A methodological approach to identifying the priority of scout/attack and attack unmanned aerial vehicles

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Abstract. *The* **Aim** *of this paper is to develop an evaluation scheme of priority indicators for scout/attack and attack unmanned aerial vehicles (UAVs).* **Methods.** *The evaluation scheme of UAV priority indicators was developed using the mathematics of metrical analysis and known expert estimates of indicators for some UAVs.* **Results.** *Development of UAV priority indicators evaluation scheme.* **Conclusions.** *The suggested UAV priority evaluation scheme can be used for rational decision-making when creating (acquiring) UAVs.*

Keywords: *selection of the model of unmanned aerial vehicle, priority estimation, unmanned aerial vehicle system, scout/strike unmanned aerial vehicle, strike unmanned aerial vehicle, estimates, metrical analysis, expert estimate*

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Introduction

The selection problem is of great importance both while acquiring certain products, and while developing them, especially complex technical systems (CTS), primarily military ones.

Nowadays, aircraft and weapons systems are designed based on the systems approach with wide use of mathematical and semirealistic simulation with subsequent ground and field tests [1]. That, for instance, was demonstrated in the presentations of the Anniversary National Science and Technology Conference Aviation Systems in the XXI Century on May 26 and 27, 2016, organized by GosNIIAS. The conference hosted a number of presentations dedicated, for instance, to the design of unmanned aerial vehicles (UAVs) and missile equipment. According to one of them, a model system for design characteristics synthesis had been developed for the purpose of researching the effect of the design parameters on the conceptual design of UAVs. The system includes the basic calculations of flight and economic characteristics, which enables comparative analysis of various types of UAVs ensuring visualization of the obtained characteristics and estimates. Thus, it was attempted to analyze the effect of new and emerging technologies on the conceptual design of UAVs [2]. Another presentation dealt with an approach to the system concept definition and general design of unmanned aircraft systems enabling reconnaissance and attack missions. A research method was suggested, a structure diagram of a system of models was developed, and a system of operational efficiency criteria was developed and substantiated [3].

There is a wide range of scientific and technical literature dedicated to both the design and the selection of optimal technical solutions when creating complex systems based, among other things, on the assessment of the quality and engineering level (EL). The bibliographical description of the sources is given in monographs [4, 5]. The relevance of scientifically substantiated selection as part of new technology development is currently supported by the publication of a number of monographs dealing with the methodology of aircraft engineering [6 – 9]. In practice, the selection of aircraft and weapons systems heavily relies on benchmarking, whereas the comparison of same-purpose items involves criteria for comparing the merits of items in terms of functional, technical and economic indicators [8, 10]. Thus, in [10], there is an example of selection of the best naval missile system based on the comparison of characteristics rendered in a single data format taking into consideration the cost of each element of the system and its life cycle as a whole. In the authors' opinion, under time constraints, implementing such approach allows optimizing the selection of a missile system and saving significant funds. Materials cited in [11] provide an insight into the complexity of the process of selection between the Rafale and the Typhoon aircraft by India. Such indicators were taken into consideration as the operational effectiveness against ground targets and in air-to-air combat, operating properties, sophistication of avionics, price, and time of project delivery. As the result, India chose the Rafale 4-th generation multirole fighter ([Delivery of the first Rafale fighter to India]. Ekspress-informatsia 2020;13:2). Field testing is an efficient tool of selecting CTS.

It must also be noted that the current stage of development of airborne armament is characterized by a significant growth of the scope of missions assigned to a strike aircraft system, and stricter requirements for the performance of upgraded and newly developed high-precision weapons amidst significant budgetary restraints. Under such conditions, the requirement of reduced time of development and selection of optimal solution as regards weapons systems actualizes the development of automated decision support systems. It is suggested to understand the solution as a man-machine

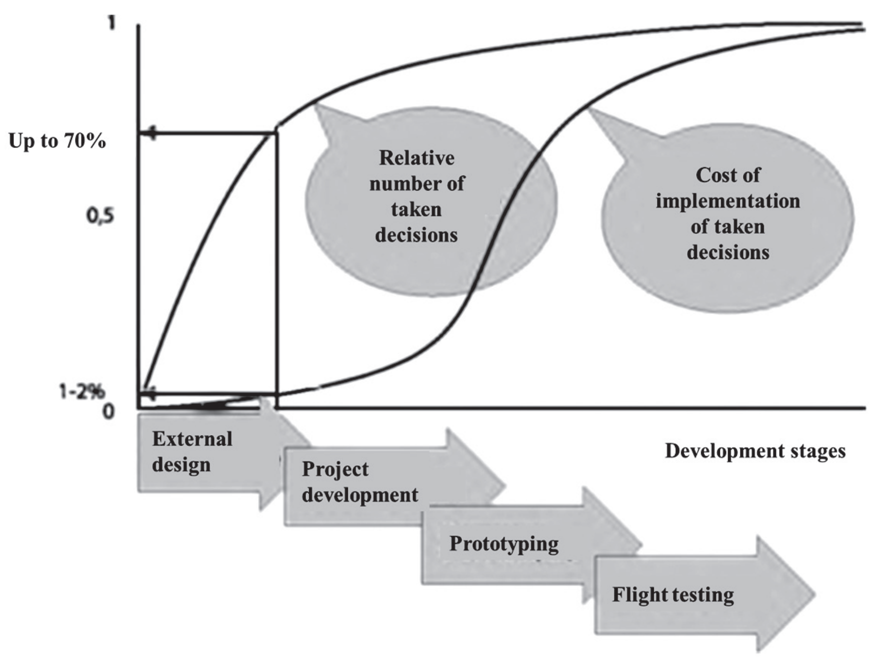

Figure 1. Significance of made decisions as part of aircraft design

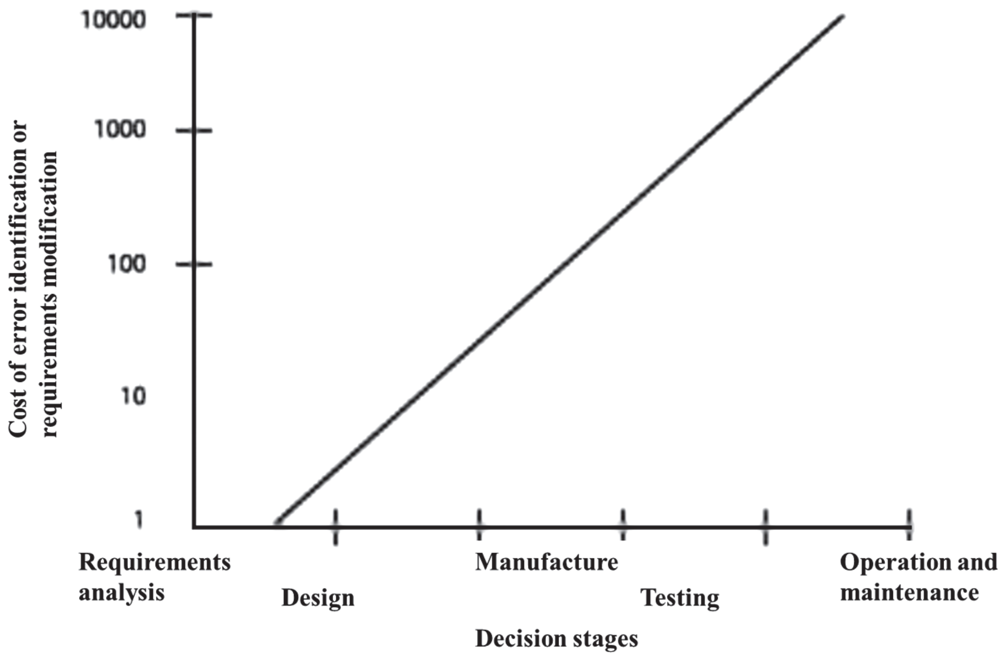

Fig. 2. Relative cost of fault correction

system that allows using both objective, and subjective data for the purpose of analyzing and solving problems, including those poorly formalized. For instance, methods were suggested for selecting the rational concepts of combat aircraft systems and rational airborne armament options based on simulation and assessment of combat effectiveness, decision theory [12-15]. In [16], a method is proposed for selecting the rational types of primary elements of developed weapons and military equipment based on expert estimations and comparison of multicriterial alternatives under uncertainty provided by the hierarchy analysis methods and decision theory. We should also name [5, 6, 17] among the works dedicated to the problem of selection of the best technical solutions, quality evaluation and EL of weapons and military equipment, which includes with the involvement of experts.

The initial stages of design are crucial in terms of defining the conceptual features of newly created products and have a large effect on the quality of the technological groundwork. The conducted systems research aimed at identifying the nature of CTS development and evaluation of their quality and EL has revealed a general trend in the correlation between the estimated effect of decision-making and the amount of incurred costs at various life cycle stages of CTS regardless of the area of scientific and technological activities. In case of aircraft systems [18], the significance of conceptual decisions is as high as 70% of the total number, while the costs are at 2% of the total cost of system development (Fig. 1). In Fig. 1, the relative significance of decision-making is defined as the percentage of made decisions.

The cost of correction of the identified errors rises exponentially in the course of entity development and at the final stage of the project life cycle as compared with the cost of such modifications at the very early stages of its development [19] (Fig. 2).

That is why the initial design stages of CTS, which includes UAV, should be the focus of attention in terms of concept definition, while the process of selection of the rational technical solution is to be regarded as conceptual.

This paper suggests an evaluation scheme of UAV priority indicators based on methods of metrical analysis as applied to scout/attack and attack UAVs with the take-off mass between 300 and 25000 kg or more as one of the most promising types of unmanned craft. The application of methods of metrical analysis with regards to applied multidimensional and multicriterial problems has shown its high efficiency [20 – 22]. As the primary criterion of UAV classification (airframe, engine, navigation and control systems, etc.) this paper considers the takeoff mass (examined in [23 – 26]) that reflects the quality of the adopted design solutions. The mass of a UAV defines its power characteristics, loadlifting capacity and cost of development. An example of such classification for UAV heavier than 100 kg is shown in Table 1 [23].

Table 1. US armed forces UAV classification

Category	Maximum takeoff mass, kg	Maximum altitude (ceiling), m	Flight duration, h
Medium	100 – 1500	3000 – 8000	2 – 24
Medium-altitude long-endurance (MALE)	1500 – 2500	3000 – 8000	12 – 24
High-altitude long-endurance (HALE)	2500 – 5000	5000 – 20 000	12 – 24
Strike/Combat	–	8000 – 12 000	–

The general view of certain scout/attack and attack UAVs is shown in Fig. 3 – 6. The engineering quality of a UAV manifests itself in the novelty and improved performance supported by technological innovation. The level of engineering quality is the property of an item that reflects the degree of incorporation of world's best engineering achievements. In [27], based on the analysis of the primary functions and states inherent to aircraft at various life cycle stages it is suggested to identify the level of engineering quality according to four composite indicators that characterize the design, operational, manufacturing and functional quality. The EL (as the criterion of technical quality) will be understood as a set of properties of an entity that reflect its engineering quality as compared with the reference. Assessing a UAV's EL is especially important both at the stage of concept definition, and the early design stages. In order for a new generation of UAV to be more advanced in comparison with the current one, it is required to ensure a higher EL.

Fig. 3. Heron TP unmanned aerial vehicle (Israel)

Fig. 4. Cloud Shadow unmanned aerial vehicle (China)

Fig. 5. Mantis European unmanned aerial vehicle aircraft (UK)

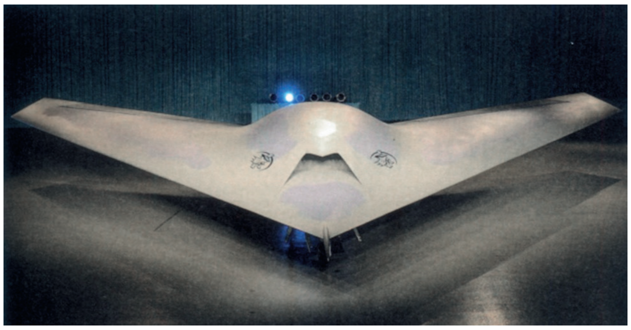

Figure 6. Phantom Ray multi-mission unmanned aerial vehicle (US)

In this paper, for the purpose of identifying the significance of the analyzed UAV in relation to other UAVs (which is equivalent to EL evaluation), whose estimated level is already known, the concept of a UAV's "priority" is introduced.

The suggested UAV priority evaluation method can be used for rational decision-making when creating (acquiring) UAVs.

In this paper, the priority of UAVs is evaluated using the following estimates: takeoff mass, mass of the payload, flight duration, flight distance, cruising speed, flight altitude.

1. Some provisions of metrical analysis used in the evaluation of unmanned aerial vehicle priority

In this paper, the UAVs with no expert estimates are evaluated with the use of an interpolation scheme based on metrical analysis. With the development of computer technology, the problem of data analysis and processing became especially relevant. Metrical analysis enables efficient solution of various problems in respect to functions of many variables without prior definition of the type of functional dependence from the variables, but using only the information from the actual values of function Y_1, …, Y_n, in points X_1, …, X_n [20-22].

1.1. Interpolation of functions of one and several variables using metrical analysis

Interpolation in numerical mathematics is a method of finding the intermediate values of a function based on the available set of known function values in a finite number of points, i.e. the values of function arguments.

We examine a problem associated with functional dependence

$$Y = F\left(X_1,...,X_m\right) = F\left(X\right) \quad (1)$$

where function $F(X)$ is unknown and is to be recovered either in one point X^*, or in a set of specified points based on the known function values Y_k, $k = 1, ..., n$, in fixed points $X_k = \left(X_{k1},...,X_{km}\right)^T$. Point **X** belongs to a unit m-dimensional cube $K \in E^m$ of space E^m.

In space E^m a normed metric is selected:

$$\|X\|^2 = \sum_{j=1}^{m} w_j * X_j^2, \quad (2)$$

where metric weights $w_j \geq 0, \sum_{j=1}^{m} w_j = m.$

Metric weights w_1, …, w_m are values that take into consideration the variation pattern of the examined function following changes in its arguments. They are calculated taking into consideration the mutual arrangement of the interpolation nodes and function values in them. An important part of the suggested metrical analysis is not the a priori definition of the weights that set the norm, but the selection of weights w_j, $j = 1, \ldots, m$, based on the set of known data Y_k, X_k, $k = 1, \ldots, n$.

In order to identify the metric weights, a number of schemes have been developed [20 – 22].

It is required to recover the function value in point X^*.

For that purpose, a matrix of metric uncertainty **W** is compiled for point X^* relative to the assembly of points $X_1, \ldots, X_n$. A matrix of metric uncertainty is a matrix of the dimension of $(n \times n)$ defined by the arrangement of the interpolation nodes $X_1, \ldots, X_n$, the value X^* and metric weights $w_1, \ldots, w_m$:

$$W = \begin{pmatrix} p^2\left(X_1, X^*\right)_w & \left(X_1, X_2\right)_w & \ldots & \left(X_1, X_n\right)_w \\ \left(X_2, X_1\right)_w & p^2\left(X_2, X^*\right)_w & \ldots & \left(X_2, X_n\right)_w \\ \ldots & \ldots & \ldots & \ldots \\ \left(X_n, X_1\right)_w & \left(X_n, X_2\right)_w & \ldots & p^2\left(X_n, X^*\right)_w \end{pmatrix} \quad (3)$$

where

$$p^2\left(X_i, X^*\right)_w = \sum_{k=1}^{m} w_k \left(X_{ik} - X_k^*\right)^2, \quad (4)$$

$$\left(X_i, X_j\right)_w = \sum_{k=1}^{m} w_k \left(X_{ik} - X_k^*\right)\left(X_{jk} - X_k^*\right), \; i, j = 1, \ldots, n. \quad (5)$$

The sought value $Y(X^*)=Y^*$ is defined by the formula:

$$Y^* = \frac{\left(w^{-1}\,\mathbf{Y}, \mathbf{1}\right)}{\left(w^{-1}\,\mathbf{1}, \mathbf{1}\right)} \quad (6)$$

where $\mathbf{1} = (1,\ldots,1)^T$, $\mathbf{Y} = (Y_1, \ldots, Y_n)^T$.

1.2. Identification of metrical weights definition through successive exclusion of arguments

If the metric weights $w_1, \ldots, w_m$ are equal to one, i.e. $w_i=1$, $i = \overline{1, m}$, the matrix of metric uncertainty will only take into consideration the geometrical arrangement of the interpolation nodes in the initial geometrical space. However, by matching the values of metric weight we can take into consideration the unequal level of variation of function

Table 2. Expert estimates of category one UAV priority.

UAV take-off mass in ascending order M_{TOM}, kg	Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Expert estimate per a 100-point scale
1100	0.32	36	4000	120	9100	100
1200	0.17	20	350	120	7000	65
1250	0.12	40	2500	800	6900	70
1300	0.46	25	1200	220	7000	80

Table 3. Expert estimates of category two UAV priority.

UAV take-off mass in ascending order M_{TOM}, kg	Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Expert estimate per a 100-point scale
3300	0.36	40	2000	220	7000	50
4000	0.10	12	1300	700	2000	20
4760	0.5	28	5900	425	15240	100

Table 4. Expert estimates of category three UAV priority.

UAV take-off mass in ascending order M_{TOM}, kg	Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Expert estimate per a 100-point scale
5300	0.40	40	3700	300	13700	100
5600	0.13	30	7000	330	9000	50

Table 5. Expert estimates of category four UAV priority.

UAV take-off mass in ascending order M_{TOM}, kg	Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Expert estimate per a 100-point scale
16556	0.12	2	2400	988	12200	20
65000	0.37	30	7500	800	13000	100

Table 6. Primary UAV performance data related to take-off mass.

UAV take-off mass in ascending order M_{TOM}, kg	Mass of the payload / Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority indicators assessment
1	*2*	*3*	*4*	*5*	*6*	*7*
300	70/0.23	8	290	150	5000	43.31
450	150/0.33	20	200	130	6000	68.24
450	140/0.31	24	250	170	5500	69.47
640	489/0.34	30	3700	210	7500	86.21
650	55/0.08	24	150	220	7000	49.64
727	90/0.12	12	260	148	4500	35.84
1000	200/0.20	24	750	250	8000	63.97
1020	345/0.34	24	1100	148	7620	77.88
1040	204/0.2	20	740	130	7600	59.93
1100	350/0.32	36	4000	120	9100	**100.00**
1100	350/0.32	36	600	110	9000	91.88
1200	200 /0.17	20	350	120	7000	**65.00**
1200	300/0.25	24	300	200	7500	67.79
1250	150/0.12	40	2500	800	6900	**70.00**
1260	345/0.27	30	2000	180	7200	77.29
1300	400/0.30	30	6000	240	9000	87.47
1300	600 /0.46	25	1200	220	7000	**80.00**
1450	350/0.24	10	1300	480	7000	48.99
1450	300 /0.20	22	260	287	7900	60.82
1451	489/0.34	30	800	250	9000	86.52
1500	400/0.27	35	2000	280	7500	82.47
1500	370/0.25	40	800	200	7500	85.81
1600	200/0.12	24	180	200	9000	58.17
1633	478/0.29	36	400	280	8840	86.96
1650	450/0.27	24	260	268	7800	69.77
2400	350/0.14	24	250	280	10600	63.05
2678	454/0.16	12	2800	720	12200	54.24
2800	400/0.14	35	6000	850	8000	69.73
2800	340/0.12	24	1000	600	8200	53.87
3000	400/0.13	6	2000	550	14000	49.74
3000	300/0.10	22	260	287	7900	50.96
3000	100/0.03	32	800	2200	6500	36.36
3200	1000/0.31	45	250	240	7000	94.93
3250	300/0.09	35	200	600	6000	57.12
3300	1200/0.36	40	2000	220	7000	**50.00**
3500	600/0.14	20	250	400	600	35.78
4000	400/0.10	12	1300	700	2000	**20.00**
4200	480/0.11	32	2000	370	9000	66.13
4500	1360/0.30	24	400	390	14000	85.46
4760	1700/0.5	28	5900	425	15240	**100.00**
4760	1800/0.38	32	1852	313	15240	94.98
4763	1746/0.36	30	5900	425	152409	93.33
4800	1589/0.33	20	6000	647	18000	96.04
5000	480/0.09	12	2500	400	7400	39.32
5000	480/0.09	15	260	253	5100	36.52
5000	480/0.09	50	260	213	9100	83.10
5300	1800/0.40	40	3700	300	13700	**100.00**
5450	1000/0.18	3	1200	920	10700	40.25
5600	700/0.13	30	7000	330	9000	**50.00**

UAV take-off mass in ascending order M_{TOM}, kg	Mass of the payload / Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority indicators assessment
1	*2*	*3*	*4*	*5*	*6*	*7*
6000	600/0.10	25	3000	400	12200	65.44
6000	800/0.13	14	500	850	12000	49.87
6146	500/0.08	16	8149	592	13700	60.08
7000	800/0.11	20	2500	555	15240	65.84
7500	2000/0.26	48	1000	250	12000	95.02
8000	950/0.12	26	1000	950	12000	61.47
8255	2948/0.35	18	1600	650	15240	85.71
9000	1000/0.11	30	1600	370	16700	80.50
10000	2000/0.20	28	4000	960	15000	80.89
13000	2000/0.15	34	3000	730	13000	79.09
16556	907/0.05	12	2800	850	12200	42.55
16556	2040/0.12	7	2200	850	12200	43.41
16556	2000/0.12	2	2400	988	12200	37.14
20190	2040/0.12	12	2960	850	12200	49.38
22000	6010/0.27	16	7000	900	1200	47.85
25000	4000/0.16	15	6000	1500	15000	60.22
65000	24000/0.37	30	7500	800	13000	**100.00**

under varying function arguments. In this paper, the metric weights were found using a scheme based on the comparison of the recovered function values in the points, in which function values are defined with sequential exclusion of each argument individually [20].

2. Estimating the priority of scout/attack and attack unmanned aerial vehicles through metrical analysis

There are data available regarding primary UAV indicators (takeoff mass, mass of the payload, flight duration, flight distance, cruising speed, flight altitude (practical ceiling)).

The experts divided the vehicles into a number of categories (depending on the takeoff mass): first, up to 1650 kg; second, from 1650 kg to 5000 kg; third, from 5000 to 10000 kg; fourth, over 10000 kg. In each category, the experts could rate the priority indicator of a certain number of UAVs on a 100-point scale (see. Tables 2 – 5) with respect to the remaining five indicators: mass of the payload, flight duration, flight distance, cruising speed, flight altitude.

It is required to, using the priority indicator values for certain UAVs provided by experts, identify the unknown values of such indicator for other UAVs.

This problem is solved using the scheme shown above in sections 1.1 and 1.2, where the priority indicator serves as the function, while the above five UAV indicators serve as the arguments.

The solution algorithm calculates the priority indicator according to formula (6), where Y^* is the priority indicator of the UAV under consideration, , k = 1, …, 5 are the five above indicators for such UAV.

The results of the priority indicator evaluation for all UAVs are shown in the last column of Table 6.

3. Integration of several expert estimates

In practice, it is not uncommon for different experts to provide a different estimate of a value. The problem of UAV estimation is no exception. In this section, the authors suggest four schemes for integrating estimates by different experts. Below, those four priority estimate integration schemes are set forth with the example of the first category of UAVs, i.e. from 1000 to 1650 kg.

Scheme no. 1. In scheme no. 1, based on each expert's estimate, the remaining UAVs are individually estimated, then the obtained estimates are averaged (Table 7). Shown in bold are the UAVs estimated by experts; shown in normal font are the estimates obtained through metrical analysis.

The initial UAV indicators shown in Table 6 were normalized relative to the mathematical expectation and dispersion:

$$\hat{X}_i = \frac{X_i - \mu}{\sqrt{\sigma^2}}.$$

Scheme no. 2. According to the second integration scheme, initially, for each estimated UAV, the expert estimates are averaged (arithmetic mean of the estimates) for a UAV (Table 8):

– No. 10: average estimate $= \frac{100+95+90}{3} = 95;$

– No. 12: average estimate $= \frac{65+63+60}{3} = 62,67;$

– No. 14: average estimate $= \frac{70+72+75}{3} = 72,33;$

– No. 17: average estimate $= \frac{80+84+85}{3} = 83;$

Then, the metrical analysis scheme is used.

Table 7. UAV priority assessment per scheme no. 1 (averaged estimate).

UAV number	UAV take-off mass in ascending order M_{TOM}, kg	Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority indicators assessment (expert estimates given in bold)			Priority indicators assessment
							1	2	3	4
1	2	3	4	5	6	7	8	9	10	11
1	1000	0.20	24	750	250	8000	43.31	39.51	39.04	40.62
2	1020	0.34	24	1100	148	7620	68.24	68.73	69.99	68.99
3	1040	0.2	20	740	130	7600	69.47	70.47	68.09	69.34
4	1100	0.32	36	4000	120	9100	86.21	84.59	85.29	85.36
5	1100	0.32	36	600	110	9000	49.64	48.24	45.83	47.90
6	1200	0.17	20	350	120	7000	35.84	33.77	34.66	34.76
7	1200	0.25	24	300	200	7500	63.97	62.65	63.54	63.39
8	1250	0.12	40	2500	800	6900	77.88	76.57	76.31	76.92
9	1260	0.27	30	2000	180	7200	59.93	57.71	59.94	59.19
10	**1300**	**0.30**	**30**	**6000**	**240**	**9000**	**100.00**	**95.00**	**90.00**	95.00
11	1300	0.46	25	1200	220	7000	91.88	97.91	95.44	95.08
12	**1450**	**0.24**	**10**	**1300**	**480**	**7000**	**65.00**	**63.00**	**60.00**	62.67
13	1450	0.20	22	260	287	7900	67.79	69.54	67.21	68.18
14	**1451**	**0.34**	**30**	**800**	**250**	**9000**	**70.00**	**72.00**	**75.00**	72.33
15	1500	0.27	35	2000	280	7500	77.29	78.58	75.31	77.06
16	1500	0.25	40	800	200	7500	87.47	85.10	86.36	86.31
17	**1600**	**0.12**	**24**	**180**	**200**	**9000**	**80.00**	**84.00**	**85.00**	83.00
18	1633	0.29	36	400	280	8840	48.99	46.01	45.17	46.72
19	1650	0.27	24	260	268	7800	60.82	62.93	60.86	61.54

Table 8. UAV priority assessment per scheme no. 2 (averaged expert assessment)

UAV number	UAV take-off mass in ascending order M_{TOM}, kg	Payload M_{PL}, kg / Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority assessment
1	1000	200/0.20	24	750	250	8000	42.36
2	1020	345/0.34	24	1100	148	7620	68.58
3	1040	204/0.2	20	740	130	7600	69.97
4	1100	350/0.32	36	4000	120	9100	86.49
5	1100	350/0.32	36	600	110	9000	47.86
6	1200	200 /0.17	20	350	120	7000	34.1
7	1200	300/0.25	24	300	200	7500	63.22
8	1250	150/0.12	40	2500	800	6900	78.07
9	1260	345/0.27	30	2000	180	7200	58.58
10	**1300**	**400/0.30**	**30**	**6000**	**240**	**9000**	95.00
11	1300	600 /0.46	25	1200	220	7000	92.01
12	**1450**	**350/0.24**	**10**	**1300**	**480**	**7000**	62.67
13	1450	300 /0.20	22	260	287	7900	67.49
14	**1451**	**489/0.34**	**30**	**800**	**250**	**9000**	72.33
15	1500	400/0.27	35	2000	280	7500	77.07
16	1500	370/0.25	40	800	200	7500	86.75
17	**1600**	**200/0.12**	**24**	**180**	**200**	**9000**	83.00
18	1633	478/0.29	36	400	280	8840	49.21
19	1650	450/0.27	24	260	268	7800	60.25

Table 9. UAV priority assessment per scheme no. 3.

UAV number	UAV take-off mass in ascending order M_{TOM}, kg	Payload M_{PL}, kg / Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority indicators assessment
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	1000	200/0.20	24	750	250	8000	42.72
2	1020	345/0.34	24	1100	148	7620	68.53
3	1040	204/0.2	20	740	130	7600	69.87
4	1100	350/0.32	36	4000	120	9100	86.45
5	1100	350/0.32	36	600	110	9000	48.39
6	1200	200 /0.17	20	350	120	7000	34.66
7	1200	300/0.25	24	300	200	7500	63.46
8	1250	150/0.12	40	2500	800	6900	78.05
9	1260	345/0.27	30	2000	180	7200	59.01
10	**1300**	**400/0.30**	**30**	**6000**	**240**	**9000**	96.5
11	1300	600 /0.46	25	1200	220	7000	91.99
12	**1450**	**350/0.24**	**10**	**1300**	**480**	**7000**	63.40
14	**1451**	**489/0.34**	**30**	**800**	**250**	**9000**	71.60
15	1500	400/0.27	35	2000	280	7500	77.16
16	1500	370/0.25	40	800	200	7500	87.0
17	**1600**	**200/0.12**	**24**	**180**	**200**	**9000**	82.20
18	1633	478/0.29	36	400	280	8840	42.09
19	1650	450/0.27	24	260	268	7800	60.44

Table 10. UAV priority assessment per scheme no. 4 (subject to the weight of each expert per sample)

UAV number	UAV take-off mass in ascending order M_{TOM}, kg	Payload M_{PL}, kg / Correlation of M_{PL}/M_{TOM}	Flight duration T_F, h	Flying range D_F, km	Cruising speed V_{CR}, km/h	Flight altitude (service ceiling) H_F, m	Priority assessment
1	1000	200/0.20	24	750	250	8000	42.03
2	1020	345/0.34	24	1100	148	7620	68.26
3	1040	204/0.2	20	740	130	7600	69.69
4	1100	350/0.32	36	4000	120	9100	86.3
5	1100	350/0.32	36	600	110	9000	47.87
6	1200	200 /0.17	20	350	120	7000	33.92
7	1200	300/0.25	24	300	200	7500	63.12
8	1250	150/0.12	40	2500	800	6900	77.8
9	1260	345/0.27	30	2000	180	7200	58.44
10	**1300**	**400/0.30**	**30**	**6000**	**240**	**9000**	95.10
11	1300	600 /0.46	25	1200	220	7000	91.88
12	**1450**	**350/0.24**	**10**	**1300**	**480**	**7000**	62.56
13	1450	300 /0.20	22	260	287	7900	67.32
14	**1451**	**489/0.34**	**30**	**800**	**250**	**9000**	72.44
15	1500	400/0.27	35	2000	280	7500	76.94
16	1500	370/0.25	40	800	200	7500	86.66
17	**1600**	**200/0.12**	**24**	**180**	**200**	**9000**	82.48
18	1633	478/0.29	36	400	280	8840	48.96
19	1650	450/0.27	24	260	268	7800	60.14

Scheme no. 3. Normally, estimates by different experts have different weights depending on such expert's experience [4]. Subsequently, that must be taken into consideration in order to obtain a more accurate final estimate using metrical analysis

$$K = \sum_{i=1}^{n} W_i * K_i,\ i = 1, \ldots, n,$$

where $\sum_{i=1}^{n} W_i = 1$, K_i is the estimate of the priority indicator of the i-th expert.

Let the weight of expert 1 be 0.5; weight of expert 2 be 0.3; weight of expert 3 be 0.2, then the priority estimate for UAV (Table 8):

– No. 10: $K_{10} = 0,5 \cdot 100 + 0,3 \cdot 95 + 0,2 \cdot 90 = 96,5;$

– No. 12: $K_{12} = 0,5 \cdot 65 + 0,3 \cdot 63 + 0,2 \cdot 60 = 63,4;$

– No. 14: $K_{14} = 0,5 \cdot 70 + 0,3 \cdot 72 + 0,2 \cdot 75 = 71,6;$

– No. 17: $K_{17} = 0,5 \cdot 80 + 0,3 \cdot 84 + 0,2 \cdot 85 = 82,2.$

The results of UAV estimation per scheme no. 3 are shown in Table 9.

Scheme no. 4. In case if the weights W_i of experts are unknown, we can find them using the initial expert estimates [20]:

$$W_i = \frac{1/\Delta_i^2}{\sum_{k=1}^{n} 1/\Delta_k^2},$$

$$\bar{K}_j = \frac{1}{n}\sum_{i=1}^{n} K_{ij},\ j = 1, \ldots, m,$$

$$\Delta_i^2 = \frac{1}{m}\sum_{j=1}^{m}\left(K_{ij} - \bar{K}_j\right)^2,$$

where m is the number of the estimated UAVs, n is the number of experts, K_{ij} is the estimated priority indicator of the j-th UAV based on the i-th expert's estimate.

The calculations provided the following values of the weight of each of the three experts: $w_1 = 0.50$; $w_2 = 0.02$; $w_3 = 0.48$.

Then, we obtain the priority estimate for four UAVs examined by the experts:

– No. 10: $K_{10} = 0,5 \cdot 100 + 0,02 \cdot 95 + 0,48 \cdot 90 = 95,1;$

– No. 12: $K_{12} = 0,5 \cdot 65 + 0,02 \cdot 63 + 0,48 \cdot 60 = 62,56;$

– No. 14: $K_{14} = 0,5 \cdot 70 + 0,02 \cdot 72 + 0,48 \cdot 75 = 72,44;$

– No. 17: $K_{17} = 0,5 \cdot 80 + 0,02 \cdot 84 + 0,48 \cdot 85 = 82,48.$

The results of UAV estimation per scheme no. 4 are shown in Table 10.

Conclusions

1. The paper shows the relevance of the selection and definition of the priority indicators of various aviation equipment and weapons, including UAVs at the initial stages of creation out of a list of existing ones or design of a new technical item.

2. The UAV priority indicators are defined using metrical analysis schemes that allow – based on experts estimates of the priority of certain UAVs – defining the priority indicators of all other UAVs knowing the initial indicators for each evaluated UAV.

3. The initial indicators for UAV priority are the mass of the payload, flight duration, flight distance, cruising speed, flight altitude.

4. The priority indicator evaluation schemes presented in the paper can be used to decide upon further development of UAVs of various purpose, as well as acquisition of ready-made UAVs.

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The authors' contribution

Kryanev A.V. Suggested a method of estimation of priority indicators for scout/attack and attack UAVs with the use of metrical analysis based on known expert estimates of the priority of some UAVs and primary UAV estimates.

Semenov S.S. Examined various methods of rational engineering solution selection in aircraft design, presented a classification and data on scout/attack and attack UAVs, suggested a method of CTS priority indicators estimation based on metrical analysis in the context of UAV under various schemes of expert estimation.

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Conflict of interests

The authors declare the absence of a conflict of interests.