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Combat survivability of hit aircratf

Keywords

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Abstract

The paper is provides a preliminary breakdown susceptibility analysis for an aircraft PZL-130 ORLIK TC II in combat conditions. An analysis of breakdown forms and consequences for aircraft sections and installations in battle conditions including probability of being shot down when hit was made. The article presents a theoretical outline for calculation methods on aircraft kill probability in case of being shot, depending on critical element configuration and number of hits. The probability figures have been calculated for a specific model describing the aircraft PZL-130 ORLIK TC II. As a result of the conducted analysis it was possible to determine, for a specified weapon caliber, probabilities and effects of receiving combat damage.

1. Introduction

PZL-130 ORLIK is a Polish two seat training aircraft designed by PZL Warszawa-Okęcie. This aircraft was designed for basic and advanced training primarily for military pilot candidates. It is not, armed aircraft however, in the event of symmetrical armed conflict could perform limited tasks liaison and reconnaissance missions, and therefore could be exposed to the enemy, both in flight and on the ground stop. Due to the purpose of operating the aircraft in combat only covers damage caused by the use of conventional warfare in the form of bullets/shrapnel 7.62 mm and 12.7 mm, and 23 mm HE projectiles.

2. Methodology of calculation

Analysis is the probability of survival for the aircraft on condition a bullet hit him. Reliability analysis developed in accordance with the procedure laid down in the book [2]. Each element of an aircraft is characterized by a certain level of vulnerability to damage. Critical components are those parts of the helicopter, the destruction of which leads to loss of the machine. In this analysis, the critical elements were: the pilots, engine, fuel tanks, outgoing tank fuel system, fuel system cables, and elevators with control system. The expression defining Orlik aircraft shot down can be represented as:

Aircraft kill = [(Pilot 1) **AND** (Pilot 2)] **OR**(Engine) **OR** (External fuel tank) **OR** (Internal fuel tank) **OR** (Outgoing tank fuel system) **OR** (Fuel system cables) **OR** (Elevators with control system) (1)

In general, the probability of destruction of aircraft due to enemy combat impact can be defined as[1]:

$$P_{K|H} = \frac{A_v}{A_p} \tag{2}$$

where all symbols are defined in *Table 1*.

The sensitive surface of *i-th* element, and are defined by the relationship [2]:

$$A_{vi} = A_{pi} \cdot P_{ki|hi} \tag{3}$$

Probability of aircraft survival defines the following general formula:

$$P_{S|H} = 1 - P_{K|H} \tag{4}$$

Table 1. Terminology definitions

Definition	*i-th* element	Aircraft
Probability of destroying *i-th* element (or aircraft) provided hits in the *i-th* element (or plane)	$P_{ki\|hi}$	$P_{K\|H}$
Probability of destroying *i-th* element provided hits in the *j-th* element	$P_{ki\|hj}$	-
The probability of hitting the *i-th* element provided hits in the plane	$P_{hi\|H}$	-
Probability of destroying *i-th* element provided hits in the plane	$P_{ki\|H}$	-
Probability of survival for the *i-th* element (or aircraft) provided hits in the plane	$P_{si\|H}$	$P_{S\|H}$
Sensitive area of the *i-th* element and (or aircraft)	A_{vi}	A_v
Area of the *i-th* element (or aircraft)	A_{pi}	A_p

3. Probability of destruction an aircraft under the influence of single-shot bullet 7.62 mm and 12.7 mm

Where the aircraft does not have a backup of critical components, and there is no overlap between the areas of critical throws elements defining shooting down a general expression is defined as:

Aircraft kill = (element 1) **OR** (element 2) **OR** ... **OR** (element n) (5)

Probability of shooting down the aircraft can be calculated with the following formula:

$$P_{K|H} = \sum_i P_{ki|H} \tag{6}$$

The sensitive area of the aircraft defined formula:

$$A_v = \sum_i A_{vi} - A_{v\ pilot} \tag{7}$$

3.1. Single top shot

On the basis of *Figure 2* in *Table 2* shows the results of calculations of probability of destruction the aircraft under the influence of single shot with the assumption that the aircraft is hit in the top position.

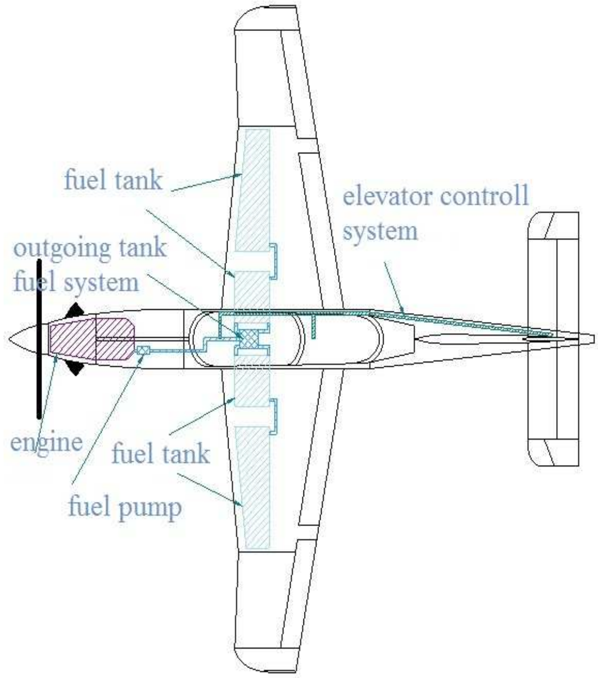

Figure 1. Scheme of PZL-130 Orlik TC II with applied geometry of critical systems and their components - the view from the top

Table 2. Summary of calculations for the airplane hit by the top position

Important element	A_{pi} [cm^2]	$P_{ki\|hi}$	A_{vi} [cm^2]	$P_{ki\|h}$
Pilot 1	4000	1	4000	0,018433
Pilot 2	4000	1	4000	0,018433
Engine	5360	0,7	3752	0,017290
External fuel tank	2·8460	0,7	11844	0,054581
Internal fuel tank	2·4170	0,7	5838	0,026903
Outgoing tank fuel system	1240	0,7	868	0,004000
Fuel system cables	100	0,9	90	0,000415
Elevators with control system	230	0,7	161	0,000742
Aircraft	**A_p = 217000 cm^2**	**-**	**A_v = 26553 cm^2**	**$P_{K\|H}$ = 0,122364**

Probability of destroying *i-th* element provided hits in the *j-th* element ($P_{ki|hi}$) were adopted on the basis of analogy to [11]. In this analysis it is assumed that the hit pilot is not able to continue the flight. In that case the probability of aircraft survival is:

$$P_{S|H} = 1 - P_{K|H} = 1 - 0{,}122364 = 0{,}877636 \qquad (8)$$

3.2. Single side shot

On the basis of *Figure 2* in *Table 2* shows the results of calculations for probability of destruction for the aircraft under the influence of single shot with the assumption that the aircraft is hit in the top position.

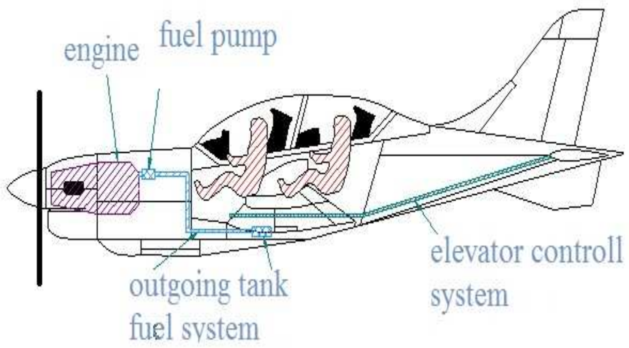

Figure 2. Scheme of PZL-130 Orlik TC II with applied geometry of critical systems and their components - the view from the side

Table 3. Summary of calculations for the airplane hit by the side position

Important element	A_{pi} [cm^2]	$P_{ki\|hi}$	A_{vi} [cm^2]	$P_{ki\|h}$
Pilot 1	4100	1	4100	0,033884
Pilot 2	4100	1	4100	0,033884
Engine	5500	0,7	3850	0,031818
External fuel tank	2·0	0,7	0	0
Internal fuel tank	2·0	0,7	0	0
Outgoing tank fuel system	400	0,7	280	0,002314
Fuel system cables	60	0,9	54	0,000446
Elevators with control system	190	0,7	133	0,001099
Aircraft	**A_p = 121000 cm^2**	**-**	**A_v = 8417 cm^2**	**$P_{K\|H}$ = 0,069562**

In that case the probability of aircraft survival is:

$$P_{S|H} = 1 - P_{K|H} = 1 - 0{,}069562 = 0{,}930438 \qquad (9)$$

4. Probability of destruction for aircraft under the influence of multiple bullet 7.62 mm and 12.7 mm shots

In order to calculate the probability of shooting down an aircraft under the influence of multiple shots can be used Markov chain. For the analysis of the case was taken when the aircraft has a spare element (it's pilot). Critical elements of the aircraft at any given time may be placed in one of five states:

1. one or more of the elements of non-redundant part is damaged, the condition is marked as *Knrc*
2. only the first pilot was shot – *kp1*
3. only the second pilot was shot– *kp2*
4. both of the pilots were shot, resulting in the downing of the aircraft – *Krc*
5. none of the pilots and none of the elements has been damaged – *nk*

As can be seen the destruction of the aircraft will take place when the aircraft is either in the first or in the fourth state.

Then, the transformation matrix $[\boldsymbol{T}]$ is constructed, where the element $T(i,j)$ describes the probability of transition from state *i* to state *j*. State vector $\{\boldsymbol{S}\}^{(k)}$ defines the probability of the aircraft in one of the five states of after *k-th* shot:

$$\{S\}^{(k)} = \begin{Bmatrix} P(Knrc) \\ P(kp1) \\ P(kp2) \\ P(Krc) \\ P(nk) \end{Bmatrix}^{(k)} \qquad (10)$$

Probability that an aircraft shot down by the *k-th* shot is defined as:

$$P_{K|H}^{(k)} = P(Knrc^{(k)}) + P(Krc^{(k)}) \qquad (11)$$

Stage *k+1* describes a situation in which the plane received another shot. Vector $\{\boldsymbol{S}\}^{(k+1)}$ is calculated using the following conversion:

$$\{S\}^{(k+1)} = [T]\{S\}^{(k)} \qquad (12)$$

The initial state is defined as:

$$\{S\}^{(0)} = [0\,0\,0\,0\,1]^T \tag{13}$$

4.1. Multiple top shots

Figure 1 shows the schematic PZL-130 Orlik TC II in the top view of the applied and the geometry of the critical elements of the installation with multiple points distributed randomly hits. Pass matrix [***T***] which describes probability of transition from state *i* to the state *j* of the aircraft in the top position is shown at (14). Probabilities were calculated based on the corresponding surface areas of critical elements in relation to the total area of the plane.

$$T = \begin{bmatrix} 1 & 0{,}104 & 0{,}104 & 0 & 0{,}104 \\ 0 & 0{,}878 & 0 & 0 & 0{,}0184 \\ 0 & 0 & 0{,}878 & 0 & 0{,}0184 \\ 0 & 0{,}0184 & 0{,}0184 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0{,}859 \end{bmatrix} \tag{14}$$

Figure 3 shows the results of calculations of the probability shooting down the aircraft hit by the multiple bullets in top position.

On the basis of formulas (11), (12) and (13) the probability of hit down the plane was calculated. The results are illustrated in *Figure 3*.

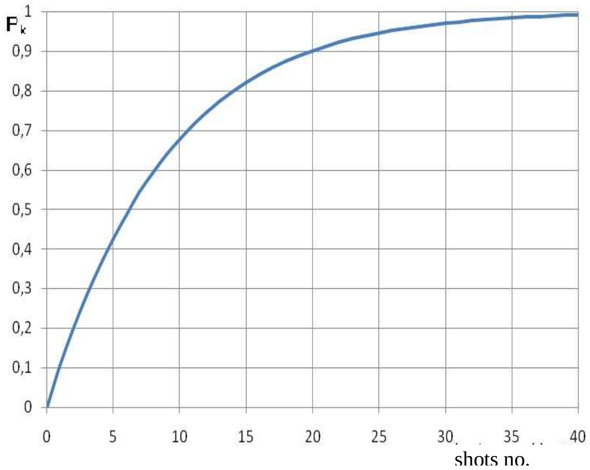

Figure 3. Probability of shooting down the aircraft hit by the top position

4.1. Multiple side shots

Based on *Figure 2*, which shows the schematic PZL-130 Orlik TC II in the top view with the geometry of the critical elements of the installation probabilities of transition from state *i* to state *j* were calculated. Pass matrix [***T***] for multiple side hits is as follows:

$$T = \begin{bmatrix} 1 & 0{,}0357 & 0{,}0357 & 0 & 0{,}0357 \\ 0 & 0{,}93 & 0 & 0 & 0{,}0339 \\ 0 & 0 & 0{,}93 & 0 & 0{,}0339 \\ 0 & 0{,}0339 & 0{,}0339 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0{,}897 \end{bmatrix} \tag{15}$$

Figure 4 shows the results of calculations of the probability shooting down the aircraft hit by the multiple bullets in side position.

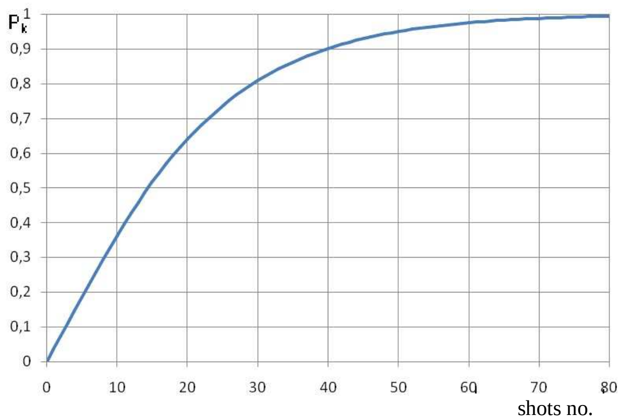

Figure 4. Probability of shooting down the aircraft hit by the side position.

5. Probability of destruction an aircraft under the influence of shot 23 mm HE bullet

In this scenario, was used to calculate the so-called increased field method [2], increasing the area of critical systems and their components beyond the surface to simulate the real property HE bullet.
Due to the specification of the high explosive bullets the assumed field for the analysis are greater.

5.1. Single top shot by 23 mm HE bullet

On the basis of *Figure 5* in *Table 6* shows the results of calculations of the probability of destruction the aircraft under the influence of single 23 mm HE bullet shot with the assumption that the aircraft is hit in the top position.

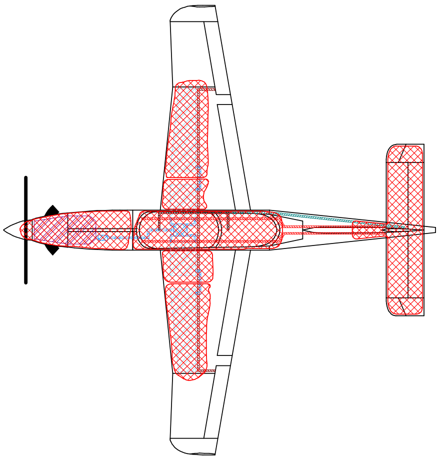

Figure 5. Top view of applied geometry of critical systems and their components

Table 6. Summary of calculations for the airplane hit by 23 mm HE bullet, top position

Important element	A_{pi} [cm^2]	$P_{ki\|hi}$	A_{vi} [cm^2]	$P_{ki\|h}$
Pilot 1	13150	1	13150	0,060599
Pilot 2	13150	1	13150	0,060599
Engine	16400	0,7	11480	0,052903
External fuel tank	2·17200	0,7	24080	0,110968
Internal fuel tank	2·6050	0,7	8470	0,039032
Elevators with control system	29900	0,7	20930	0,096452
Aircraft	**A_p= 217000 cm^2**	**-**	**A_v= 78110 cm^2**	**$P_{K\|H}$= 0,359954**

In that case the probability of aircraft survival is:

$$P_{S|H} = 1 - P_{K|H} = 1 - 0{,}359954 = 0{,}640046 \qquad (14)$$

5.2. Single side shot by 23 mm HE bullet

On the basis of *Figure 6* in *Table 7* shows the results of calculations of the probability of destruction the aircraft under the influence of single 23 mm HE bullet shot with the assumption that the aircraft is hit in the side position.
In that case the probability of aircraft survival is:

$$P_{S|H} = 1 - P_{K|H} = 1 - 0{,}269256 = 0{,}730744 \qquad (15)$$

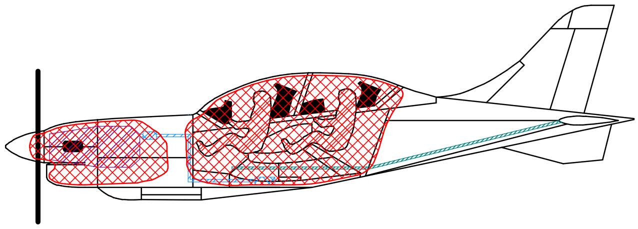

Figure 6. Scheme of PZL-130 Orlik TC II with applied geometry of critical systems and their components - the view from the side

Table 7. Summary of calculations for the airplane hit by 23 mm HE bullet, side position

Important element	**A_{pi} [cm^2]**	**$P_{ki\|hi}$**	**A_{vi} [cm^2]**	**$P_{ki\|h}$**
pilot 1	20750	1	20750	0,171488
pilot 2	20750	1	20750	0,171488
engine	16900	0,7	11830	0,097769
Aircraft	**A_p= 121000 cm^2**	**-**	**A_v= 32580 cm^2**	**$P_{K\|H}$= 0,269256**

3. Conclusion

The analysis of the form and effects of damage in combat of Orlik units and installations was possible to determine the effects of damage to units and installations aircraft and determine the probability of downing. Shot down is included in the highest category level of destruction.
The analysis of the form and effects of damage on the battlefield aircraft units and installation can be a starting base for the development of new armed version of the aircraft.
This work is a prelude to further discussion, which may included the different position of the plane at the moment of the shot, such as the bottom position occurring during the fire from the ground, or the positions, where the plane is in the front or the back view.

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