Data evaluation for identifying meaningful engineering characteristics of the flexible panels used for aerial module for pedological drought

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ABSTRACT – REZUMAT

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The existing worldwide information related to the aerial modules used for transporting mulching substances is particularly pernicious. Thus, at this moment, on an international level, cargo transport solutions for mulching lands affected by soil drought are limited to identifying the maximum value of the load (1250–4500 kgf), the type of raw material from which it is made (polyamide), the shape (quadratic, octagonal, rectangular) and its dimensions (2.13 m × 3 m for a maximum transport capacity of 1250 kgf – 5.5 m × 5.5 m for a maximum transport capacity of 4500 kgf). Also, among the solutions for protecting lands affected by wildfires, the sowing technique with the help of drones was identified. Thus, the seeded compost balls are allowed to fall by gravity from the drones, being released randomly in the demineralised areas, difficult to reach by land transport. The paper presents the latest research of INCDTP specialists – carried out in the national premiere – regarding the iterative-incremental development of a multi-role collapsible aerial module that has as its theatre of operations the desertified areas (due to the pedological drought) of Romania. The central point of the research is focused on: i) the experimentation in the accredited laboratories of INCDTP, of flexible panels joined by mechanical-textile technology; ii) statistical analysis of values; iii) predicting the minimum values of the physical-mechanical characteristics of the composite material.

Keywords: *composite materials, flexible panels assembly, descriptive statistics, normal distribution, ultimate load coefficient*

Evaluarea datelor pentru identificarea caracteristicilor inginereşti semnificative ale panourilor flexibile utilizate ca modul aerian pentru seceta pedologică

Informațiile existente pe plan mondial legate de modulele aeriene utilizate pentru transportul substanțelor de mulcire sunt deosebit de pernicioase. Astfel, în acest moment, pe plan internaţional soluţiile de transport cargo pentru mulcirea terenurilor atinse de seceta pedologică se rezumă la identificarea valorii maxime a încărcăturii (1250–4500 kgf), tipul de materie primă din care este realizat (poliamida), forma (pătratică, octogonală, dreptunghiulară) și dimensiunile acestuia (2.13 m × 3 m pentru o capacitate de transport de maxim 1250 kgf – 5,5 m × 5,5 m pentru o capacitate de transport de maximum 4500 kgf). De asemenea, printre soluțiile de protecţie a terenurilor afectate în urma incendiilor de vegetaţie, s-a identificat tehnica de însămânţare cu ajutorul dronelor. Astfel, bile de compost însămânţat sunt lăsate să cadă gravitaţional din drone, fiind eliberate aleatoriu în zonele demineralizate, greu accesibile prin transport terestru. Lucrarea prezintă ultimele cercetări ale specialiștilor din INCDTP – realizate în premieră națională – referitoare la dezvoltarea iterativ-incrementală a unui modul aerian colapsabil multirole, ce are ca teatru de operațiuni zonele deşertificate (datorate secetei pedologice) ale României. Punctul central al cercetărilor este axat pe: i) experimentarea în laboratoarele acreditate ale INCDTP, a panourilor flexibile îmbinate prin tehnologie mecano-textilă; ii) analiza statistică a valorilor; iii) predicţionarea valorilor minimale ale caracteristicilor fizico-mecanice ale materialului compozit.

Cuvinte-cheie: *materiale compozite, asamblare panouri flexibile, statistica descriptivă, distribuţie normală, coeficient de sarcina ultim*

INTRODUCTION

No country is immune to disasters. Recent events: war, migration, wildfires, flood, earthquakes, global pandemic, medical isolation, and supplies have proven that disasters know no borders and can simultaneously hit one or several countries without warning [1–3]. Infectious disease COVID-19 caused by a novel virus unknown to infect humans before December 2019, broke out into a global pandemic in a matter of a few months of isolation for people across the world [4, 5]. Another adverse event witnessed in recent years is related to extreme weather and other disasters caused by natural hazards, some of which occurred with new intensity and patterns [6–8]. Many regions from the entire plan have faced life-threatening heatwaves and huge floods that disrupted critical infrastructure and consequently, restrictions on the supply of food and medicines to the affected population So, accidental, natural hazards and the human-induces disasters threaten people, the environment, and property, and cultural heritage [2, 7, 9]. A robust understanding of disaster risks is considered essential to address the risks effectively by framing risk management policies [10, 11]. The Union Civil Protection Mechanism (UCPM) is at the heart of cooperation between the EU Member States on civil protection against natural hazards and man-made threats [2, 12], by regularly exchanging information on disaster risks, running exercises together to better prepare for emergencies, and pool rescue teams and equipment that can be rapidly mobilized when a disaster overwhelms a Member State or any other country in the world [8, 13, 14]. In recent years, the changing risk landscape, the experience of several consecutive deadly wildfire seasons, and, most recently, a pandemic have revealed the limitations of the Mechanism. In addition to funding, the EU macro-regional strategies [2, 11] provide useful networks for regional coordination of investment in disaster risk management for implementing strategic projects and for cooperating across sectors, governance levels, and stakeholders. At the national level, the Romanian Air Force operates at Base 90 Air Transport (military transport aviation), which performs transport missions, both in the national airspace and in crisis or conflict zones (under UN, OSCE, or NATO mandate) or in support of local institutions and authorities in civil emergencies and aeromedical evacuation. It is a relatively new activity in our country since it is equipped with C-130 Hercules (in service since 1996), C27 J SPARTAN (in service since 1996) aircraft, and IAR-330 Puma SOCAT and IAR-330 SOCAT helicopters (both in service since 1995) that ensure airdropping military forces, equipment, and materials, vehicles, light artillery, light helicopters, etc.). The main problems developed within Romanian Air Transport missions refer to improved interoperability within the ground-handling domain (Lighthouse Project – LHP, 2023). On the other side, in 2023, air transport missions were carried out to respond to emergencies caused by: natural disasters (fires – destination: military airport Elefsis - Greece and floods – destination Benghazi – Libya) and medical problems (humanitarian mission in Germany). Pooling together civil capacities and capabilities allows for a stronger and more coherent societal response for diminishing the losses caused by disasters. The paper presents the research carried out by INCDTP specialists for the incremental development – in the national premiere – of a functional model of the multi-role collapsible aerial module used to combat soil drought. The special results obtained so far have led to the conclusion that the functional model of the multi-role collapsible aerial module used to combat pedological drought must: be made of composite material, with 100% PES woven structure reinforcement, and its covering should be made with PVC and have the type-dimensions characterized as follows: 4 square panels with dimensions of 3000 ± 20 × 3000 ± 20 mm, 8 quarter ellipses with a length of 380 ± 5 mm and 4 rectangular panels with dimensions of 1000 ± 10 × 960 ± 10 mm. The work focuses on predicting the minimal physical-mechanical characteristics of a composite material to be considered an integral part of the functional model.

MATERIALS AND METHOD

The composite material was tested in INCDTP laboratories, accredited according to SR EN ISO 17025/2018. Static tests are well-known in the field of engineering, for which it was not considered necessary to explain the need to perform them. However, kinematic testing, being complex and not very used in the textile field, requires clarification and assimilation, even at the definition level, of certain specific terms. Thus, as previously highlighted, the functional model of the multi-role collapsible aerial module for pedological drought requires the use of composite material, for which the behaviour in real conditions of use is not known, or, using the language of fluid mechanics, the behaviour of the loaded structural element, in the area of section changes where stress distributions appear characterized by peak stress the reaches higher values than the nominal stress, so a stress concentration. The presence of tension concentrators reduces the resistance of the structures in a dynamic stress regime, especially with variable stress (the case of the multi-role module (figure 1). Practically, any geometric discontinuity on the MF surface can act as a primer for a fatigue crack.

It is immediately noticeable that the direction of the stress flow, so the force transmission from one point to another of the MF is smooth because the inner and outer corners are smoothed. Moreover, to be able to determine the behaviour of the composite material – without continuity – it was considered necessary to describe the behaviour of thin profiles, which can be assimilated to films deposited on textile support – 4 panels must be made, as an integral part of the functional model of the aerial module. It is known

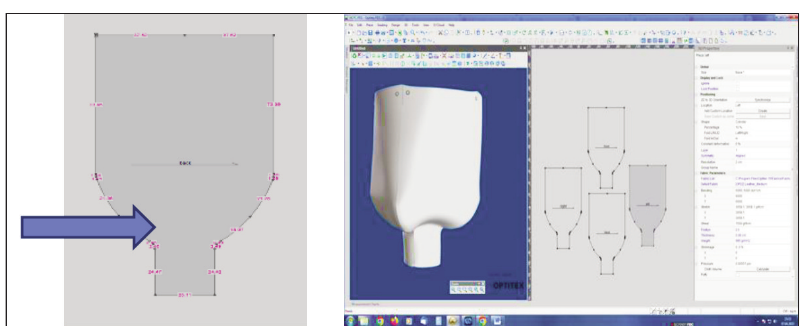
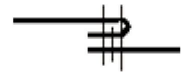
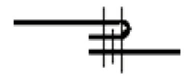


Fig. 1. Photos of: *a* – panel - multi-role collapsible module for pedological drought; *b* – the 3D model obtained by assembling the panels

Table 1

PANELS MADE OF COMPOSITE MATERIALS JOINED BY SEWING DIFFERENT SEAMS			
Variant	**Composite material identifier**	**Stitch code**	**Representation**
CM1	100% PA6.6 - coated	301-LSb-3	
CM2	100% PA6.6 - coated	301-LSb-4	
CM3	80% p-aramid/20% PES	301-LSb-3	
CM4	80% p-aramid/20% PES	301-LSb-4	

that, for non-conventional materials (composite material type, from the textile structure with polymer coating), there is no continuity, so the behaviour of the material cannot be anticipated.

In this case, the equations for the prediction of fatigue resistance have no solutions, except in the situation where logical restrictions are imposed related to constraints, limitations of the stress intervals, variations in tangential stresses, values of shock forces, etc. For example, in the case of the iterative analysis, to solve the integral equation where it is considered that there is a variation of the tangential stress, the relationship can be used:

$$\tau_0 = 0.0225\,\rho V_\infty^2 \left(\frac{\nu}{V_\infty \delta}\right)^{\frac{1}{4}} \qquad (1)$$

which solves the integer-differential relation very simply:

$$\frac{d}{dx}\int_0^\delta \rho v_x^2 dy - V_\infty \frac{d}{dx}\int_0^\delta \rho v_x dy = -\tau_0 \qquad (2)$$

with ρ for loose mulch is 100 kg/m^3, V_∞ – the speed of the current in which the MF acts, 25 m/s, ν – the kinematic coefficient of viscosity, $7 \cdot 10^{-5}$ m^2/s, from which it immediately follows:

$$\int_0^\delta \rho v_x dy - \int_0^\delta \rho V_\infty \left(\frac{y}{\delta}\right)^{\frac{1}{7}} dy = \frac{7}{8}\rho V_\infty \delta$$
$$\int_0^\delta \rho v_x^2 dy - \int_0^\delta \rho V_\infty^2 \left(\frac{y}{\delta}\right)^{\frac{2}{7}} dy = \frac{7}{9}\rho V_\infty^2 \delta \qquad (3)$$

So:

$$\frac{7}{72}\rho V_\infty \frac{d\delta}{dx} = \tau_0 = 0.0225\,\rho V_\infty^2 \left(\frac{\nu}{V_\infty \delta}\right)^{1/4}$$
$$\delta^{1/4} d\delta = 0.0225\,\frac{72}{7}\left(\frac{\nu}{V_\infty}\right)^{1/4} dx \qquad (4)$$
$$\delta = 0.37\left(\frac{\nu}{V_\infty x}\right)^{1/5} x \;\Rightarrow\; x = 3.46\left(\frac{V_\infty}{\nu}\right)^{1/4} \delta^{5/4}$$

x is an abscissa measured along a portion of the MF (for example, for the square area, the side is 0.80 m).

It results from the need to study the behaviour of the composite material also for discontinuous surfaces, that is, exactly where the flexible panels are joined. Thus, 4 panels made of composite materials with textile matrices (panel 1) were tested, which were joined by sewing, using 301-LSb-3 and 301-LSb-4 seams (table 1). The experiments were carried out in the accredited laboratories of INCDTP, the resulting values being presented in table 2, for each test (variable) determining 25 values.

The database included 4 variables (100 values) employing descriptive statistics:

- the parameters that show the extent to which the data are homogeneous or not were determined.
- coefficients of variability were calculated to determine the homogeneity and heterogeneity of the groups.
- the asymmetry of the distribution was highlighted, with the predominance of frequencies or variables.

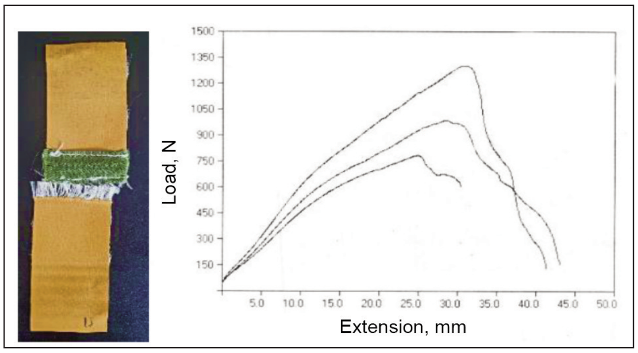
The images obtained and the graphs drawn with the help of the digital tool included in the test device are shown selectively, in figure 2, and the values obtained for the 4 panels joined by the 2 types of stitches are presented in table 1.

RESULTS AND DISCUSSIONS

The descriptive statistical analysis report suggests the following:

- For the synthetic indicators of the variant: the values obtained for the coefficient of variability of the studied variables demonstrate that $V \leq 3\%$, so the series are very homogeneous, with very little variation, the average being very representative. The quartiles highlight the fact that approx. 60% of the values/characteristics are placed between the 75th percentile and the maximum value.
- Asymmetry indicators by using the relationships $\bar{x} > Me > Mo$ and $\bar{x} < Me < Mo$ taking into account the Skewness and Kurtosis values, it can be appreciated that for all the variables studied, the series shows right or negative asymmetry, with large values predominating.

To ensure the operational safety of the multi-role collapsible aerial module (the elimination of tension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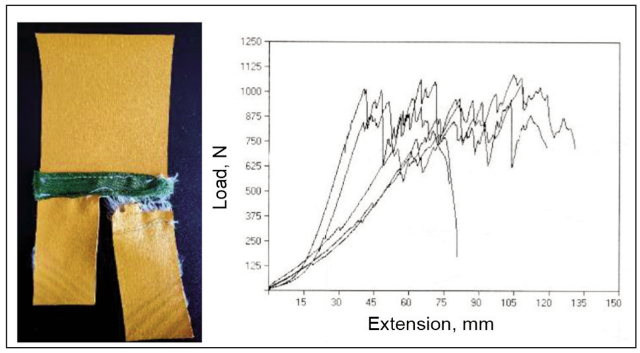
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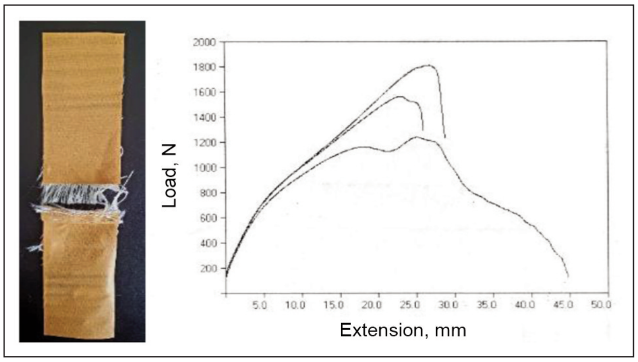
a *b*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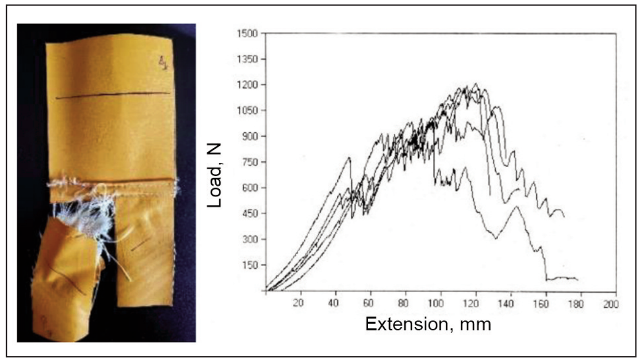
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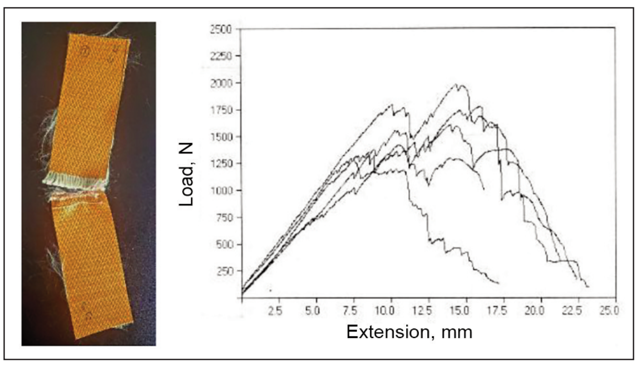
c *d*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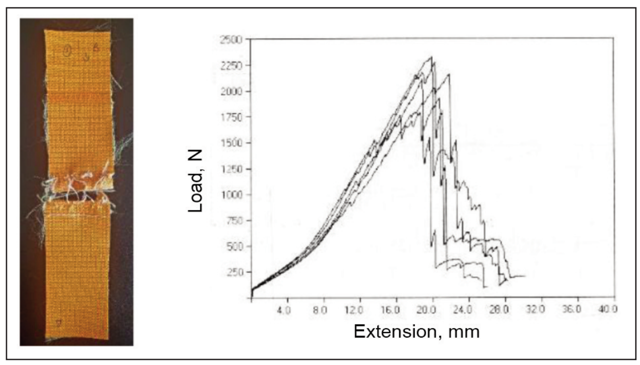
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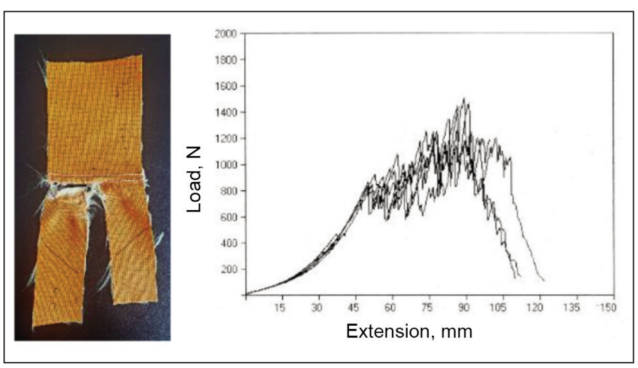
e *f*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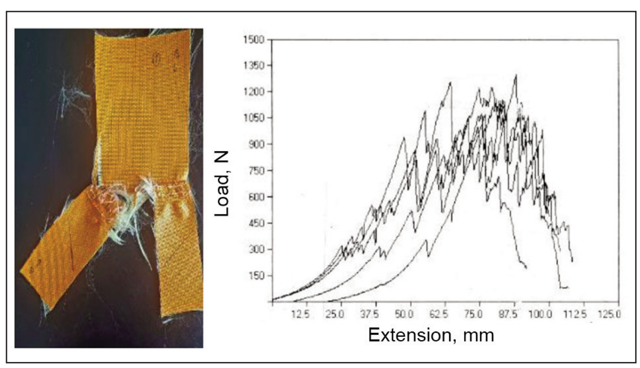
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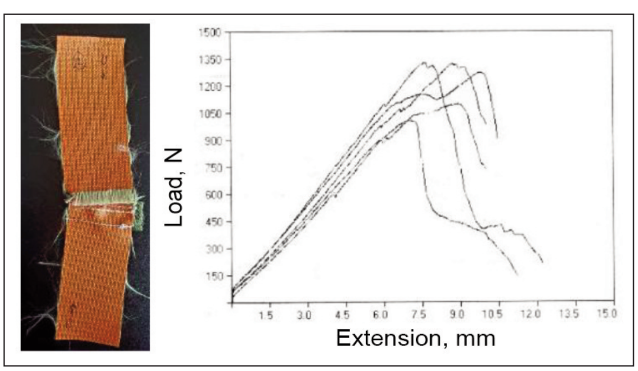
g *h*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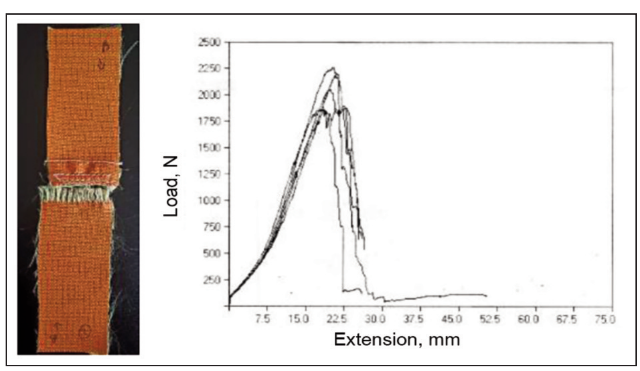
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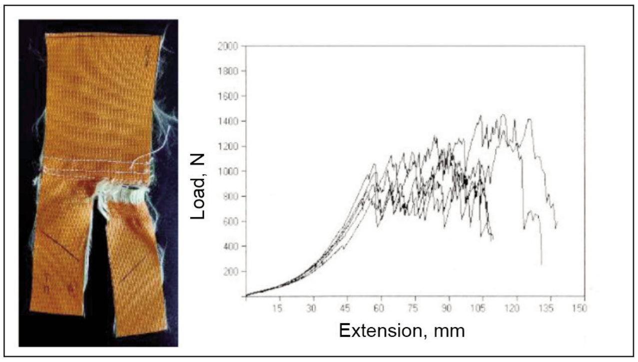
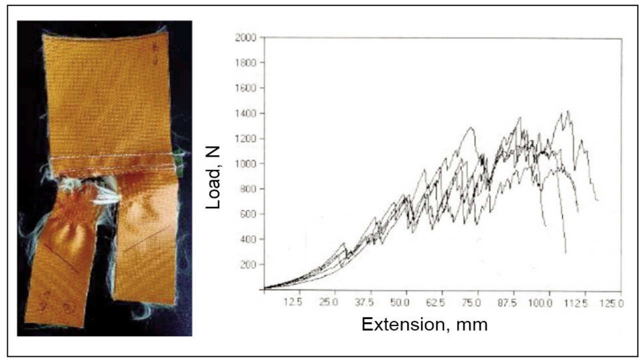
i *j*



k



l

Fig. 2. Photos of: *a* – the maximum breaking force with the strip-shaped test specimen and the corresponding stress-elongation diagrams CM1 – both joint points arranged in the weft direction; *b* – the tear force with the wing-shaped test specimen and the corresponding stress-elongation diagrams CM1 – both joint points arranged in the warp direction; *c* – the maximum breaking force with the strip-shape test specimen and the corresponding stress-elongation diagrams CM2 – both joint points arranged in the warp direction; *d* – the tear force with the wing-shape test specimen and the corresponding stress-elongation diagrams CM2 – both joint points arranged in the weft direction; *e* – the maximum breaking force with the strip-shaped test specimen and the corresponding stress-elongation diagrams CM3 – both joint points arranged in the warp direction; *f* – the maximum breaking force with the strip-shaped test specimen and the corresponding stress-elongation diagrams CM3 – both joint points arranged in the weft direction; *g* – the tear force with the wing-shaped specimen and the corresponding stress-elongation diagrams CM3 – both joint points arranged in the warp direction; *h* – the tear force with the wing-shaped specimen and the corresponding stress-elongation diagrams CM3 – both joint points arranged in the weft direction; *i* – the maximum breaking force with the strip-shaped specimen and the corresponding stress-elongation diagrams CM4 – both joint points arranged in the warp direction; *j* – the maximum breaking force with the strip-shaped specimen and the corresponding stress-elongation diagrams CM4 – both joint points arranged in the weft direction; *k* – the tear force with the wing-shaped specimen and the corresponding stress-elongation diagrams CM4 – both joint points arranged in the warp direction; *l* – the tearing force with wing-type specimen and corresponding CM4 stress-elongation diagrams – both joint points arranged in the weft direction

Table 2

RESULTING VALUES FOR EACH TEST (VARIABLE)				
Tests	**Mean**			
	CM1	**CM2**	**CM3**	**CM4**
	matrix: 100% PA6.6	**matrix: 100% PA6.6**	**matrix: 80% p-aramid / 20% PES**	**matrix: 80% p-aramid / 20% PES**
Determination of the maximum strength by the strip test method (N), warp-warp/ weft-weft points	1075/1080	1600/1700	1850/2000	1200/2000
Determination of the elongation at maximum force by the strip test method (%), warp-warp/ weft-weft points	10/11	12/12	8/11	4/7
Determination of the tearing force of the specimens (wing type) (N), warp-warp/ weft-weft points	1000/1050	1200/1250	1400/1300	1000/1000

concentrators that appear under dynamic stress and the determination of the values of the length and the number of suspensions connecting with the aircraft-helicopter), it was considered necessary to determine the values for the tearing force of the specimens, wing-shaped. The recorded values do not differ significantly from one panel to another, so neither the positioning of the landmarks nor the type of joint does not influence this characteristic.

The practice of designing aerial systems has required the consideration of some coefficients specific to the field because the dynamic conditions in which it develops are unpredictable and discontinuous and can cause its collapse. Additionally, the behaviour of the textile matrices and implicitly of the composite material in real conditions of use can be predicted by using the strength loss coefficients. In this regard, for the dimensioning of the panels and the determination of the design parameters, the input data must include the values of the ultimate load coefficient (table 3).

The ultimate load factor of 1.85 was considered when designing and making the functional model of the multi-role collapsible aerial module, in the sense of

Table 3

DESIGN PARAMETERS OF THE PANELS			
No.	Name	Justification/Motivation	Value
Load coefficients, $C_i = C_s \cdot C_d \cdot C_a$			
1	Safety coefficient, C_s	the possibility of failure or failure of an element (subassembly)	1.45
2	The dynamic loading coefficient, C_d	the effects of dynamic loads	1.30
3	Asymmetric loading coefficient, C_a	uniform distribution of forces, regardless of the location of the section perpendicular to the axis of symmetry	1.40
Resistance loss coefficients $C_p = C_r \cdot C_o \cdot C_m$			
4	Coefficient of loss of resistance at joints, C_r	making "joints of equal strength"	2.50
5	Resistance loss coefficient due to fatigue, C_o	the effects of multiple uses	0.95
6	Resistance loss coefficient due to environmental factors, C_m	the effects of solar radiation and very high temperatures	0.80

developing and determining the level of resistance of the analysed assembly, to the effects of specific loading conditions and the effects of mechanical and environmental factors.

CONCLUSIONS

The ultimate load coefficient, which defines the resistance level of the analysed assembly, and includes both the effects of specific loading conditions and the effects of mechanical and environmental factors, must be considered when designing the aerial module.

The proven experience of INCDTP specialists in digital design, realization, and experimentation of various systems used in the aeronautical field (variation range of kinematic and dynamic demands, system stability, shock resistance, suspension convergence coefficient, etc.), allowed the prediction of the variation ranges of the values of the physical-mechanical characteristics of the composite material, as an integral part of the aerial module used to combat soil drought. Thus, it must present the following minimum physical-mechanical static characteristics: maximum breaking force warp/weft, min. 2500 N, elongation at break, max. 45%, tearing force, min. 200 N. These values will also determine a technical reserve of at least 100 consecutive uses (for a transport mass of min. 2500 kg). However, in the system complex, all aspects and components of the whole must be analysed very carefully, because a simple analytical omission (lack of support net, suspension convergence, performance reproducibility) can cause module damage and even premature disconnection from the aircraft.

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REFERENCES

[1] European Parliament and Council, *Directive 2000/60/EC on establishing a framework for community action in the field of water policy*, 2000

[2] IOGP, *Environmental fates and effects of ocean discharge of drill cuttings and associated drilling fluids from offshore oil and gas operations. Report 543*, 2016

[3] European Parliament and of the Council, *Directive 2004/35/EC on environmental liability about the prevention and remedying of environmental damage (Environmental Liability Directive)*, 2004

[4] European Commission, *Best Available Techniques Guidance Document on upstream hydrocarbon exploration and production*, 25 February 2019, 124-193

[5] Leaning, J., Guha-Sapir, D., *Natural disasters, armed conflict, and public health,* In: New England Journal of Medicine, 2013, 369, 1836–1842, https://doi.org/10.1056/NEJMra1109877

[6] McIlhagger, R., Quinn, J.P., McIlhagger, A.T., Wilson, S., Simpson, D., Wenger, W., *The influence of binder tow density on the mechanical properties of spatially reinforced composites. Part 2 - Mechanical properties*, In: Composites: Part A, 2008, 39, 334–341

[7] Ratna, D., Chongdar, T.K., Chacraborty, B.C., *Mechanical Characterization of New Glass Fiber Reinforced Epoxy Composite,* In: Polymer Composite, 2004, 25, 165–171

[8] Kendon, E.J., Roberts, N.M., Fowler, H.J., Roberts, M.J., Chan, S.C., Senior, C.A., *Heavier summer downpours with climate change revealed by weather forecast resolution model,* In: Nature Climate Change, 2019, 4, 7, 570–576, https://doi.org/10.1038/nclimate2258

[9] Scardino, F., *An Introduction to Textile Structures and Their Behavior,* In: Textile Structural Composites, Composite Materials Series, eds. Chou T.W. and Ko F.K, Elsevier, 1989, 3
[10] Gibson, L.B., Cumiskey, S., Macosko, C.W., *Compaction of Fiber Reinforcements,* In: Polymer Composites, 2002, 23, 307–318
[11] Carayannis, E.G., Grigoroudis, E., Campbell, D.F.J., Meissner D., Stamati, D., *The ecosystem as helix: an exploratory theory-building study of regional co-opetitive entrepreneurial ecosystems as Quadruple/Quintuple Helix Innovation Models,* In: R&D Management, Special Issue: Beyond "Triple Helix" toward "Quadruple Helix" Models in Regional Innovation Systems: Implications for Theory and Practice, Wiley Online Library, 2018, 48, 1, 148–162
[12] Kendon, E.J., Roberts, N.M., Fowler, H.J., Roberts, M.J., Chan, S.C., Senior, C.A., *Heavier summer downpours with climate change revealed by weather forecast resolution model,* In: Nature Climate Change, 2019, 4, 7, 570–576, https://doi.org/ 10.1038/nclimate2258
[13] McAdam, M., Debackere K., *Beyond 'triple helix' toward 'quadruple helix' models in regional innovation systems: implications for theory and practice*, In: R&D Management, Special Issue: Beyond "Triple Helix" toward "Quadruple Helix" Models in Regional Innovation Systems: Implications for Theory and Practice, Wiley Online Library, 2018, 48, 1, 3–6
[14] Niculescu, C., Salistean, A., Butoescu, V., Olaru, S., *Equipment for paraglider – the emergency parachute*, In: Industria Textila, 2010, 61, 1, 11–16

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