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Casualty Risk Analysis for Remotely Piloted Aircraft Systems Operations

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This paper offers an alternative *Casualty Area* assessment. This parameter appears in all flying vehicles risk evaluation. This work arises from the intention of contributing to the subject of risk assessment in aviation. All the formulations of the *Casualty Area* — which will be analyzed in this paper — are tailored for debris with high kinetic energies. These models lead to an overestimation of the risk associated with small drones flight, preventing both their use and the implied operational benefits. The proposed version tailors the small Remotely Piloted Aircraft Systems (commonly known as drones) falling under the A2 European Aviation Safety Agency (EASA) category, C2 class [European Aviation Safety Agency, Civil drones (Unmanned aircraft, 2018), https://www.easa.europa.eu/easa-and-you/civil-drones-rpas, accessed November (2019)], i.e. drones with a mass up to 4 kg. To obtain the new formulation, the authors started with the most used formula, proposed by Montgomery [R. M. Montgomery and J. A. Ward, Casualty Areas from Impacting Inert Debris for People in the Open (Research Triangle Institute, 1995)], used by FAA (Federal Aviation Administration, [Range Safety Group, Common Risk Criteria for National Test Ranges Inert Debris (Range Commanders Council, 2000)] and [Range Safety Group, Common Risk Criteria Standards for National Test Ranges (Range Commanders Council, 2010)]), adopting new hypotheses but following the same process. The results allow a risk formulation more suitable for drones of the above-mentioned size. The proposed formulation can be of use for specific regulatory issues. As a matter of fact, many services use small drones: aerial photography during public assemblies, concerts, sporting events, home deliveries, buildings thermal evaluation, to name just a few. The implementation of the present results allows a wider series of operations previously restricted due to the estimation of an incompatible level of risk. In fact, with the new formulation of the *Casualty Area*, the level of risk is safely lowered, mainly addressing the small dimension drones [European Aviation Safety Agency, Civil drones (Unmanned aircraft), https://www.easa.europa.eu/easa-and-you/civil-drones-rpas, Online accessed November (2019)]. The steps leading to the final formulation derive from a comprehensive analysis, coherent with the guidelines set by FAA and EASA.

Keywords: Casualty area; risk assessment; remotely piloted aircraft systems.

Nomenclature

- α : impact energy required for a fatality probability of 50% with p_S = 0.5, according to Ref. [14]
- β : impact energy required to cause a fatality as p_S goes to zero, according to Ref. [14]
- γ : glide angle (see Fig. 3)
- σ : population density
- x, y : ground coordinates
- A_C : casualty area
- DS : distance that the vehicle needs to come to a stop once hit the ground
- E_C : casualty expectation on the ground
- E_{imp} : energy of the debris at the impact
- f_{GIA} : rate of ground impact accident
- h_p : average person height (Fig. 1)
- k : casualty area correction factor
- L_f : fragment length
- MTOW : Maximum Take Off Weight
- P_k : probability a target is incapacitated [6]
- p_s : shelter factor [14]
- $P(F|E)$: probability of a fatality given the exposure (Eq. (5.10) in [14])
- r_f : half of the fragment maximum dimension (Fig. 2)
- r_p : radius of the right circular cylinder representing a person (Fig. 1)

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S_{ref} : reference surface of the aircraft i.e. usually the wing platform area
W_f : fragment width

1. Introduction

Many aerial services would benefit from the contribution of Remotely Piloted Aircraft Systems (RPAS), commonly known as Unmanned Aerial Vehicles (UAV) or drones. Such services have conceptually proven their both technical and business feasibility in future smart cities environments, but they are still not available today [1,2]. The problem encountered, still not overcome, is mainly a regulatory issue. The risk related to the use of drones over populated areas, based on current risk estimation methods, is so high that it makes their use impossible or illegal over many environments. The use of drones is mainly critical in cities, where it would be more profitable. The limitations on drone overflight prevent both aerial services and their side beneficial effects. One of the reasons for the drone overflight ban is the current vehicle overflight risk assessment. Aviation authorities mainly use risk evaluation methodologies related to airplanes but applied to vehicles, the drones, for which these methodologies have not been originally developed to. The result is an overestimation of the resulting drone-related risk in case of an impact with the ground.

An element that appears in almost all of the risk assessments is the dimension of the *Casualty Area*. Its evaluation is the determining factor in assessing the risk associated with the flying vehicles. The formulas available in the literature for its estimation — in Table 1 — are not suitable for small drones. Being derived from aircraft or space debris cases, the available *Casualty Area* formulas overestimate the associated risk. Using them, a drone and an airplane would produce comparable levels of lethality in the event of ground impact. In this work, an attempt is made to offer a *Casualty Area* formula fitting small drones falling under the A2 European Aviation Safety Agency (EASA) category, C2 class [3], i.e. drones with a mass up to 4 kg.

Montgomery *et al.* [4] provide a correct definition of the *Casualty Area*. They state that it is *"the region on the ground within which 100% casualties occur and outside of which no one is injured."* Montgomery also states that a formulation of the *"Casualty Area"* must take into account the *"size of the person, falling debris, and angle on impact."* This last claim, called by the authors *"Montgomery's condition,"* invalidates several original Casualty Area formulations, which are invariant to these factors.

2. Casualty Area Literature Review

This section analyzes the various currently available *"Casualty Area"* formulations. The underlying hypotheses and the limits led to the need to introduce the present formulation suggested by the authors, which will be analyzed as well. Dalamagkidis [5] proposes a widely accredited risk evaluation formula (Eq. (1) — see also Sec. 4)

$$E_C(x,y) = f_{\text{GIA}} \cdot \sigma(x,y) \cdot A_C \cdot P(F|E)(x,y). \tag{1}$$

Equation (1), like the other risk evaluation formulas, takes into account some parameters of interest. In each risk evaluation formulation, the risk is proportional to the involved area population density (σ), to an area related to the characteristics of the flying vehicle (called *Casualty Area*, A_C) and its trajectory (determined by the glide angle γ) at least. The evaluation of the *Casualty Area* is, therefore, crucial. Many authors proposed their original formula for its evaluation, taking into account also the "*dimension of a person*" (Fig. 1), "*dimension of the debris*" (Fig. 2), and the "*falling debris trajectory path angle*" (Fig. 3).

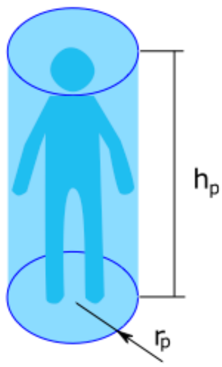

Fig. 1. Graphical representation of the right cylinder representing a human, including the variables h_p and r_p as well.

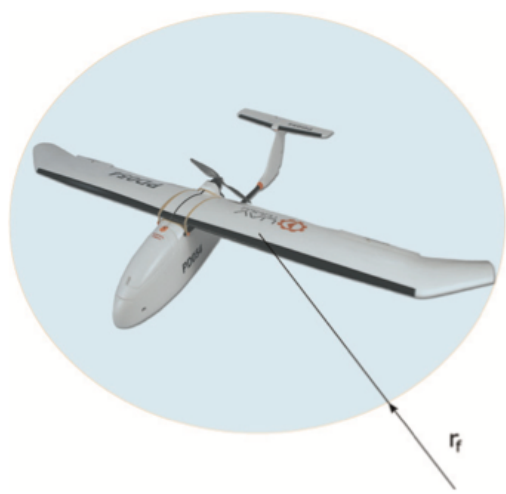

Fig. 2. The sphere containing the UAV and its radius r_f. The variable r_f represents half of the fragment maximum dimension.

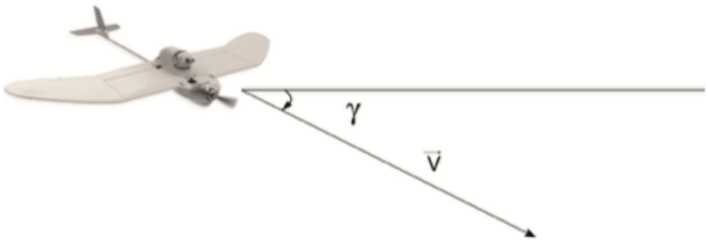

Fig. 3. Representation of the glide angle γ, the angle between the horizontal plane and the drone (or fragment) velocity.

Table 1 shows how some authors have defined the "*Casualty Area*" in their work. Myers in [6] lists some of the sizing factors, including velocity fall-off law, number of obstacles present in the affected ground area, fragment mass distribution, fragment density, and initial fragment velocity; anyway, it is difficult to evaluate some of those factors because of the random nature of the overall dynamics. Myers also provides his formulation of the *Casualty Area*, as shown in Table 1. Myers' formula fulfills Montgomery's condition: it could be used in risk assessment even if introducing a further issue. The problem with his mathematically exact formulation is that it is not practically applicable.

Being a nonpractical formula, the Myers' one cannot determine any quantitative value, and soon, more practical formulations have been proposed. The simplest evaluation of the *Casualty Area* is the one proposed by Weibel and Hansman in [7]. They state that the *Casualty Area* equals the debris frontal area, as shown in Table 1. This definition does not take into account essential factors, such as the glide angle γ (Fig. 3). It proposes, therefore, a constant value — as not respecting Montgomery's criteria, the Weibel's formula cannot be directly used as a *Casualty Area* in risk assessment.

EASA, in [8], also used to associate the *Casualty Area* to the reference area (S_{ref}) and the Maximum Take Off Weight (MTOW) via a k factor, as shown in Table 1. This formula, like the one derived by Weibel, was proposed for an immediate evaluation. Even this formula, however, does not respect Montgomery's condition: it produces a constant

Table 1. Comparison of the critical area models.

Authors	Corresponding critical area model
Myers [6]	$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_k(x,y)\,\mathrm{d}x\mathrm{d}y$
Weibel [7]	Falling object frontal area
EASA [8]	$k \cdot (\frac{\text{MTOW}^2}{S_{\text{ref}}})^{\frac{2}{3}}$
Grimsley [9]	$(L_f + h_p/\tan(\gamma) + 0.6)(W_f + 0.6)$
Dalamagkidis [5]	$W_f \cdot [L_f + \frac{h_p}{\sin(\gamma)}]$
Montgomery [4]	$\begin{cases} 2(r_p + r_f)h_p/\tan(\gamma) + \pi(r_p + r_f)^2 & \gamma < 90^\circ \\ \pi(r_p + r_z)^2 & \gamma = 90^\circ \end{cases}$

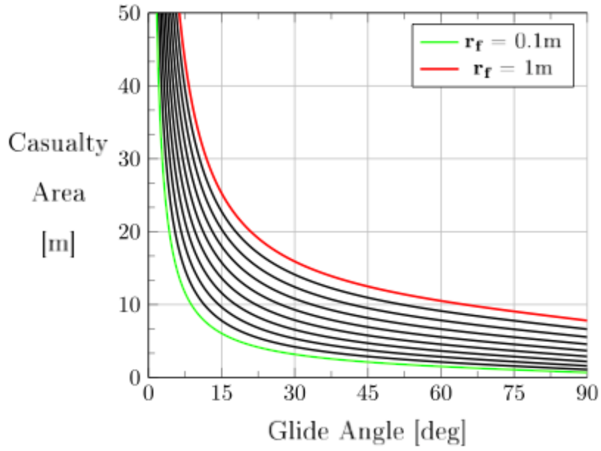

Fig. 4. Casualty Area proposed by Grimsley in [9], see Table 1. The graph is parameterized for the UAV fragment radius, r_f.

result. For this reason, it cannot be used *as is* in the risk assessment procedure.

Grimsley [9] proposes his own formula, included in Table 1, and represented in Fig. 4. In this formula, the size of the debris (given by dimensions L_f and W_f), the height of an average person (h_p) and the glide angle γ (Fig. 3) are taken into account.

Grimsley's formulation complies with Montgomery's requirements for the *Casualty Area*. However, it does present a problem. By using the tangent trigonometric function, it is not determined if γ equals zero. As Fig. 4 shows, it offers very large values for small γ. Since the risk linearly depends on the *Casualty Area* — as it can be deduced from Eq. (1), the formula used for risk assessment, proposed by Dalamagkidis in [5], — Grimsley's formulation can lead to very high risk values, tending towards infinite. This conclusion is not logically acceptable: a drone cannot produce infinite risk. It follows that even the Casualty Area related to a drone cannot be infinite at any point. Grimsley's formulation is therefore unsuitable, at least to describe the Casualty Area related to small-sized drones.

Dalamagkidis [5] analyzes a wide set of flying vehicles, presenting a series of useful improvements in the risk evaluation. He also proposes an original Casualty Area assessment, shown in Table 1 and Fig. 5. This formula presents the same problem as the one proposed by Grimsley; since the limit as γ approaches zero equals infinite, this formula cannot be used without limitations for drone's risk assessment, even meeting Montgomery's requirements.

Montgomery, after suggesting the criteria for the Casualty Area formula, proposed an alternative solution. This formulation — given by Eq. (2), in Table 1 and in Fig. 6 — had a great success; among others, it was used by Ranger Commanders Council (R.C.C.) [10,11], and by the FAA [12], while EASA previously used to exploit it.

Montgomery was the first to state that a formulation of the Casualty Area must take into account the *size of the*

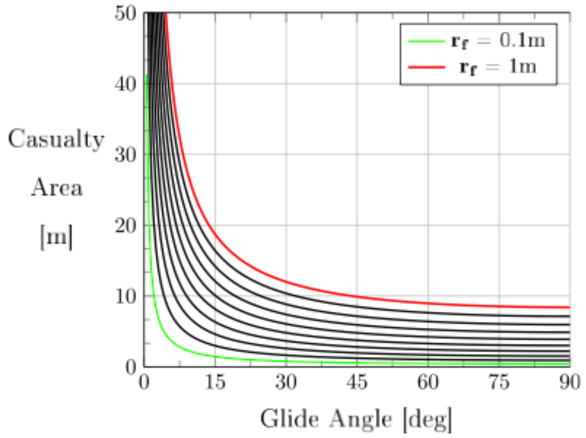

Fig. 5. Casualty Area proposed by Dalamagkidis [5], see Table 1. The graph is parameterized for the UAV fragment radius, r_f.

person (Fig. 1), *the size of the debris* (Fig. 2) and, the *glide angle* (Fig. 3). As Fig. 6 shows, Montgomery's formulation also presents the Casualty Area value divergence problem for γ approaching zero. This formulation is not suitable to represent the overall risk due to drone overflight. This paper tries to tailor the Montgomery's formulation to small size drones belonging to the A2 EASA category, C2 class [3], i.e. with a mass up to 4 kg. It will be fulfilled by varying some underlying hypotheses, following the same process fulfilled by Montgomery, as explained in Sec. 3. The original formulation respects the guidelines set by the aviation authorities (FAA and EASA). The vehicle impact is considered without a slide, bounce, and fragmentation.

3. Methodology

The present formulation of the *Casualty Area* respects the criteria that Montgomery identified in [4]. The authors take into account the size of the human (a person on the ground, represented by the magnitudes r_p and h_p, Fig. 1), of the falling debris (represented by the magnitude r_f, Fig. 2), and the angle of impact (glide angle γ, Fig. 3). These parameters are the same used by Montgomery for his *Casualty Area* formula, Eq. (2), and they are defined as follows. Each person is assumed to be equivalent to a vertically-oriented, right circular cylinder h_p high, and with radius r_p. The parameters h_p and r_p are set to 6.0 ft (1.8 m) and 1 ft (0.3 m) [10], as shown in Fig. 1. All the falling debris are assumed spherical with the debris's most massive cross-sectional length as diagonal; r_f is the radius of such a sphere (see Fig. 2). Figure 3 denotes the *glide angle*, γ, as the angle between the horizontal plane and the drone impact velocity. This paper uses such variables in the same definition. We use a different hypothesis, the original *Casualty Area* formula is based on, with respect to the Montgomery's one, the kinetic energy of the falling debris. When Montgomery defined his formulation [4], he considered that the kinetic energy of the debris was so high that any obstacle found to the ground kept its path unchanged; the debris stops only when finally touching the ground [12]. The authors assume debris with low kinetic energy at the impact, such as stopping its fall, impacting with the first object encountered along the path. Presently, a new right cylinder called *buffer cylinder* is introduced, created by adding the debris radius r_f to the right-man cylinder dimensions r_p and h_p.

The Casualty Area, according to Montgomery, equals the area that the *buffer cylinder* projects on the floor illuminated by γ-inclined radial lines (see Fig. 8).

Figure 9 shows Montgomery's Casualty Area breakdown into a circle and a rectangle.

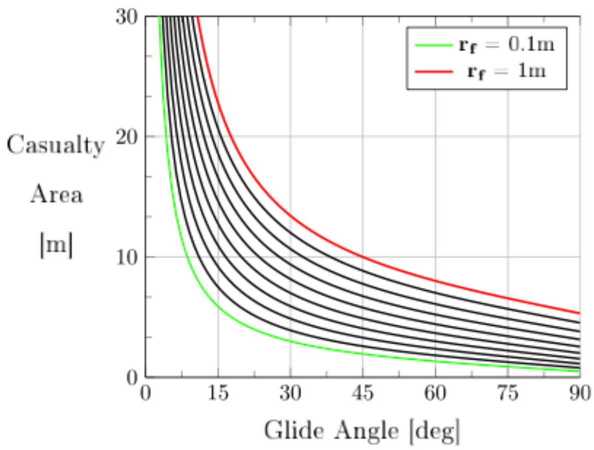

Fig. 6. Graphical representation of the Casualty Area as a function of the glide angle γ according to Montgomery formula [4] in Eq. (2). The graph is parameterized for the UAV fragment radius, r_f.

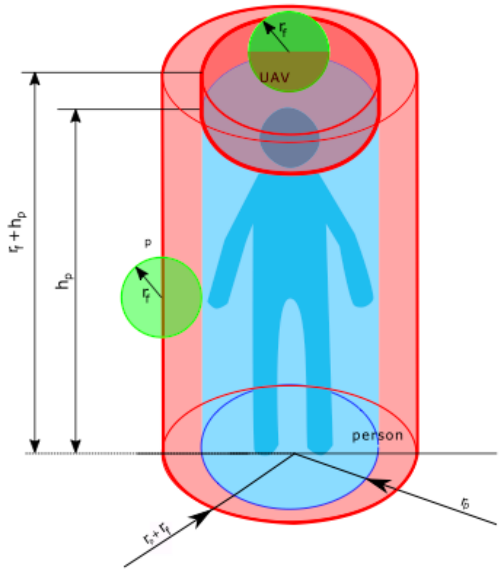

Fig. 7. Buffer cylinder, as in the formulations given by R.C.C. [10–12], Montgomery [4], and in the present formulation.

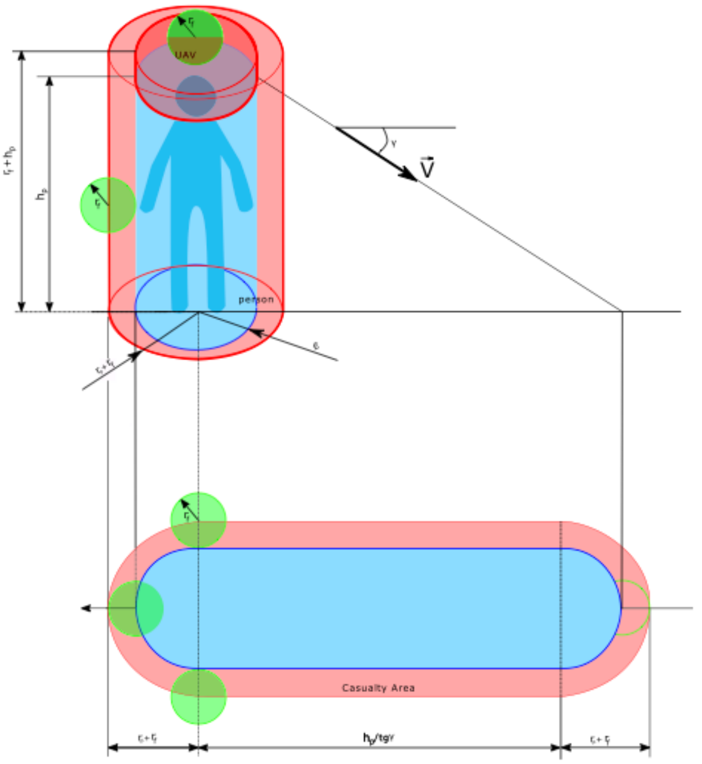

Fig. 8. Definition of the Casualty Area, according to Montgomery [10] in the nonvertical impact case.

Montgomery, in [4], proposes the following formula (Fig. 6 provides its graphical presentation):

$$\begin{cases} A_{C_{\text{old}}}(\gamma, r_f) = 2(r_p + r_f)h_p/\tan(\gamma) \\ \qquad\qquad +\pi(r_p + r_f)^2 & \gamma < 90^\circ, \\ A_{C_{\text{old}}}(\gamma, r_f) = \pi(r_p + r_f)^2 & \gamma = 90^\circ. \end{cases} \quad (2)$$

The subscript "*old*" refers to the Montgomery formula. Montgomery's equation (2) can assume two different forms, depending on γ. The former one when γ belongs to $[0^\circ, 90^\circ)$, the latter when γ equals to 90°. Equation (2) shows an issue, as previously clearly explained; its limit as γ approaches zero equals infinite, as Fig. 6 shows on its left side. Dalamagkidis in [5] proposes the most accreditated risk evaluation formula, Eq. (8) presented in Sec. 4; the authors of this paper also use it. Equation (8), like the other risk evaluation formulas, shows a risk trend proportional to the *Casualty Area*. When the Casualty Area becomes infinite, then the risk becomes infinite as well. This conclusion is not logically acceptable: a drone cannot produce infinite risk. This problem is overcome by deriving a new Casualty Area formulation assuming that the kinetic energy of the falling debris is such to stop when the first object is encountered on the path.

Montgomery's model represents the high kinetic energy falling debris case that does not stop except on the ground. Montgomery's formulation is correct but substantially not suitable for the small kinetic energy debris case, as the impact of drones belongs to the A2 EASA category, C2 class [3], where drones belong to a mass category up to 4 kg. In this last case, the most realistic hypothesis assumes debris with low kinetic energy at the impact, such as stopping its fall, impacting with the first object encountered along the path. This hypothesis underlays the *Casualty Area* formula proposed by the authors of this paper. It excludes an infinite Casualty Area (as for Montgomery in the null γ case). The projection of the buffer cylinder on an inclined plane represents a more realistic modeling of the *Casualty Area* in this case.

Conceptually, the original formulation of the *Casualty Area* is equivalent to the area of the buffer cylinder projection on a plane (see Fig. 7, the same used by Montgomery [4]); the cylinder is intersecting with γ-inclined radial lines while the plane is normal to them, as Fig. 10 shows (unlike the Montgomery model where the plane is always horizontal, as shown in Fig. 8). Figure 11 makes clear the breakdown of the novel *Casualty Area* model into an ellipse and a rectangle. In the horizontal flight path case, i.e. $\gamma = 0$, the *Casualty Area* equals the $2(r_p + r_f)$ by $(h_p + r_f)$ rectangle sized surface while in the vertical fall case, i.e. $\gamma = 90^\circ$, equals an $(r_p + r_f)$-radius circle surface, see Eq. (3).

$$\begin{cases} A_{C_{\text{new}}}(\gamma = 0^\circ) = 2(r_p + r_f)(h_p + r_f), \\ A_{C_{\text{new}}}(\gamma = 90^\circ) = \pi(r_p + r_f)^2. \end{cases} \quad (3)$$

The subscript "*new*" refers to the novel *Casualty Area* formulation introduced by the authors of this paper. In the

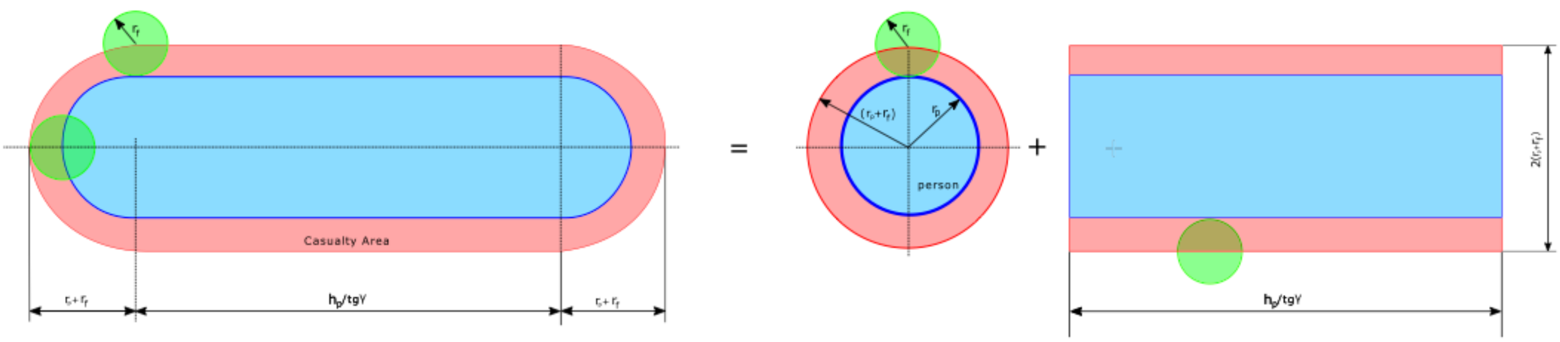

Fig. 9. Definition of the Casualty Area, according to Montgomery [10] (breakdown into circle and rectangle).

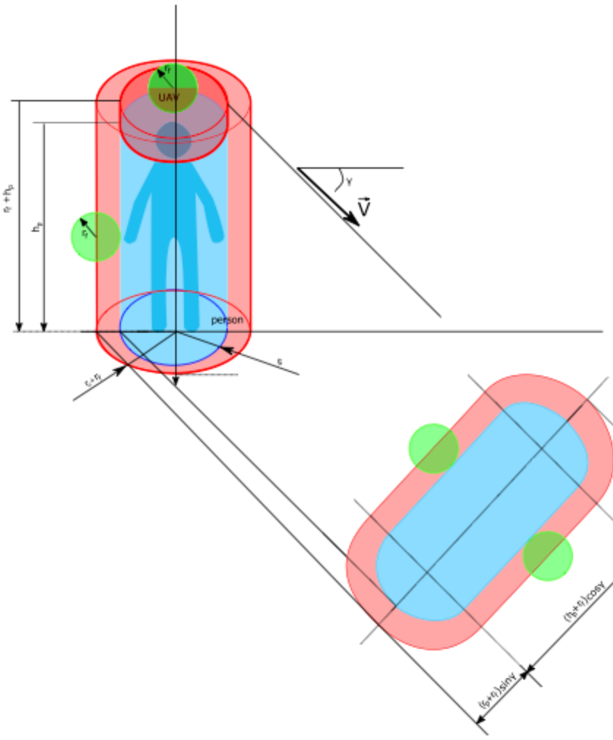

Fig. 10. Present definition of the Casualty Area.

intermediate γ range, the Casualty Area has both a contribution deriving from the circle — that becomes null if γ is null — and one deriving from the rectangle — that becomes null if γ equals $90°$. These contributions show a γ-trigonometric trend. The one related to the circle varies as the sine of γ and the one related to the rectangle varies as the cosine of γ. The new formula of *Casualty Area* results in the following equation:

$$A_{C_{\text{new}}}(\gamma, r_f) = \pi(r_p + r_f)^2 \sin(\gamma) + 2(r_p + r_f) \times (h_p + r_f)\cos(\gamma). \tag{4}$$

Figure 12 shows the present formulation (Eq. (4)) as a function of γ for several drones' sizes r_f while Fig. 13 overlaps the Montgomery's and the present formulation, highlighting the differences for small γ, where Montgomery's formula, Eq. (2), diverges while Eq. (4) is still defined.

The trend of Eq. (4) is continuous and finite for $\gamma \in [0°, 90°]$; for this reason, Eq. (4) admits a relative maximum. Equation (4) links a maximum finite *Casualty Area* value to each debris size r_f. Given the uncertainty about the angle γ at impact, the relative maximum of each curve assumes a significant value. The dotted line in Figs. 12 and 14 shows this value, called "*Exploitable Casualty Area*," $A_{c\,\text{exp}}$. Figure 14 plots $A_{c_{\text{exp}}}$ as a function of r_f, pointing out that the Casualty Area is not a function of both γ and r_f, but just of r_f. The "*Exploitable Casualty Area*" $A_{c_{\text{exp}}}$ is the value of the Casualty Area when γ fulfills the following condition:

$$\left.\frac{\partial A_{C_{\text{new}}}(\gamma, r_f)}{\partial \gamma}\right|_{r_f} = 0 \tag{5}$$

this condition occurs if

$$\gamma_{\text{exp}}(r_f) = \arctan\left[\frac{\pi(r_P + r_f)}{2(r_f + r_f)}\right]. \tag{6}$$

Therefore,

$$A_{c_{\text{exp}}}(r_f) = A_{c_{\text{new}}}(\gamma_{\text{exp}}(r_f), r_f). \tag{7}$$

This change in formulation turns out to be necessary considering the random nature of γ; a precise value of the "*Casualty Area*" can be assigned for each drone, as its "*Exploitable Casualty Area*" $A_{c_{\text{exp}}}$.

4. Influence of Different Casualty Areas on Risk Assessment

This section provides the influence of the various *Casualty Area* formulas in drone overflight risk assessment. As previously explained, the Casualty Area is a determining factor in the drone overflight risk assessment. Several formulations for risk calculation exist, but in this section, the one given by Dalamagkidis [5] as Eq. (8) is used, which to date is

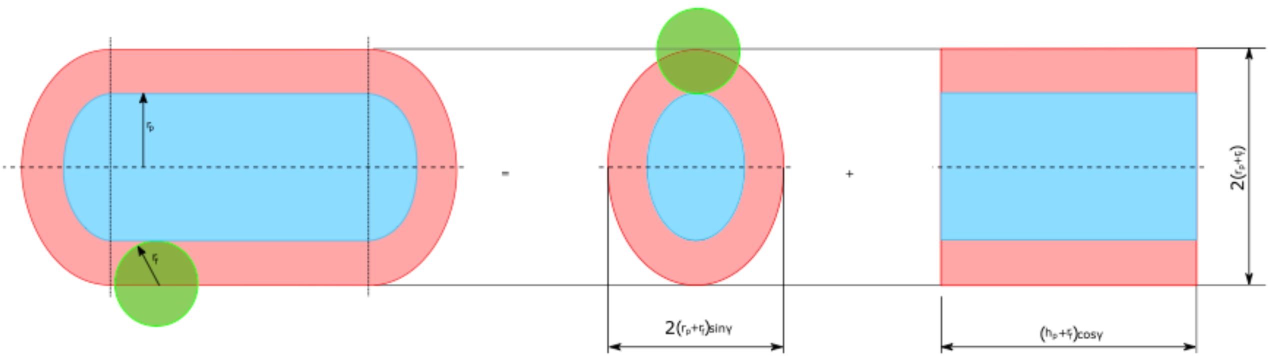

Fig. 11. Decomposition of the Casualty Area as the union of the areas of ellipse and rectangle.

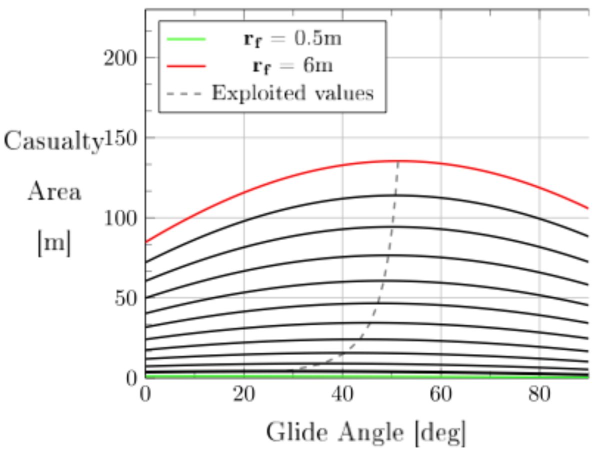

Fig. 12. Graphical representation of the Casualty Area as a function of the glide angle γ, according to Eq. (4). The graph is parametrized for UAV fragment radius, r_f.

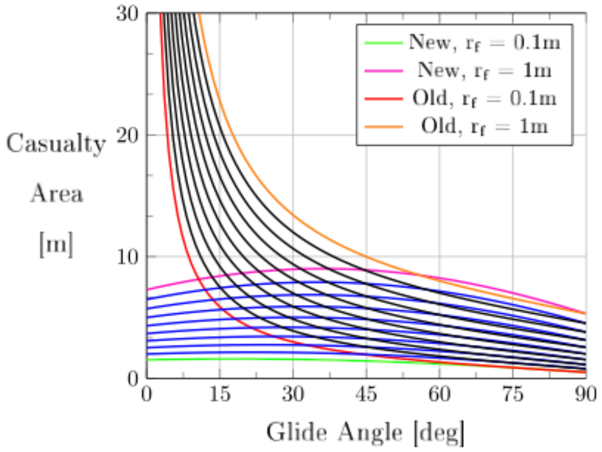

Fig. 13. Overlap of Eq. (2) [4], subscript *"Old,"* and the present formulation as Eq. (4), subscript "*New.*"

the best one fitting the impact of drones. The formulation of Dalamagkidis [5] contains some elements, including the *Casualty Area*. Formula (8) derives from a statistical analysis based on civil aviation casualties and reference

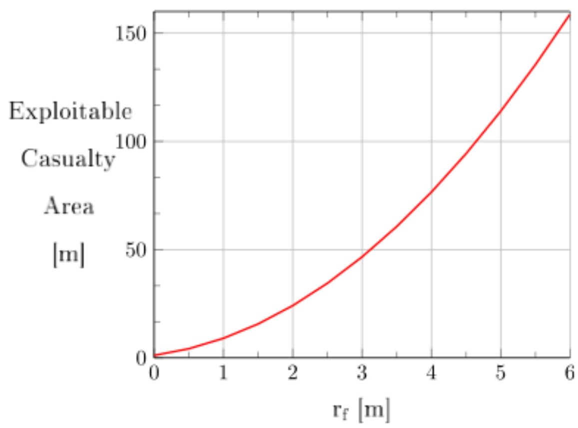

Fig. 14. Exploitable Casualty Area as a function of r_f.

Table 2. Data used for the risk assessment in Table 4.

UAV type	Fixed-Wing	Mass	1.5 kg
wing span	1.2 m	operative speed	12 m/s
$P(F\|E)$	1	E_{imp}	216 J
$p_s(x,y)$	0	f_{GIA}	10^{-7}
α	100 kJ	β	34 J

statistics. The formulation requires elements related to the area to overfly (population density, shelter parameter), some factors specific for the aerial vehicle (rate of ground impact accident, casualty area) and, finally, the probability of a fatality given the exposure. The result is the number of casualty expectation within the time reference.

$$E_C(x,y) = f_{\text{GIA}} \cdot \sigma(x,y) \cdot A_C \cdot P(F|E)(x,y). \tag{8}$$

Table 2 describes the data exploited for the risk assessment in this section and they refer to a fixed-wing drone as it is most likely to exhibit low glide angle γ at the impact.

Table 3 shows the *Casualty Area* according to different references and the effect of angle γ, while Table 4 reports the values of the risk using the various definitions of the *Casualty Area*. Both Tables 3 and 4 refer to a hypothetical case described by the reference data in Table 2. Knowing γ at impact with high accuracy is quite critical. The use of $A_{c_{\text{exp}}}$ over $A_{c_{\text{new}}}$ is a conservative choice. As a matter of fact, $A_{c_{\text{exp}}}$ provides the maximum value, among the $A_{c_{\text{new}}}$ values related to a specific drone. Compared to the other Casualty Area assessments presented in literature, $A_{c_{\text{exp}}}$ gives a lower value in the range γ (0°, 30°) and higher in the remaining range. In particular, the *Casualty Area* assessment available in the literature leads to divergent values of the Casualty area, and therefore of risk, for γ null. It is reiterated that diverging risk value is unreasonable for the drones this

Table 3. Comparison of Casualty Area definitions.

γ \ $A_C[\text{m}^2]$	Exploitable	New	Montgomery [4]	Dalamagkidis [5]	Grimsley [9]
0°	5.02	4.32	∞	∞	∞
5°	5.02	4.52	39.58	26.51	40.70
10°	5.02	4.69	20.92	14.17	22.05
15°	5.02	4.83	14.64	10.07	15.76
30°	5.02	5.01	8.16	6.05	9.28
45°	5.02	4.85	5.78	4.78	6.91
60°	5.02	4.36	4.41	4.22	5.54
75°	5.02	3.58	3.41	3.96	4.54
90°	5.02	2.54	2.55	3.88	3.67

Table 4. Risk evaluated with different Casualty Area definitions.

γ \ $E_C[\times 10^{-5}]$	Exploitable	New	Montgomery [4]	Dalamagkidis [5]	Grimsley [9]
0°	10.04	8.64	∞	∞	∞
5°	10.04	9.04	79.16	53.02	81.40
10°	10.04	9.38	41.84	28.34	44.10
15°	10.04	9.66	29.28	20.14	31.52
30°	10.04	10.02	16.32	12.10	18.65
45°	10.04	9.70	11.56	9.56	13.82
60°	10.04	8.72	8.82	8.44	11.08
75°	10.04	7.16	6.82	7.92	9.08
90°	10.04	5.08	5.10	7.76	7.34

work refers to, or more generally drones with a mass up to 4 kg.

The advantage in the adoption of $A_{c_{\text{exp}}}$ over the Casualty Area assessment available in the literature and $A_{c_{\text{new}}}$ is twofold. In the former, the value of the *Casualty Area* is limited for small γ; in the latter, it introduces a constant value to induce the effect of γ as negligible. $A_{c_{\text{exp}}}$, by proposing a constant *Casualty Area* value, produces a constant risk value as well.

5. Conclusions

The paper proposes a new approach for the definition of the *Casualty Area*, as it is fundamental in all flying vehicles risk assessment methodologies. Among references, there do not exist alternatives to the formulation proposed by Montgomery (see Eq. (2)), the most widely used. FAA still uses it, while EASA has abandoned its use. Now EASA sets a value for each aircraft, as shown in Table 1. Montgomery's equation, Eq. (2), fits the high kinetic energies debris case. Piloted aircraft belong to this category as they show high probabilities of damage or casualties in case of an impact on the ground. Using this formulation in the small drone case leads to unlikely high values of the associated risk. To overcome such problem, an original "*Casualty Area*" formula is proposed, following the same logical process adopted by Montgomery [4], only changing the hypothesis about the kinetic energy of the debris (i.e. the drone). The kinetic energy associated with drones, specifically the ones belonging to A2 EASA category, C2 class [3], drones with a mass up to 4 kg, in the event of a fall is low. The result is provided in Eq. (4). The novel methodology fulfills the FAA and EASA requirements. The consequences are essential. Since the risk associated with drones via the original Casualty Area formula is limited (and even constant), drones would be allowed to fly over areas previously unapproachable. This possibility potentially paves the way for drone services, currently not implemented.

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