RISK EVALUATION THROUGH THE GLIDER STALL

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Summary

This paper concerns soaring safety. The purpose of this work is to evaluate the hazard and risk of the unintentional glider stall (by pilot's mistake). Special attention is paid to the hazard model, which constitutes a main part of a risk model. The probabilistic hazard model based on the event and fault trees has been proposed. As a result of the hazard model research the hazard distribution in a function of stall altitude has been obtained.

Introduction

The stall is the one of the most significant undesirable events which may initiate glider accidents and lead to losses. A decrease in glider speed to glider stall speed or the effect of a gust of wind may cause a stall. A spin is often the result of a stall.

As can be seen in accident statistics, the largest percentage (40%) of fatal accidents involve the stall/spin. Over 60% of all stall/spin accidents resulted in a fatality. During 1987-1996 in Poland 43 fatal or serious glider accidents took place, and 21 accidents were stall initiated. Typical events which appeared in such scenarios: a stall (resulting from loss of flight speed), a pilot's reaction to the stall, a spin, a pilot's reaction to the spin, instructor's reaction on the ground (by radio), a renewed pilot's reaction to the spin, recovery or ground crash, injury or loss of pilot's life. Usually, only a few of these mentioned events occur in a single incident.

The aim of this presentation is to evaluate the hazard level in relation to the unintentional stall (by mistake). The assessment of the safety and risk requires a knowledge of hazards. In many works, among others in [1, 3, 4, 5], it was proved, that risk level is dependent on a reliability level (possibility of undesired events occurrence) and a hazard level (possibility of losses in consequence of those undesired events) (Figure 1). The risk is usually defined as the possibility of losses in consequence of undesired events occurrence, which can occur in a considered fragment of man-technology-environment system in a determined time interval. It usually considers only human losses. Thus, safety is defined as the opposite concept to the risk of health and life to people.

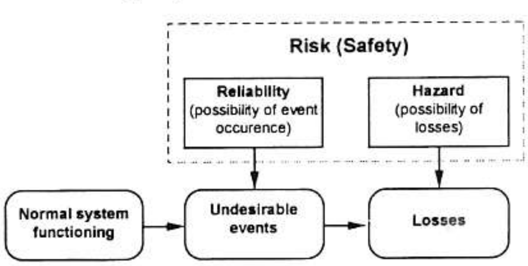

Figure 1. Factors determining risk level.

The hazard model through the stall will be presented as an illustration of theory discussed in reference 4. Their study showed that the measure of partial risk $\Lambda^{(k)}$ connected with the undesired event $A^{(k)}$ of k-form (for instance a glider stall) can be formulated as:

$$\Lambda^{(k)} = Q^{(k)}(\delta t) \cdot Z^{(k)}, \tag{1}$$

where $Q^{(k)}(\delta t)$ is the probability of occurrence of the event $A^{(k)}$ within the interval δt. The measure of the hazard $Z^{(k)}$ connected with an event $A^{(k)}$ is the probability of fatality on condition that event $A^{(k)}$ occurs:

$$Z^{(k)} = P\left\{C > 0 \mid A^{(k)}\right\}, \tag{2}$$

where C means the loss of human life (fatality: $C = 1$, otherwise: $C = 0$).

Assumptions

The most important assumptions are stated below.

1) It was assumed that the stall, denoted by $A^{(1)}$ is unintentional and occurs at altitude *h [m]*. The intentional stalls are characterized by different reaction times.

2) In this approach, no consideration is given to the fact that after recovery from one stall the pilot can start another stall. In every one event sequences only one stall has been considered. The possibility of second stalls has not been investigated. Secondary stalls are often observed in real flights; hence one should go into details of this matter in the future.

3) It was assumed that events which follow the stall do not depend on the past. The influence of dependency between events before and after the stall has been ignored.

4) It was assumed that a glider starts spinning if there is no correct pilot's reaction within several seconds after the stall. This time is treated as random variable characterized by the uniform distribution function, denoted by $\mathbf{T}_{k_r}$ *(In this work the symbols of random variables are printed as bold)*. The times connected with pilot reaction: $\mathbf{T}_{P1}$, $\mathbf{T}_{P2}$, $\mathbf{T}_{P3}$ and instructor reaction: $\mathbf{T}_{K1}$ are taken as random variables. There are sums of times introduced below:

T_{P1} - the time from a stall till start of pilot's reaction plus time of pilot's reaction plus time of glider's reaction;

T_{P2} - the time from start of spinning till start of pilot's reaction plus time of pilot's reaction (aimed at stopping auto-rotation) plus time of glider reaction;

T_{K1} - the time from start of spinning till start of reaction by the instructor on the ground (instruction by radio) plus time of instructor's reaction;

T_{P3}- the time from ground instructor's reaction till start of pilot's reaction to the spin plus time of pilot's reaction (aimed at stopping auto-rotation) plus time of glider reaction.

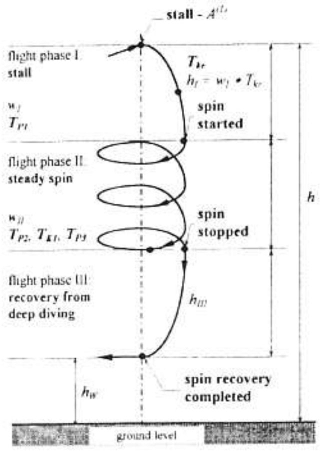

Figure 2. Flight phases following a stall.

5) We can distinguish three flight phases after the stall (Figure 2): a stall in straight flight, steady spin and recovery from deep diving. The transitional zones between distinguished phases have been neglected.

6) Consider constant glider sink speeds in first two flight phases after the stall, denoted by: w_I, w_{II} $[m/s]$. Hence result linear functions of losses of glider altitude: h_I, h_{II} $[m]$. The altitude loss after spin stopped can also be a constant value. Date values were assumed as follows: $w_I \approx 10\ m/s$, $w_{II} \approx 20\ m/s$, $h_{III} \approx 50\ m$. Nearer to real functions can be obtained from glider motion equations.

Hazard model

The hazard measure through the stall, denoted by $Z^{(1)}$ is the probability of fatality on condition that the event $A^{(1)}$ occurs:

$$Z^{(1)} = P\{C > 0 | A^{(1)}\}. \tag{3}$$

But a hazard through a glider ground crash, denote by Z, depends on the flight phase (see Figure 3):

$$Z = P\{C > 0 | \text{ground crash(flight phase)}\}. \tag{4}$$

In Figure 3 we can see the hazard models in consequence

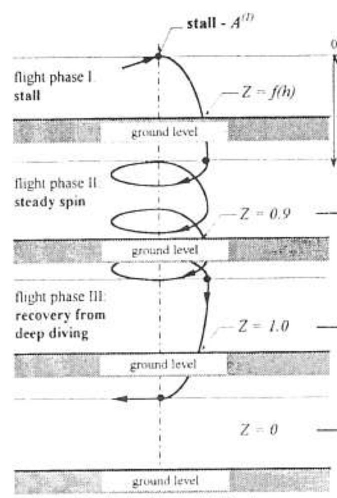

Figure 3. Hazard models in consequence of the glider ground crashing in selected flight phases after stall.

of the glider ground crashing in selected flight phases after stall. In phase I it is assumed that the hazard is a linear function of the stall altitude h. In phase II during steady spin the hazard is constant, equals $Z = 0.9$. In phase III during recovery from deep diving the hazard is also constant, but equals $Z = 1.0$. For example, if hazard $Z = 0.9$, it means that the probability of fatality ($C=1$) equals 0.9 and the probability of pilot survive ($C=0$) equals 0.1.

Next the event tree for a stall has been constructed (see Figure 4). Other event sequences not shown in Figure 4 have been ignored.

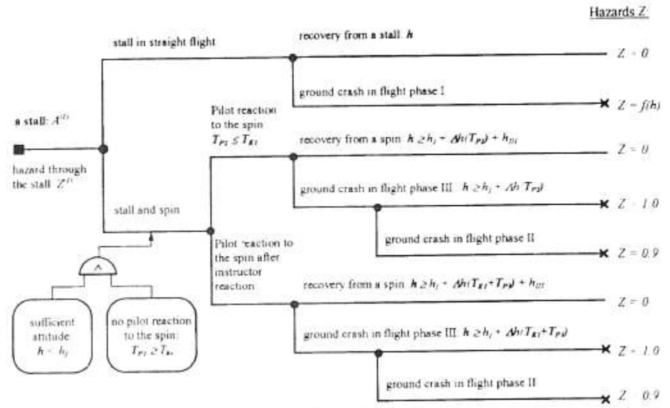

Figure 4. The event tree for the glider fall.

The Rasmussen human reliability model taken from reference [2] has been used in order to describe the time of the pilot's reaction and time of instructor's reaction. Let us now assume that these reaction times are treated as random variable and are characterized by a Weilbull distribution function, given by:

$$F(\tau) = 1 - \exp\left[-\frac{\frac{\tau}{T_{1/2}} - \gamma}{\eta}\right]^{\beta} \tag{5}$$

$F(\tau)$ - the Weibull distribution function;

τ - the reaction time;

$T_{1/2}$ - the estimated median time taken by the crew to complete the task (assessed by expert opinion);

b, g, h-the Weibull distribution parameters used in this analysis are given in Table 1.

Table 1. Weibull distribution parameters (following the Rasmussen classification [2]).

Type of cognitive processing	β	γ	η
Skill	1.13	0.720	0.388
Rule	1.27	0.148	1.14
Knowledge	0.795	0.389	0.969

According to Rasmussen classification there are three types of human cognitive processing: skill, rule and knowledge based. For example, pilot's reaction to a stall (moving the stick forward) is simple and can be determined as a skill-based reaction, but the reaction to a spin (apply full opposite rudder and then move the stick steadily forward until the glider stops spinning) is more complicated and should be determined as rule-based. The instructor's reaction is suitable as knowledge-based.

The method and results

To the research model computer simulating method was applied. Many experiments have been carried out on the model instead of the real object. In this case every experiment is a simulated stall according to an event tree shown in Figure 4. The determined sequence appears depending on time values: T_{kr}, T_{PI}, T_{P2}, T_{P3}, T_{KI} and altitude h. Random time values are selected using a random number generator and the appropriate distribution function of the random variable: Weibull and uniform. Following this operation event sequence is already known, hence also corresponding hazard Z. Based on this information, random loss value C is determined (pilot killed or not). A special computer program has been created to run the above procedure.

Simulated results of individual cases of stall for random altitudes h are presented in Table 2. Stalls number 1 and 5 resulted in recovery ($C=O$), while stalls number 2, 3 and 4 resulted in fatal crashes ($C=l$). There was a spin in cases 3, 4 and 5 (spin recovery only in case 5) while in case number 3 the glider crashed in steady spin in phase II (Z=0.9), in case 4 the glider crashed during spin recovery in phase III (Z=l.0).

Table 2. Random event sequence for a number of stalls.

	stall no. 1	stall no. 2	stall no. 3	stall no. 4	stall no. 5
event sequence	stall pilot's reaction altitude loss recovery	stall pilot's reaction altitude loss ground crash	stall spin pilot's reaction ground crash	stall spin instructor's reaction pilot's reaction ground crash	stall spin pilot's reaction recovery
h [m]	103.8	10.5	99.5	178.8	104.2
h_W [m]	87.8	-6.1	-58.8	-6.4	6.3
Z (hazard)	0	0.39	0.9	1.0	0
C (loss)	0	1	1	1	0

But even more interesting are the results of the investigation of many stalls, as this makes it possible to determine a whole population of stalls. As a result of conducting many ($N_s = 2000$) computer simulated experiments for selected altitude h in $0 \div 200$ metres range a following sequence of losses has been obtained:

$$\text{for example: } C = \underbrace{\{0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, \ldots\}}_{N_S}, \quad n_S$$

where n denotes number of experiments in which loss **C** equals 1^s(for established altitude h)

The sequence of losses was subject to statistical analysis. Estimated hazard through the stall $Z^{(1)}$ can be calculated by following equation:

$$\hat{Z}^{(1)}(h) = \frac{n_S(h)}{N_S}. \qquad (6)$$

Figure 5 shows the hazard distribution as a function of the stall altitude.

Conclusions

Consequently, it can be said that the variation of hazard assessed on the basis of presented model in the function of a stall altitude $Z^{(1)} = f(h)$ is significant. Figure 5 shows that the maximum hazard value is achieved for an altitude of about

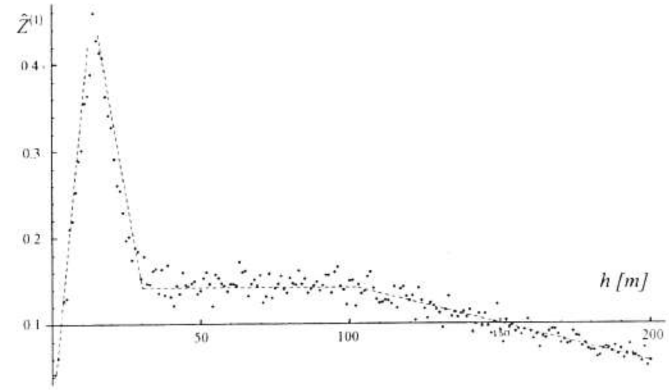

Figure 5. Hazard through the stall as a function of stall attitude.

20 m. In the 30 - 100 m range this means the hazard value equals $\bar{Z}^{(1)} \approx 0.14$. It means that the probability of pilot's death resulting from an unintentional stall in this altitude range equals 0.14. It seems that this value and the character of this curve corresponds with the common pilot's intuition.

Hence, the risk connected with a stall in the 30 - 100 m range can be determined as follows (see reference [4])

$$\Lambda^{(1)} = P\{A^{(1)}\} \cdot \bar{Z}^{(1)}, \qquad (7)$$

where $P\{A^{(1)}\}$ - is the probability of glider stall per unit time (for example as per one flight hour) in a determined altitude range. Therefore, to determine the risk, it is necessary to assess the hazard.

The majority of this work has been concentrated in the area of quantitative hazard evaluation. Numerical results presented for the glider stall solution shows the effectiveness of this method. The proposed model may be applied successfully to several another problems connected with gliding safety.

Acknowledgments

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References

[l] Aven T.: *Reliability and risk analysis*. Elsevier 1992.

[2] Boffi V.C., Santucci R., Vestrucci P.: *Operator action sequence simulation*. Proc. of the Inter. Conf. on Probabilistic Safety Assessment and Management, Ed. G. Apostolakis. Elsevier 1991, p. 953-958.

[3] Dhillon B.S.: *Mechanical reliability: theory models and applications*. AIAA education series 1988.

[4] Pancewicz T., Szopa T.: *Tree methods for risk evaluation of the glider flight*. Proc. of XXV OSTIV Congress, Saint Auban, France, 3-11 July 1997.

[5] *Structural safety & reliability*. Proc. of ICOSSAR'93. Ed. G.I. Schuoller, M. Shinozuka, J.T.P. Yao. A.A. Balkema 1994.