occasion of the NATO summit in Lisbon) can be noticeable to the concept of resilience.

In 2014, due to the annexation of Crimea by the Russian Federation, during the Summit in Wales, the participating countries mention in Wales Summit Declaration:

„*The Alliance does not seek confrontation and poses no threat to Russia. But we cannot and will not compromise on the principles on which our Alliance and security in Europe and North America rest. NATO is both transparent and predictable, and we are resolved to display endurance and **resilience**, as we have done since the founding of our Alliance*", also:

„*As the Alliance looks to the future, cyber threats and attacks will continue to become more common, sophisticated, and potentially damaging. (…) The policy reaffirms the principles of the indivisibility of Allied security and of prevention, detection, **resilience**, recovery, and defence*."[12]

In 2016, during the meeting of the North Atlantic Council in Warsaw, the heads of participating states and governments adopt „Commitment to enhance resilience", commitment that states very clearly that „Resilience is an essential basis for credible deterrence and defense and effective fulfillment of the Alliance's core tasks."[13]

In 2020, at the "Coordinated Coordinates of Military Strategy under the conditions of a synergistic approach in the field of security", the deputy general of NATO, Mircea Geoană, made the following statement:

„*There is no performance without rehearsal and without practice. That is why I am convinced that Romania can and must be a champion in what means the transformation of lessons learned in the field of resilience and impact of these crises on society for the good of the whole alliance and of the citizens we are called to protect. The construction of the resilience of our societies and the defense infrastructure in this part of the world must be a priority for us as an individual nation, as a region and for our trans-Atlantic partnership*".[14]

Another important moment for the development and implementation of the concept of resilience for Romania, took place on May 31, 2021, when the "Euro-Atlantic Center for Resility E-ARC" was inaugurated.

According to the statements made by the Ministry of Foreign Affairs, this Center will provide a platform for strategic discussions and development of concepts, training and exercises, as well as the collection and provision of lessons learned and will allow the development of different programs and initiatives in the field of resilience over the next three pillars:

1. Combating/reducing risks by anticipation and adaptation;
2. Developing analytical tools and good practices;
3. Practical cooperation in the field of education, training and joint exercises. [15]

The main themes on which the working groups will concentrate are:

- societal resilience
- resilience in the field of emerging and disruptive technologies
- resilience of communications systems and new technological ecosystems
- resilience to complex crises and emergencies
- resilience of ensuring continuity of governance and essential services;
- transport infrastructure resilience;
- the resilience of the states in the vicinity of NATO and the EU to the anti-occidental influences of the state and non-state actors.

CONCLUSIONS

The concept of resilience, applicable in the military environment, refers to both the individual ability of a military and the level of military actions where it refers to the capabilities of some systems.

At the individual level, resilience has a complex psychological aspect and is defined both as a skill and as a resilient process that several factors compete as: environment, family, service colleagues, friends, etc. Resilience can be a part of the emotional intelligence of an individual through his or her human relations. Through self-management, individual emotions and experiences become a dimension of interpersonal relationships. Resilience is an ability to be developed in the military educational system within leadership programs. Resilience can develop, over time, exponentially at the level of the whole human resources of the military system if higher education institutions form leaders capable of further transmitting knowledge and skills. Resilience at the individual level can be developed by maintaining the cohesion of the group, optimism, confidence in their own forces; support from specialists in resilience, colleagues, family, friends, cultivating optimism, and motivation, regular sports activity. All these means of developing resilience can be used in programs that should be part of the military school curriculum.

The resilience of a system of the size of an alliance of states (NATO, EU) can be interpreted as the ability of societies to adapt to internal or external crises and recover. The context of the crisis caused by the Covid-19 pandemic was a difficult test for societies, resilience being a desire that can be best achieved by common effort. As a result of this "experience", as at the individual level, both NATO and the EU are stronger.

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HUMAN RESOURCES MANAGEMENT AFTER THE COVID-19 PANDEMIC: BACK TO 2019 OR AHEAD TOWARDS A NEW MANAGEMENT OF HUMAN RESOURCES?

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Abstract: *During the COVID-19 pandemic the management of human resources changed dramatically, especially since digitalization grew overwhelmingly overnight and multi-national companies were forced to close office buildings and work remotely. In other words, the IT industry went sky high and the demand for IT specialists increased as everything became automatized. Working from home has increased the demand for specialists and software in every branch of any company and even after COVID-19, people find it difficult to readjust to the lifestyle they were accustomed to before 2020, due to the fact that in the meantime, they have learned to use software that can help them do the same thing from home, but faster and in a more precise way than previous software versions would have allowed. Thus, the hybrid working system is more viable nowadays and even reducing the number of working days per week may soon become possible.*

Keywords: *Human Resources Management, COVID-19 pandemic, demand for IT specialist*

1. INTRODUCTION

Before the COVID-19 pandemic, the human resource department in any company was digitalized at a certain level and the majority of documents where still signed personally and there were stacks of paperwork and filles in the archive. No one digitalized the information because the was no need and the statistics show that more than 70% only knew the basics about computer programs and they do not have the necessary skills to create automate situation even for a simple .xls file. Over time and due to the pandemic harnessing abilities, such as introduction information in database, manipulating information, data analysis and so on became a necessary requirement in a job interview. In other words, any new employ needs to know how to manipulate and study the data so they can improve and produce more money to the company. The company employees that were hired and did not possess the necessary knowledge were sent to courses in other companies to learn and improve their work. This represents an evolution on the working market, but it also represents a huge risk due to the fact that these companies can recruit their students while teaching them. The latest statistics show that the younger people change their job often. They want to build a career till they are 35, get married between 35 and 40 and have children after 40 years. This trend in 2022 became more and more realistic because people want to have experience before embarking on a long experience. The fact that they can work from everywhere in the world mean that they can live in paradise islands and still do the job they most desire without any restrains.

If in the past the young people in Romania where stressed because they stuck to acquire a lot of experience before they could reach a certain lifestyle and could move to other cities after a certain age, nowadays the multi-national companies agreed to grant them full trust and allow them to work from anywhere as long as they do their job. Who wouldn’t love to do that? [1]

2. WHAT DID THE COVID-19 PANDEMIC CHANGE IN THE HUMAN RESOURCES MANAGEMENT IN A MULTINATIONAL COMPANY?

After the total lockdown in the world due to the COVID-19 pandemic, the human resource market shifted its course and started developing new remote departments so it can sustain its new way of doing business. At the same time the smart equipment market went sky high even if the demand was high before. All the industries demanded the best hardware equipment to sustain long working hours from home and thus a new demand appeared on the market: data analysis engineer. As we can observe in the following graphic, there is a growth tendency within the data analysis engineer and an involution on logistics. In other words, we digitalized our work more and we can create digital reports faster and way more efficient, thus there is no need for a growth of personnel on logistics [2]. (Fig. 1)

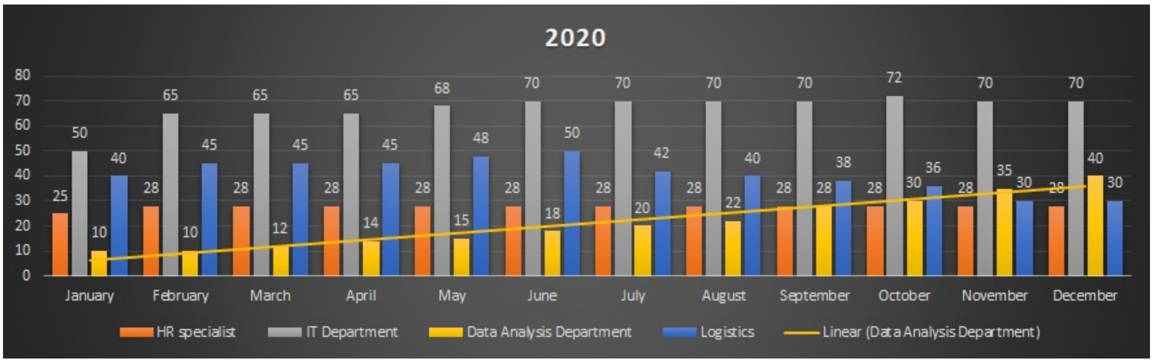

FIG.1 Demand for Data Analysis specialist in 2020

In 2021 the demand for analysts grew even more, thus other departments in a company were reduced due to the fact that these people can process a large volume of data in any department and had better and faster results. To counter this high growth personnel from the other departments took advantage of the online courses which were used everywhere because of the pandemic and gain knowledge in computers and databases. Even though they did the basics, it improved their work and understanding the importance of technology and why do we need so many engineers in a company. It is without any doubt that the necessity will grow even more (Fig. 2.)

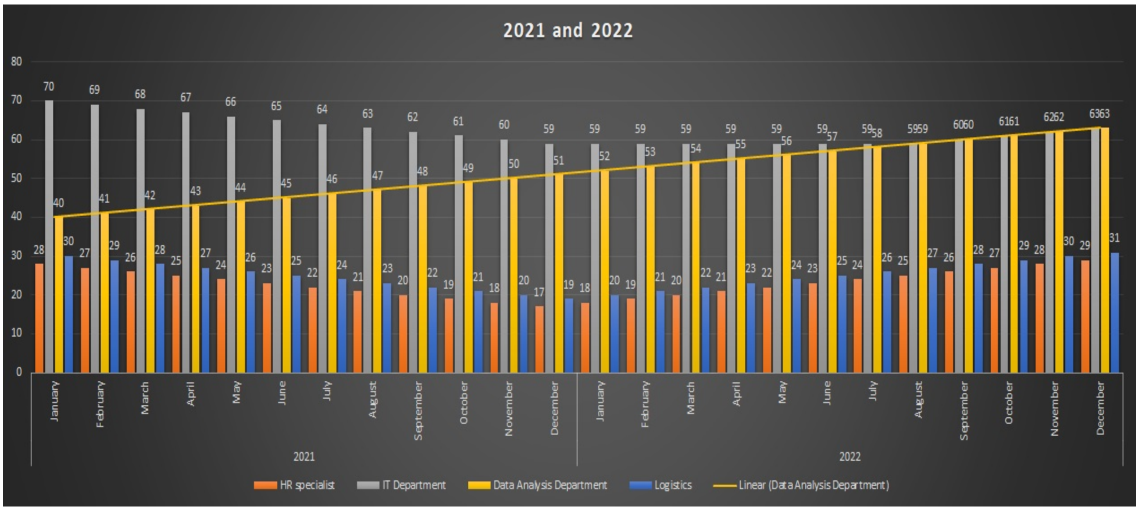

FIG. 2 Increase in data analysis between 2021 and 2022

At the beginning of 2022, we can observe an increase on all types of personnel, meaning that the industry is coming back even stronger than before. This is a result of hiring more engineers that process data and made estimations on the market in every day thus having the worst-case scenario prepared and everything that was over it meth an evolution in the company [3][4].

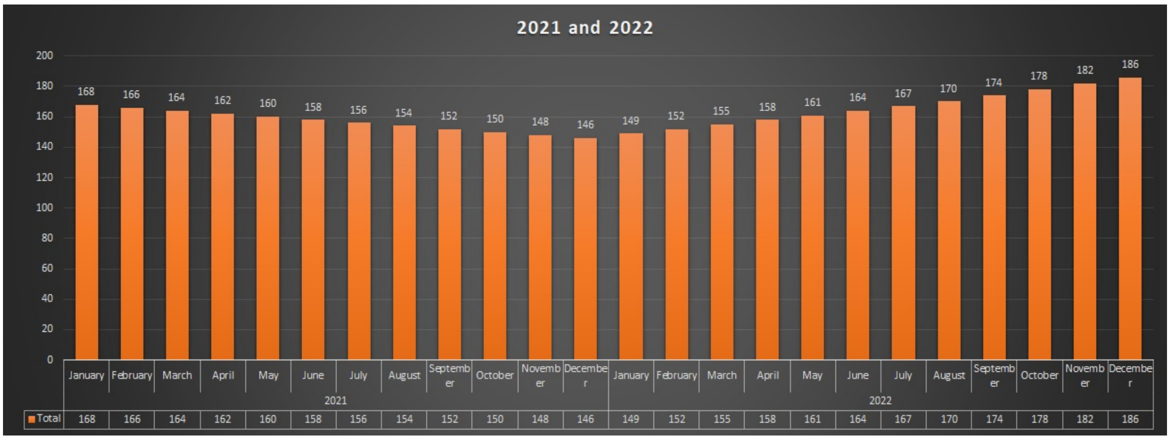

FIG. 3 Total personnel in multinational companies during the COVID pandemic in 2021 and 2022

From the looks on the total personnel graphic we can observe that at the begging of 2022 the human resource department has increasingly upgraded its hiring capacity. The companies demand to evolve and increase their budget in order to hire a specialist that can do the job faster and more efficient. At the same pace, other engineers create statistics on growth and possible evolution in real time, thus the company board have all the details the approve any changes, but in the same time the human resources department also see the results of their work. This helps improve their recruiting abilities from month to month.

3. A THEORETICAL PERSPECTIVE ON HUMAN RESOURCE MANAGEMENT

3.1 How Does Digital Human Resource Management Work in the 21st Century?

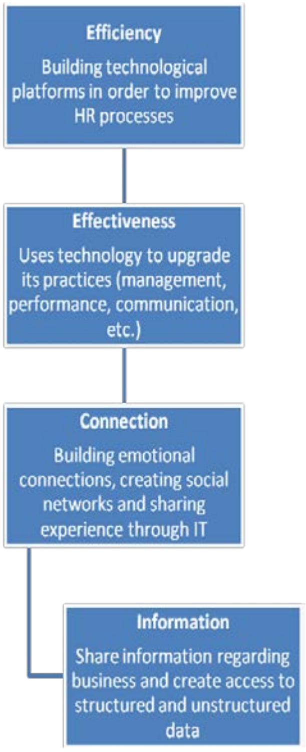

FIG. 4 Framework for the 4th Industrial Revolution (The 4th Industrial Revolution changed the organization, society, operating structure of the organization, life style of employees, etc)

With the help of digital processes, employees will now fully know about the recruitment process, the time spent to find the adequate person for the job and the possibility to transform into the best version of themselves, but at the same time, a company's productivity is likely to increase due to the fact that they have more and more trained specialists.

3.2 Basic Requirements for the Digitalization of Human Resources Departments

Over the years, human resource management evolved from conventional to high tech software that generates and filters information according to employer needs [5][6].

A. A digital workforce

In the new millennial era, the current generations are already considered a digital workforce. This is due to the fact that they have smartphones and internet connected devices that are synchronized with web-based applications and are used on a daily basis for everyday tasks. Having such technology at the peak of the eye, the new HR management department is embedded with mobile apps, design thinking, video, behavioral economics, and the use of system analytics.

B. **Digital work and tasks**

All company employees must have access to the online platform, being able to read tasks and use the company software to file complaints regarding the system's functionality, so that everything that is introduced in the database is live and the CEO may map of the whole situation.

Having live access to such data could lead to an evolution of the company and could also help us escape dangerous situations such as a market failure.[7][8][9]

C. **Digital support management**

This involves planning, implementing, and using digital technologies to support the Human Resources Department activities:

- payroll processing;
- reward and compensation;
- performance management;
- training;
- development.

D. Updated hr technology

There is a huge change in conventional Human Resources, in other words going from local networks to cloud-based systems. Computers transformed into tablets and smartphones and social platforms became important tools in recruiting new personnel.

3.3 Benefits of Digital Human Resource Management

OLD HR RULES	NEW HR RULES
1. HR Department focuses on process design and harmonization to create standard HR practice.	1. HR department focuses on optimizing employers' productivity, teamwork, engagement, and career growth.
2. HR selects a cloud-based vendor and implements out-of-the-box practices to create scale.	2. HR builds innovative, company-specific programs, and leverages the platform for scale.
3. HR centre of excellence focus on process design and process excellence.	3. HR centre focuses on excellence leverage, AI, Chat, APPS, and other advanced technology.
4. HR focuses on self-service as way to scale service and support.	4. HR focuses on enablement to help people to get work done in more effective way.
5. HR programs are designed for scale and consistency around the world.	5. HR programs target employees' segments, personae, and specific groups [10][11][12].

4. CONCLUSIONS

The digitalization of Human Resource Management (HRM) is considered to be the basic need of any business organization today. There are many organizations that have a long way to go before they are able to adopt the new technology for digitalization. Digital HRM maintains a strong relationship between management and employees. The present study has highlighted the importance of digital HRM: it enhances the recruitment process by employing more specialists to create applications and thus leads to self-development. In other words, companies would hire a number of IT and data analysis specialists who produce software to improve productivity in every department of the company. The scenario presented earlier is living proof that multinational companies change their HR strategy and their progress is faster than ever.

As a main conclusion, the use of digital Human Resources through social media, internet, AI and other organizational technologies can maintain or improve the recruitment process and improve the standards regarding the employees.

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