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CONDITIONS FOR UNMANNED AIRCRAFT RELIABILITY DETERMINATION

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In the paper the required level of reliability is determined for several Unmanned Aerial Vehicles developed in Poland in order to get an achievement enabling these vehicles to operate within the Single European Sky. Calculations were made on the basis of an air crash model as well as the model capable to estimate the number of casualties resulting from an aircraft catastrophe. The provided examples allow us to specify Tactical and Technical Conditions pertaining in particular to the area of the operation of the aforementioned aircraft.

Keywords: Unmanned Aerial Vehicle, ground impact model, mid-air collisions model, hazard analysis.

W pracy wyznaczono niezbędną niezawodności kilku opracowanych w Polsce samolotów bezpilotowych, której osiągnięcie umożliwia ich eksploatacje w połączonej przestrzeni powietrznej. Obliczenia prowadzone były wg modelu katastrofy powietrznej oraz modelu pozwalającego na oszacowanie liczby ofiar na skutek rozbicia się samolotu. Podane przykłady pozwalają na sprecyzowanie Warunków Taktyczno – Technicznych, w szczególności dotyczących obszaru eksploatacji tychże samolotów.

Słowa kluczowe: samolot bezpilotowy, model zderzenia z ziemią, model kolizji powietrznej, analiza zagrożenia.

1. Introduction

The concept of an unmanned aerial vehicle (UAV) is not new as the first structures of this type were manufactured as early as in the First World War. In order to evaluate the current "scale of the phenomenon", the easiest way to do it is a collective specification following the Jane's Unmanned Aerial Vehicles and Targets catalogues that demonstrates that at the moment there are more than 400 UAVs and 120 flying targets that have been formally classified.

What makes their use in the public sector so rare if they show conspicuously identified advantages in terms of their use? One of the reasons is undoubtedly an insufficient level of reliability of current solutions that leads to a potentially unacceptably high probability of an accident or a catastrophe.

The basis for implementation of any UAV system for use in a civil and definitely in the Single European Sky (SES) in the future is a positive completion of a proper certification process. In the case of Europe, an entity that supervises actions of this type is EASA (the European Aviation Safety Agency) whose objective is to develop guidelines for a certification program referred to as CS (Certification Specifications). In the US market, a relevant certifying agency is the FAA (Federal Aviation Administration).

Pursuant to the assumptions adopted by the FAA and EASA [4] and [14], the UAV certification process, as assumed, is based on vast expertise and regulations that have been developed for civil aircraft, in particular, the guidelines for ensuring flying safety of civil aircraft in the following documents:

- AMC 25-1309 for transportation aircrafts,
- FAA AC 23 –1309-1C – for GA aircrafts.

Allocation of a specific UAV to one of the classes (Tab. 1) as anticipated in the legislation. In involves a comparison of its kinetic energy with the average kinetic energy of aircraft of a given class. It is simultaneously assumed that the maximum kinetic energy of a UAV is calculated for two following scenarios:

a) A UAV lands in an unfamiliar area for unintended reasons, then its calculation speed is assumed to be 130% of the speed of attraction in the configuration of landing;
b) The control over a UAV is lost which results in its crashing, then its calculation speed is assumed to be 140% of the maximum operating speed.

2. Catastrophic Events Involving UAVs

Apart from the economic issues related to a failure, downtime and finally with the destruction of an aircraft, the problem of a UAV catastrophe may be considered from the perspective of ensuring the level of reliability of UAVs, in order:

a) to not exceed a critical probability of a catastrophe in the air κ_{UAVkr}, calculated for one hour of flight;
b) in the event of its catastrophe featuring the probability equal σ_{UAV}, the ratio of third parties (on the surface) has not exceeded a critical value of γ_{UAVkr}, calculated into one hour of flight;

The values of κ and γ ratios have been adopted pursuant to a theory of controlling the risk [14], [6] stating that "*Catastrophic conditions of damage must be extremely unlikely*". The critical value of κ_{UAV} is assumed to be (according to Table 1) a constant $\kappa_{UAVkr} = 10^{-9}$, regardless of the type of UAV – a perpetrator of a crash which is equivalent to the FAA and EASA recommendations of the maximum level of hazard of a civil aerial vehicle flying in SES. In order to determine the value of σ_{UAVkr}, Table 1 may be found useful because it specifies the figures of probability of an event subject to the class of a civil aerial vehicle [14]. A method that allows transformation of the contents of Table 1 to make it useful for a UAV, will be presented in a description of a model of catastrophe involving a crash of a UAV.

Exemplary calculations have been made for thirteen UAVs, including seven UAVs that are currently manufactured or designed in Poland and five manufactured abroad. The smallest MAV Black Widow has a MTOW (Maximum Take-off Weight) of m = 60g, but for the largest Global Hawk m = 11 622kg. All UAV parameters required for

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

Table 1. Probability of an event (according to EASA)

<table>
<tr><th rowspan="2" colspan="3">Document</th><th colspan="7">Probability of an event</th></tr>
<tr><th>10⁻³ – 10⁻⁴</th><th>10⁻⁴ – 10⁻⁵</th><th>10⁻⁵ – 10⁻⁶</th><th>10⁻⁶ – 10⁻⁷</th><th>10⁻⁷ – 10⁻⁸</th><th>10⁻⁸ – 10⁻⁹</th><th>10⁻⁹ below</th></tr>
<tr><td colspan="3">FAA SSH</td><td colspan="2">P</td><td colspan="2">O</td><td colspan="2">E.O</td><td>E.N</td></tr>
<tr><td colspan="3">CS 25</td><td colspan="2">P</td><td colspan="4">N</td><td>E.N</td></tr>
<tr><td rowspan="4">CS 23</td><td rowspan="4">Class</td><td>IV</td><td colspan="2">P</td><td colspan="2">O</td><td colspan="2">E.O</td><td>E.N</td></tr>
<tr><td>III</td><td colspan="2">P</td><td colspan="2">O</td><td>E.O</td><td colspan="2">E.N</td></tr>
<tr><td>II</td><td colspan="2">P</td><td>O</td><td>E.O</td><td colspan="3">E.N</td></tr>
<tr><td>I</td><td>P</td><td>O</td><td>E.O</td><td colspan="4">E.N</td></tr>
</table>

P – Likely ; O – Remote; E.O – Extremely remote; N – Unlikely; E.N – Extremely unlikely.
Class I Typical with a piston engine below 6000lbs,
Class II – Piston multi-engines or turbine engines below 6000lbs,
Class III Typical with piston engine, piston multi-engines or turbine multi-engine above 6000lbs,
Class IV – Commuter category.

Table 2. Calculation parameters of exemplary UAVs

Ref.	UAV	MTOW [*kg*]	S [m^2]	S_R [m^2]	ε_G	ε_A
1	Global Hawk	11622	50.00	546.00	0.93	1
2	Predator	1 021	13.50	51.00	0.58	1
3	Czajka	473	10.20	21.94	0.21	1
4	Pheonix	270	56.80	3.31	0.09	1
5	Shadow 200	159	2.99	12.00	0.24	1
6	Samonit 2	50	2.05	3.20	0.13	0.5
7	OCP Jet	40	1.10	3.59	0.18	0.4
8	SMCP Szerszeń	39	1.82	2.48	0.12	0.39
9	MJ-7 Szogun	29	1.11	2.33	0.13	0.29
10	SMCP Komar	25	1.10	1.92	0.12	0.25
11	FlyEye	11	0.95	0.71	0.10	0.11
12	Mini	4.36	0.60	0.28	0.09	0.043
13	Black Widow	0.06	0.03	0.01	0.06	0.0006

calculations included in Table 2 where: S – is a surface of reference, S_R – striking zone, ε_G – penetration ratio, a ε_A – a ratio used in a model of air crash.

3. Reliability of UAVs and a number of casualties among third parties

Assuming that the level of safety of use of UAVs in SES may not be lower than a value assumed for civil and military aircrafts, based on the regulations of FAR/CS 25 and 35 maximum ratio of casualties caused by the UAV crash, EASA suggests that one should assume $\gamma_{UAVkr} = 10^{-6}$ which is a maximum of one casualty per million UAV flying hours.

Alternatively, in studies [8] and [14], authors assume the equivalence of the relation below, which seems to be more universal,

$$\gamma_{UAV_{kr}} = \sigma_{A/C_{kr}} \tag{1}$$

i.e. the equality of a ratio of the number of casualties for a UAV and the probability of a loss of a civil aircraft as a result of an event of a catastrophic nature, according to the FAA, resulting in:

a) casualties among the crew and passengers;
b) casualties among third parties;
c) usually the loss of an aircraft.

Both approaches (assumptions) for UAV of a weight of $m < 6\ 000 lbs$ propelled by piston engine, lead to the following assumption $\gamma_{UAVkr} = 10^{-6}$. For a bigger UAV or the ones with a turbine drive, in turn, these values will be smaller, according to the contents of Table 1.

The equation (1) may be transformed to the following,

$$\sigma_{UAV_{kr}} \cdot \Pi = \sigma_{A/C_{kr}} \tag{2}$$

where: σ_{UAVkr} – probability of a catastrophe of a UAV, a Π – probability of casualties in case of a UAV crashing to the ground. Thus, having known (from Table 1) the value of $\sigma_{A/Ckr}$, determine the required critical reliability of UAV, equal to

$$\mathrm{Re}_{UAV_{kr}} = 1 - \sigma_{UAV_{kr}} \tag{3}$$

there is a necessity to calculate the probability of having casualties upon crashing with a UAV, according to the following model,

$$\Pi = S_R \cdot D \cdot \varepsilon_G \tag{4}$$

where: S_R – is a striking zone characteristic of each of the UAVs in questions, D – population density in the area of a catastrophe, and ε_G is a so-called penetration ratio taking into account the mitigation of the effects of a catastrophe if potential victims are, e.g. in buildings that provide some shelter to them. The size of the striking zone is determined by means of an empirical relation below

$$S_R = 0.028 \cdot \left(\frac{m}{S}\right)^{2/3} \quad (5)$$

where: m – is a weight of UAV determined [4] on the assumption that it is proportional to the energy of an aircraft at the moment of crash, made up mainly of its kinetic energy and the fuel explosion energy. The S_R figures for the analysed UAVs are presented in Table 2 and Figure 1 presents them for the GA (General Aviation and Transportation) aircraft subject to a ballistic ratio β determined pursuant to the following relation where c_x is a resistance force ratio.

$$\beta = \frac{m}{c_x \cdot S} \quad (6)$$

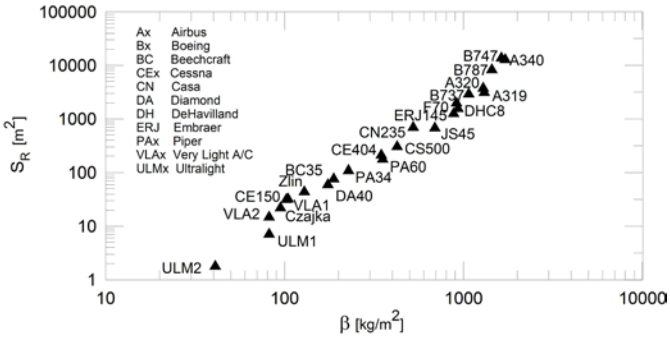

Fig.1. A size of a striking zone for the selected UAVs, Gas and Transpiration

A precise determination of a striking zone is of the utmost importance (linear dependency) for the precision of a model of the UAV catastrophe, for obvious reasons. Thus, an attempt was made to verify relation (5) involving a comparison of the real spot of the Tu 154M's catastrophe of 10 April 2010 in the vicinity of the Severny airport near Smolensk shown in Figure 2 with a value calculated according to relation (5). Assuming the data from Jane's catalogue, the calculation value S_R for Tu 154M aircraft is $S_R = 3\,788m^2$. By calculation using a satellite image of the crash spot, we arrive at the following: $S_R \approx 150{\times}25 = 3\,750m^2$ which verifies relation (5) in a positive manner.

For the analysis of UAV system design, it is also useful to determine its reliability defined by the following relation,

$$\mathrm{Re}_{UAV_{kr}} = e^{\frac{-t}{MTBCF}} \quad (7)$$

Fig. 2. Crash spot of the Tu 154M aircraft (Severny)

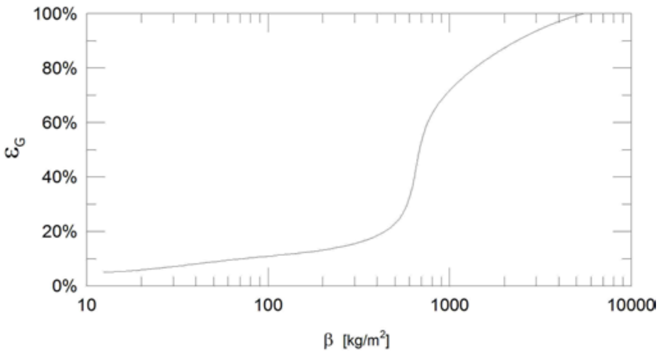

Fig. 3. A penetration ratio subject to a ballistic ratio

where, MTBCF is the Mean Time Between Critical Failure. A reverse of MTBCF is a number of defects (or a set of defects) of an UAV expected within an hour that would lead to a catastrophe.

A presented model of an assessment of the risk level imposed potentially by UAV for the third parties was subject to a model experiment that produced the following results specified in collective Table 3. Three various mission scenarios were taken into account:

a) flight between the EPMO airport located near Modlin, and EPSO located in the vicinity of Sochaczew. The flight route presented in Figure 2 of the total approximate length of $L = 38km$ crosses three administrative districts: Nowy Dwór ($L_1 = 24{,}5km$), Warsaw West ($L_2 = 5{,}5km$) and Sochaczew ($L_3 = 8km$) which feature a population density of 61 – 103 60 persons per $1km^2$ respectively;

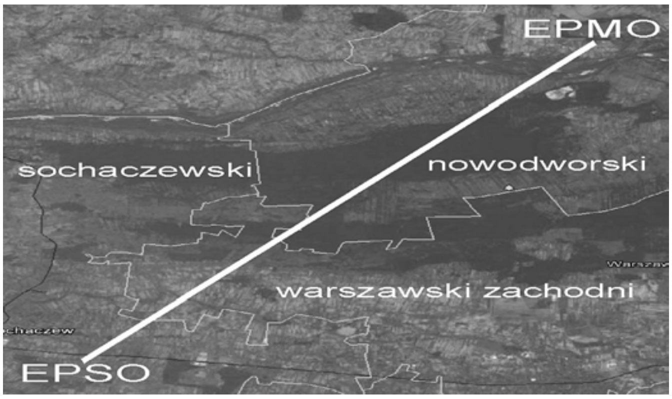

Fig. 4. Flight route between EPMO and EPSO

b) patrol mission in equal shares (25% each) over four suburbs of the Capital City of Warsaw featuring the highest population density defined as the number of inhabitants per 1km2, Ochota (D_1 = 9 215), Śródmieście (D_2 = 8 120), Wola (D_3 = 7 149) and Mokotów (D_4 = 6 372);

c) patrol mission in equal shares (25% each) over four suburbs of the Capital City of Warsaw featuring the lowest population density defined as the number of inhabitants per $1km^2$ Białołęka (D_1 = 1 222), Bielany (D_2 = 4 142), Bemowo (D_3 = 4 532) and Żoliborz (D_4 = 5 654).

An order of UAVs in Table 3 is determined by their weight. The heaviest aircraft are at the beginning of the specification, and the lightest are at the end. It is clear that, as expected, the requirements pertaining to the reliability of UAVs usually reduce in proportion to their weight. Two UAVs are exceptions to the rule: no. 4 being stratospheric Phoenix and No. 7 an aerial target featuring a jet engine OCP – Jet. Through analysis of the contents of Table 3 we find that for a large Phoenix aircraft featuring a wing span of 38.2m the requirements pertaining to its minimum reliability are significantly lower than the ones determined for an obviously smaller Czajka air-

Table 3. A collective specification of the a, b and c model experiment results

Ref.	Aircraft	Mission „a"		Mission „b"		Mission „c"	
		Re_{UAVmin}	$MTBCF_{min}$	Re_{UAVmin}	$MTBCF_{min}$	Re_{UAVmin}	$MTBCF_{min}$
1	Global Hawk	0.99997	34 014	0.999999	999 999	0.999999	999 999
2	Predator	0.99950	1 981	0.999996	228 044	0.999991	114 986
3	Czajka	0.996759	308	0.999972	35 520	0.999944	17 910
4	**Phoenix**	**0.949840**	**19**	**0.999564**	**2 294**	**0.999139**	**1 156**
5	Shadow 200	0.994817	192	0.999955	22 202	0.999911	11 195
6	Samonit 2	0.964074	27	0.999688	3 203	0.999380	1 614
7	**OCP-Jet**	**0.976927**	**43**	**0.999800**	**4 988**	**0.999602**	**2 515**
8	SMCP Szerszeń	0.949923	19	0.999565	2 298	0.999137	1 158
9	MJ-7 Szogun	0.950772	20	0.999572	2 331	0.999152	1 178
10	SMCP Komar	0.935233	15	0.999437	1 777	0.998884	896
11	FlyEye	0.789390	4	0.998170	546	0.996371	275
12	Mini	0.466845	~1	0.995367	215	0.990813	108
13	Black Widow	~1	~0	0.729767	3	0.464069	1

craft. A reason for these facts is the relative small ballistic ratio of the Phoenix aircraft that gives, in turn, a small penetration ratio and a minimum relation of weight to the reference surface resulting in an exceptionally low (compared to the size of an aircraft) striking zone. Similar substantive reasons (mainly a relatively high penetration ratio) make the requirements pertaining to the minimum reliability of a smaller OCP-Jet aircraft featuring a relatively contained design higher than those of the larger and heavier Samonit – 2 UAV.

4. Reliability of the UAV and the risk of a collision in the air

It is useful to analyse the probability of a mid-air collision between a UAV and other SES users using the "gas model [5], [14] the idea of which has already been presented in Figure 5. In this model the UAV is treated as a particle - a material point moving inside the space of a controlled volume of **V**. Other civil users 1, 2..*n* however are treated as particles of a characteristic size S_{expi} being a field of exposure (a front surface) *i* of this civil aircraft. At the same time it is assumed that for the entire time of observation **T**, a UAV is inside the controlled space and other users do not have any equipment and systems to prevent a collision (e.g. TCAS Traffic Collision Alert System). A probability of a catastrophe is calculated from the following relation:

$$ {}_{UAV} = \frac{\sum_{i=1}^{n} L_i \cdot S_{\exp_i} \cdot \varepsilon_{A_i}}{V \cdot T} \tag{8}$$

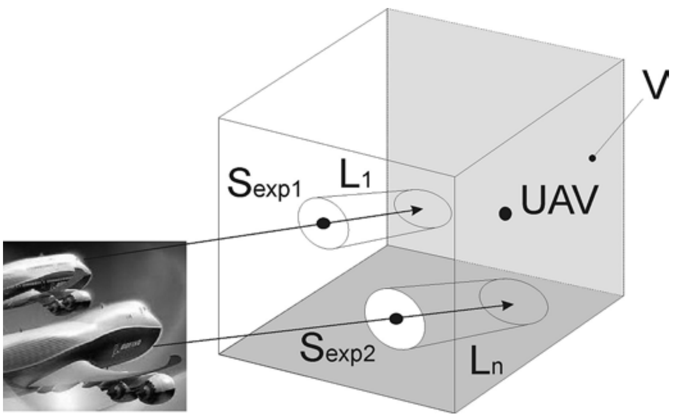

Fig. 5. A concept of a "gas model" of a mid-air collision (according to [5])

where: L_i a road covered inside the space, and $\varepsilon_{Ai} \le 1$ – is a ratio taking the inevitability of a catastrophe as a result of a collision of *i* of this aircraft with UAV. For the sake of calculation, it may be assumed that

$$\varepsilon_A = \begin{cases} m/100, m < 100kg \\ 1, m \ge 100kg \end{cases} \tag{9}$$

which means that each collision of an aircraft with a UAV the weight of which is $m > 100kg$ leads inevitably to a catastrophe. For UAVs of a weight of $m \le 100kg$, however, the value of its ratio ε_A decreases in a linear proportion assuming the ultimate value of $\varepsilon_A \approx 0$ for the smallest MAVs.

The presented model calculating the probability of an air collision was reviewed involving the required calculations based on observation of the real movement of aircraft traffic in the air space surrounding the Warszawa Okęcie (EPWK) Airport as shown in Figure 6. The dimension of a cuboid control zone was assumed to be $10^5 \times 10^5 \times 1{,}2 \cdot 10^4 m$. As shown in Figure 4, EPWK was located cen-

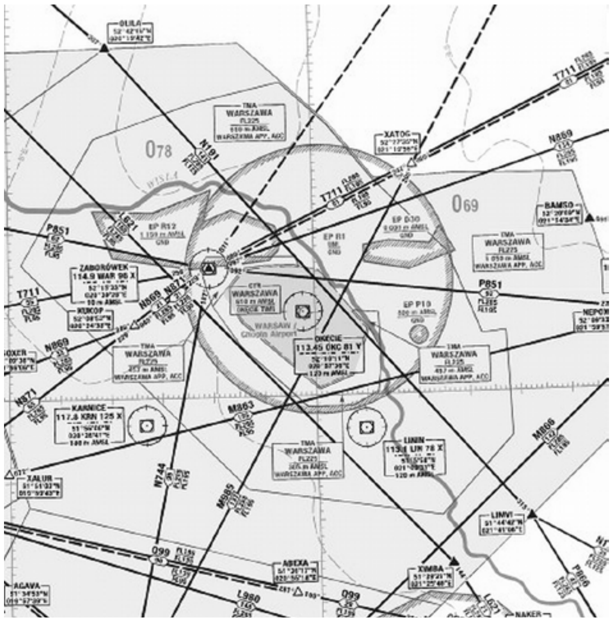

Fig. 6. A "map" of a measuring zone with marked air routes for FL ≤ 285

Table 4. A collective specification of results of the a, b, c and d model experiment

Ref.	Aircraft	Mission „a" κ_{UAVV}	Mission „b" $\kappa_{UAVFL<160}$	Mission „c" $\kappa_{UAVFL=340}$	Mission „d" $\kappa_{UAVLANDING}$
1	Global Hawk	3.99E-7	3.83E-7	2.14E-5	0.943
2	Predator	3.99E-7	3.83E-7	2.14E-5	0.943
3	Czajka	3.99E-7	3.83E-7	2.14E-5	0.943
4	Phoenix	3.99E-7	3.83E-7	2.14E-5	0.943
5	Shadow 200	3.99E-7	3.83E-7	2.14E-5	0.943
6	Samonit – 2	2.00E-7	1.91E-7	1.05E-5	0.472
7	OCP – Jet	1.60E-7	1.53E-7	0.88E-5	0.377
8	SMCP – Szerszeń	1.56E-7	1.49E-7	0.82E-5	0.368
9	MJ-7 Szogun	1.16E-7	1.11E-7	0.61E-5	0.274
10	SMCP – Komar	0.98E-7	0.95E-7	0.53E-5	0.236
11	FlyEye	0.44E-7	0.42E-7	0.23E-5	0.104
12	Mini	0.17E-7	0.17E-7	0.09E-5	0.041
13	Black Widow	**0.002E-7**	**0.002E-7**	0.01E-5	0.0004

trally relative to the base of the zone. The air traffic observations were performed for two morning peak hours between $7^{00} \div 9^{00}$ on 29th February 2012. At that time, there were 30 aircraft in the zone altogether. 10 of them took off from EPWK, 7 landed there and 15 crossed the zone at various *FL* (Flight Level) out of which 6 were performing a transit flight at *FL* 340. The altitude and speed of the flight as well as the length of the route covered by a given aircraft inside the measuring zone were recorded. Each of the observed aircraft was identified, which made it possible to determine its exposure zone of S_{exp} based on the catalogue data.

The completed calculations and registrations made it possible to determine the probability of an air collision according to relation (8) with one of the UAVs that are present there (calculations were made for each of the UAVs from Table 3). In particular, four scenarios were assumed for the calculations presented in Table 4 in which a UAV hypothetically moved regardless of their operating parameters over the entire time of observation of the UAV:

a) inside the entire measurement zone;
b) below *FL* 160 (aircrafts taking off and landing);
c) on the top flying route at *FL* 340;
d) on the descending route starting from 10*NM*.

While analysing the calculation results presented in Table 4, it is obvious, that apart from a very small Black Widow the remaining UAVs pose a real, unacceptably high risk to current air traffic; this assumption is made pursuant to the model that they move in an uncontrolled manner in SES. The value of probability of occurrence of an air catastrophe involving a UAV strongly depends on the space in which a flight is performed. The probability of collision is definitely higher in the area of an approach to airports on pre-determined air routes. In the remaining areas, this likelihood is much lower but remains at the level recommended by FAA/EASA of 10^{-9} of catastrophes per one hour of flight.

Integration of UAV systems with SES requires development of new methods to protect the air traffic safety in terms of air collision, prevention and minimising the number of potential victims among third parties arising from a crash of an UAV.

The aforementioned models (of collision and crash of UAV) provide an effective tool for establishing the specified tasks.

In particular, *The UAV Crash Model* makes it possible to determine the required level of reliability of the entire UAV system in respect of ensuring the required level of safety related to the risk posed by a UAV in the event of its catastrophe, for third parties. While analysing the model, it is easy to notice that UAVs that are bigger and that move faster must be more reliable than MAVs, the potential risk of which is relatively low. The expected operating area also plays a major role. UAVs designed for operation in major urban agglomerations must definitely be more reliable compared to the ones used e.g. for patrolling of borders along which the population density is usually low.

5. Conclusions

Presented model indicates severe challenges for designers of major UAVs for which the total required MTBCF is comparable to the time of defects of a simple electronic (!) e.g. a simple fuse used in military aircrafts. Simple measures improving the reliability of these aircraft e.g.: application of the selected, top quality elements or redundancy of critical systems appears to be insufficient. Thus, it is probably a reason why decision-making entities (EASA, FAA) consider an option to implement a principle of permanent monitoring of UAV by a surface operator with an option of overtake of control as a matter of emergency in critical situations. On the one hand such solution imposes more stringent requirements pertaining to communication e.g. high reliability, short transmission delay or resistance to disturbance and on the other hand, it redefines a checklist of critical events that used to be classified as catastrophic for UAVs (i.e. shortens it).

A mid-air collision model is a sufficient premise for the development of special ATM (Air Traffic Management) procedures dedicated for UAVs and to integrate them with avionic systems of the equipment preventing air collisions e.g. TCAS (Traffic Collision Avoidance System). This model also shows that the reliability of systems preventing air collisions of these UAVs that according to assumptions are expected to move only in the areas of an approach to airports or on air routes must be higher than the ones designated to be used above an area designated for civil flights (HALE aircrafts) or operating locally at very low altitudes where there is practically no air traffic.

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References

1. Boeing. Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations 1959 – 2008. 2009.
2. Columbia Accident Investigation Board. Determination of Debris Risk to the Public, Due to the Columbia Breakup During Reentry. Report Volume II 2003.
3. DeGarmo M.T. Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace.Center for Advanced Aviation System Development 2004.
4. EASA. Advance -notice of proposed amendment (NPA) No 16/2005.
5. Endoh S. Aircraft Collision Models, M.S Thesis. Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge 1982.
6. FAA. System safety analysis and assessment for part 23 airplanes. AC No: 23.1309-1D, 2009.
7. Goraj Z,Frydrychewicz A,Świtkiewicz R, Hernik B, J. Gadomsk J, Goetzendorf-Grabowski T, Figat M,Suchodolski S, Chajec W. High altitude long endurance unmanned aerial vehicle of a new generation – a design challenge for a low cost, reliable and high performance aircraft. Bulletin of the Polish Academy of Sciences 2004; Technical sciences, vol. 52, no. 3.
8. King D.W, Bertapelle A, Moses C. UAV failure rate criteria for equivalent level of safety, International Helicopter Safety Symposium, Montréal 2005.
9. MurrayD.P. A Tiered Approach to Flight Safety Analysis. Keystone 2006.
10. Office of the Secretary of Defence. Airspace Integration Plan for Unmanned Aviation, 2004.
11. Pettit D, Turnbull A. General Aviation Aircraft Reliability Study, Hampton 2002; NASA/CR-2001-210647.
12. Prażewska M.Niezawodnośćurządzeńelektronicznych. WKiŁ Warszawa 1987.
13. Tsach S, Penn D, Levy A. Advanced technologies and approaches for next generation UAVS. 23rd Congress of International Council of the Aeronautical Sciences Toronto 2002.
14. Weibel R.E, Hansman R.J. Safety considerations for operation of UAVs in the NAS; Report No. ICAT-2005-1March 2005.

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