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SAFETY PERFORMANCE INDICATORS ASSESSMENT FOR SMALL AIRCRAFT AIRFRAME SYSTEMS

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Abstract

Safety performance indicators are the parameters used for monitoring and assessing safety performance. Such factors are determined based on available safety databases, collected on government level (in Poland Civil Aviation Authority) or by aircraft operators. Aircraft system failure during different flight phases can cause an accident or an incident. Polish Civil Aviation Authority between other data bases manages two important ones called: European Coordination Centre for Aviation Incident Reporting Systems (ECCAIRS) and Aircraft Continuing Airworthiness Monitoring (ACAM).General Aviation (GA) operates mainly aircraft with MTOM<5700 kg powered by the single piston engine. At present, reliability of GA aircraft systems in Poland is unknown. Increasing size of this fleet in Poland requires taking necessary measures in order to establish safety risks and safety performance targets for GA fleet. The authors have performed processing of the data included in available databases analysing airframe failures based on criteria like: phases of flight, ATA chapters concerning aircraft systems and the category of occurrence. The goal of this article is to present method of the current reliability of GA aircraft systems assessment. The results of this analysis can support the decisions of supervisory authorities in the areas where security threats are most important also can help production organizations in identification of the aircraft systems, which required design changes.

Keywords: *aircraft system, small aircraft, ATA chapter, safety risk*

1. Introduction

Statistical tools are a powerful support to reliability engineering and related disciplines. Reliability engineering is not just an application of probability and statistics. Reliability engineering is the science of designing products and making the processes reliable. Probability and statistics are simply means that can help evaluate, predict and measure reliability thereby safety management. This is the process of the control over the possibility that "… harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management…" [6].

Quality of the statistical calculations and analysis depend on accuracy of the data were subject to mathematical processing. It is very important, because data based decision-making is one of the most important features of aviation safety management system.

Importance of safety matters especially in the area of the light aircraft is a subject of many research organizations interest worldwide [5], including the Institute of Aviation [7].

In order to establish safety performance indicators and then systems vital for flight safety airframe, the database named European Coordination Centre for Aviation Incident Reporting Systems (ECCAIRS) has been utilized by authors. Such database consists of information concerning aviation's events.

Table 1 shows an example of the some information included in this database, which were processed by the authors. Requirements of the data confidentiality do not allow showing aircraft registration as well as any names.

Tab. 1. The examples of some reports in the database ECCAIRS

Report number	0003/2012	0011/2010	0014/2009
Aircraft type	Liberty XL2	Cessna525	PiaggioP.180
Engine type	Continental IOF-240-B	Williams FJ44-1AP	PT-6A-66
Date of occur.	2012-01-02	2010-01-06	2009-01-09
Event	Occurrence	Incident	Incident
Flight phase	Standing	En route	Take-off
Description	During a pre-flight inspection of Liberty XL-2 there was stated a fuel leak seen in the lower and front side of the fuel tank. Because of little amounts of fuel spilled on big surface and a lack of access to the front part of the fuel tank, it was difficult to find the accurate place of fuel leak.	The pilot of Cessna 525 during climbing, before reaching of FL100 noticed "Engine control system fault" illumination and informed ATC. Then, he followed the checklist. An engine parameters-standard. The crew requested ATC for "Priority Handling" to make a precautionary landing at the departure airport. The aircraft landed at 13.48 UTC.	The crew of Piaggio P.180 rejected take-of due to fox crossing RWY. The crew performed back-track and executed another take-off. Inspection (performed on crew's ask after take-off) showed no animals presence in RWY area.
ICAO occur	SCF-NP	SCF-PP	WILD

2. Research method

They were 2009 reported events involving Polish registration aircraft with MTOM<5700 kg in years 2008-2015. All of them were carefully analysed and one from the ICAO Aviation Occurrence Categories has been assigned to each event [1]. Technical events (SCF-NP and SCF-PP) additionally were coded using ATA 100 chapters [4].

The current way of analysing the data contained in ECCAIRS is based on comparing the number of events in the current year, with a corresponding number of events in the previous year. The decrease in the number of events is considered as an indicator of a safety improvement. Such a method does not reflect changes in traffic and the number of registered aircraft.

During 2008-2015 the number of aircraft involved in air traffic changed. In order to objectify the analysis of the data a coefficients relating number of all the events or in any category to the number of aircraft registered in this category (per, 1000 aircraft) was introduced.

$$ZS_{GA(X)} = \frac{1000 * \mathrm{LZ}_{\mathrm{GA}}}{\mathrm{LSP}_{\mathrm{GA}}}, \tag{1}$$

where:

LZ_{GA} –number of events for aircraft MTOM<5700,
LSP_{GA} –number of registered aircraft MTOM<5700 kg,
X –index for any category or ATA chapter.

The authors propose forecasting based on observation of the trend of several years and setting alert levels (maximum acceptable level) assuming a normal distribution. The forecasts should be verified annually by comparing them with an actual number of events.

To determine the alert levels the method of Shewhart Control Charts could be used that allows for an observation of process variability, as well as identifying the reasons that cause this increase in volatility [3]. Shewhart divided causes of process variation into random and special ones.

Random causes are numerous and the effect of each one is relatively small compared with the result of the occurrence of special causes, but the cumulative effect of random causes is usually quite significant. The main purpose of such a process monitoring is thus signalling the deviations from a statistically stable condition, caused by special reasons. They are associated with human activities (operator, pilot ...), characteristics of the machine changes (e.g. aircraft) and when found they should be removed or a corrective action has to be taken.

The Shewhart Control Chart limits (see Fig. 1) are located 3σ on each side of the centre line (average values m), where σ is the standard deviation in each subset of the population estimated on variability of the samples. Interval from -3σ to +3σ comprises 99.73% of the total area of the characteristic dispersion. The boundaries established at 3σ show that about 99.73% of the subset would be in the area defined by the control lines assuming that the process is statistically regulated. Control chart contains also 2σ limits on both sides of the line of mean values m, as alert levels. In this area should be 95.4% of the variation of the studied phenomenon.

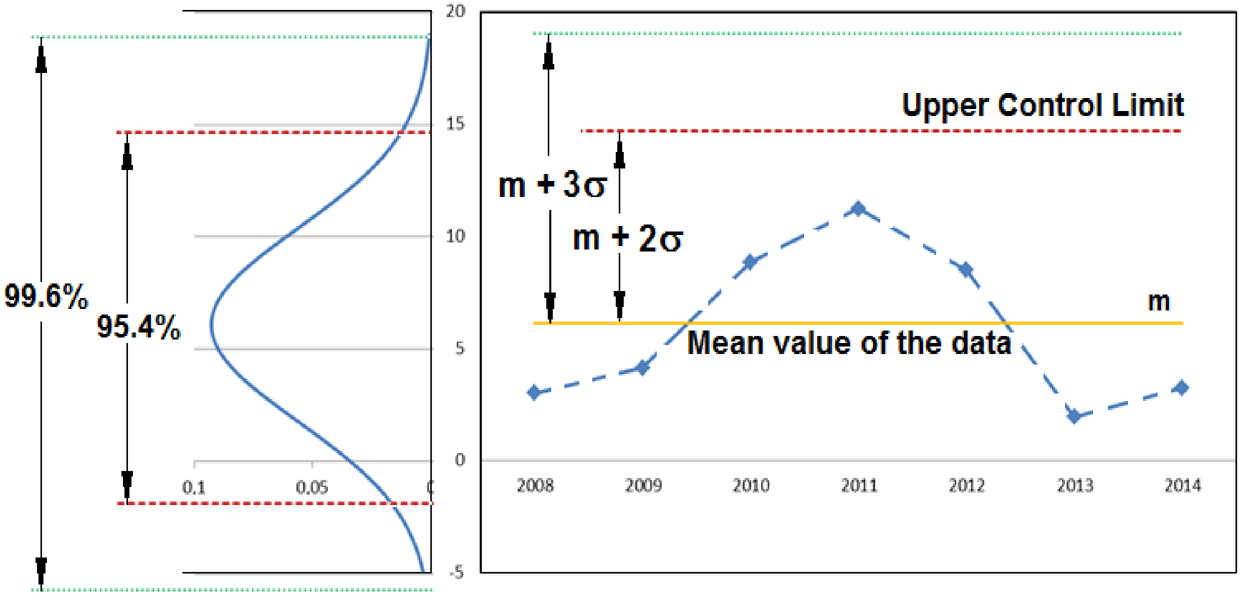

Fig. 1. Dependence between confidence level and confidence interval: m – mean; σ – standard deviation

Samples that appear outside 2σ may indicate the possibility of going beyond the defined control limits. Methodology for determining the forecast for the next year and determining alert levels for specific types of events taking 2σ criterion has been developed.

3. Events according to ICAO Aviation Occurrence Categories

Although subject of this article concerns airframe systems, it needs to be highlighted that it is the only one out of thirty-six ICAO's aviation occurrence categories. It means that first of all safety indicators from them should be determined. Fig. 2 shows frequency in percent of certain reported events occurrence between 2008-2015 for MTOM < 5700 kg aircraft.

The "advantage" of the part of the events associated with the aviation technology (SCF-NP System/Component Failure Non Powerplant and SCF-PP System/Component Failure Powerplant) does not require any comment. However, it has to be emphasized the other categories influence on aviation safety like Abnormal Runway Contact (ARC), Collision with obstacle(s) during Take-off and Landing (CTOL), Midair Collisions (MAC) and Glider Towing (GTOW).

As an example, only one from the essential safety performance indicators (SCF-NP, SCF-PP, ARC, CTOL, MAC, GTOW) is analysed in details because of events consequences in that category.

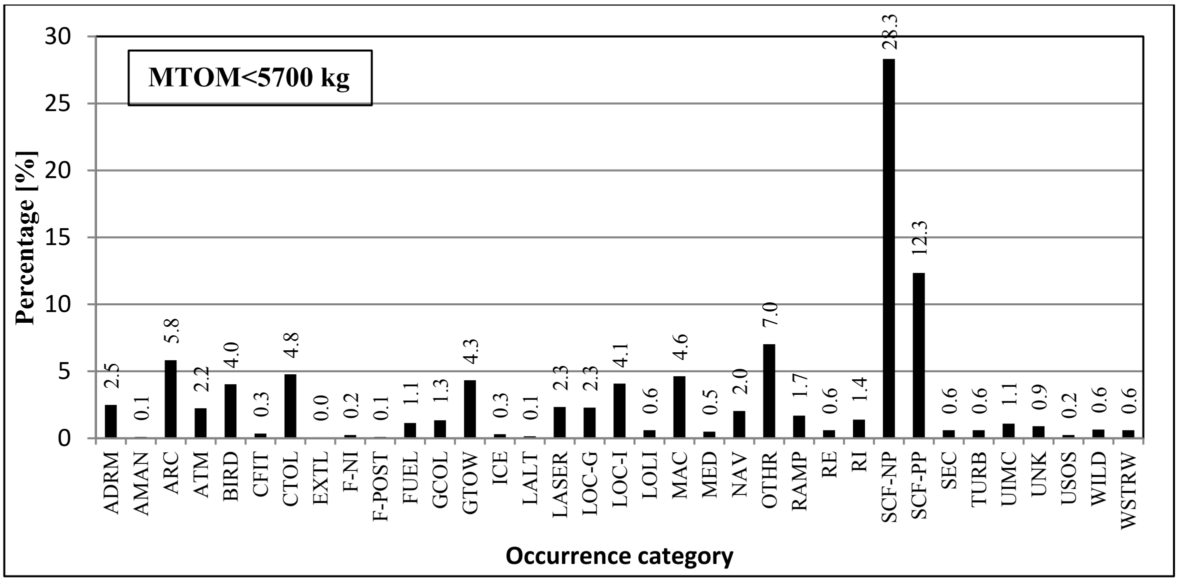

Fig. 2. Reported events per aviation occurrence categories in Poland for MTOM < 5700 kg aircraft in the years 2008-2015

Between 2008 and 2015, eighty-two events coded as a GTOW were reported. The number of occurrences in this category in the coming years changed periodically, and fluctuations from year to year sometimes exceeded 100% of the previous year value (see Fig. 3).Forecasting for the next years (see Fig. 4) in this case is very difficult, because the phenomenon is not "statistically normalized". That is why the level of the maximum predicted values (AL), also referred to as alert levels, for 2016 and 2017 is so high.

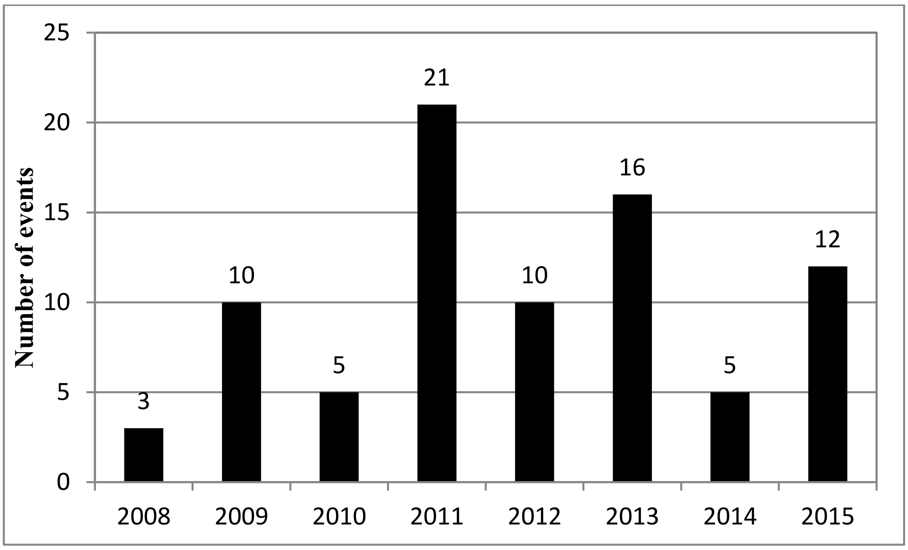

Fig. 3. Annual number of events for GTOW aviation occurrence category

Tab. 2. Causes and consequences of GTOW events

WAY OF TOWING	AIRCRAFT	43
	WINCH	36
	AIRPORT TRACTOR	3
CAUSES (FAULT, ERROR)	PILOT	42
	EQUIPMENT	30
	INSTRUCTOR	5
	AIRPORT HANDLE	5

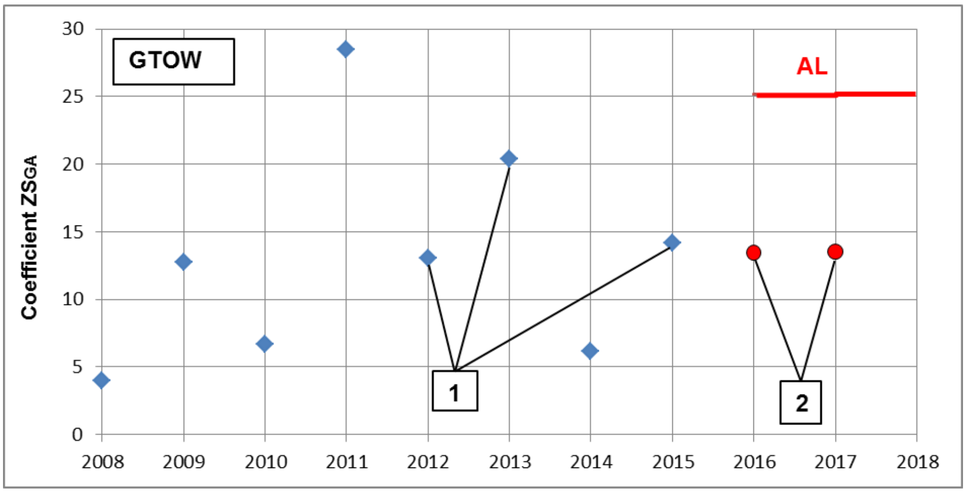

Fig. 4. Value of annual and forecasted gliders ZS_{GAGTOW} coefficient for GTOW category, 1 – current year coefficient value 2– forecasted mean, AL –calculated predicted alert level

Unfortunately, in this category a relatively large number of fatalities occurs. Methods for towing (winch, aircraft) do not substantially affect the number of events, but they are different in both causes of the event. When towing by the aircraft glider pilots often make errors for example, yawing and aircraft tail lifting forcing it to dive, which is particularly dangerous.

When towing by winch cases of breaking this process dangerous are, because it requires an appropriate pilot response (flight alignment, detaching towing ropes, landing straight or with a turn depending on the current altitude). Gliders stall, "placing" towing rope on the wing and even into the gap between the aileron and the wing (due to a sharp decrease glider's nose) were noted. Equipment malfunction is often the inability to detach the rope (towing hitch blockage). Similar way has been adopted in order to analyse the remaining most frequent occurrences.

4. Safety performance indicators for airframe systems

As it was shown in Fig. 2 airframe systems failures (SCF-NP) are the biggest contributor (28%) to the total reported aviation events in Poland in the MTOM< 5700 kg aircraft class. This ICAO event occurrence category dominantly effects safety of flight operations in the light of the aircraft category.

Figure 5 shows frequency of airframe systems defects appearance in the years 2008-2015.

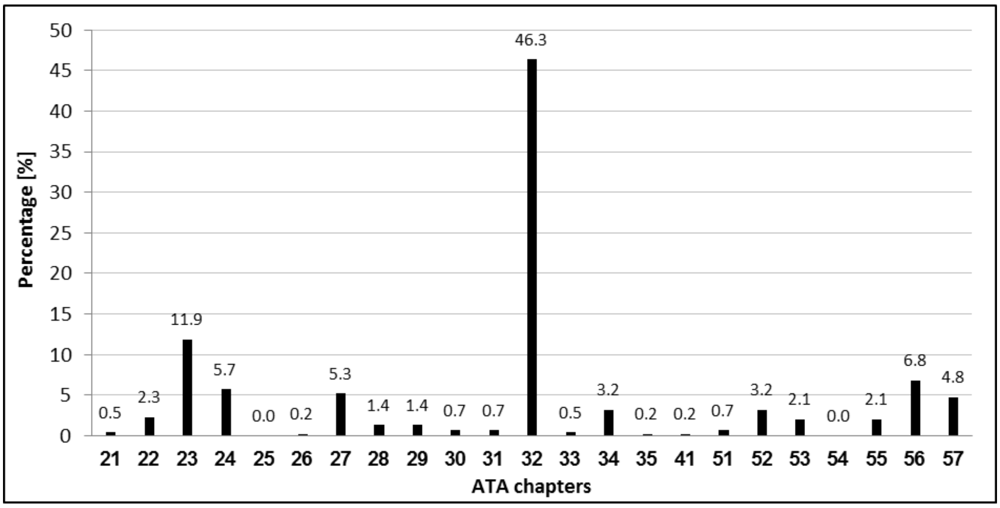

Fig. 5. Share of each airframe system (ATA-100 chapter) for SCF-NP category events in percent for MTOM < 5700 kg aircraft

As SCF-NP is a primary cause of events in aviation occurrence categories, so the landing gear (ATA-100 chapter 32) is the main reason of airframe systems failures and thereby one of the most important safety performance indicators. Others are communications (ATA-100 chapter 23), windows (ATA-100 chapter 56), electrical power (ATA-100 chapter 24), and flight controls (ATA-100 chapter 27). Each of these groups were analysed from the statistical as well as technical points of view. For selected two chapters 32 and 56 statistical analysis is shown in Fig. 6 and 7 respectively.

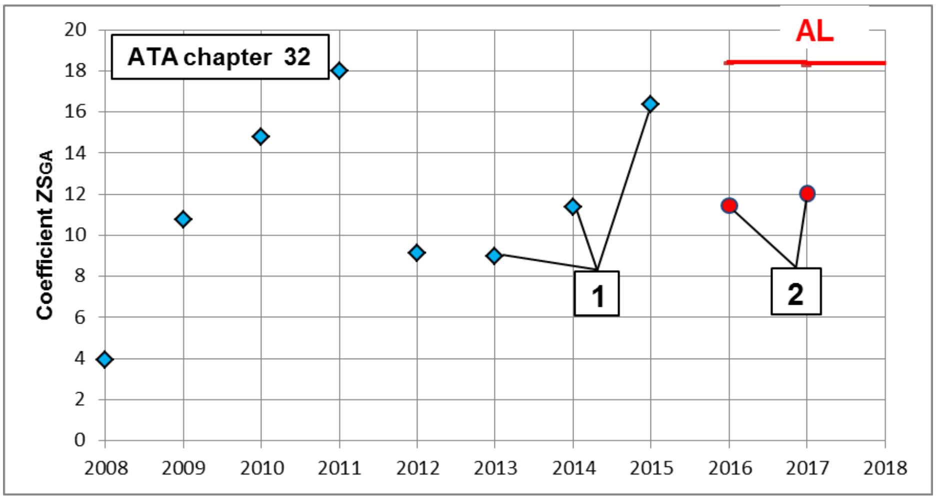

Fig. 6. Annual and forecasted value of ZS_{GA32} coefficient for landing gear: 1 – current year coefficient value, 2– forecasted mean, AL –calculated predicted alert level

For three years, a systematic growth of reported events caused by the landing gear has been noted. There is wide variety of landing gear failures from tyre perforation through brakes failures to fatigue cracks of the struts. They also are vulnerable to damage mainly due to numerous landings outside the airfield, and also because of the poorly trained pilots, for example, students during training. It is difficult clearly to identify the main reasons for landing gear defects. Their increasing number, however, should be a warning signal for civil aviation authority to take necessary steps in order to prevent such growth.

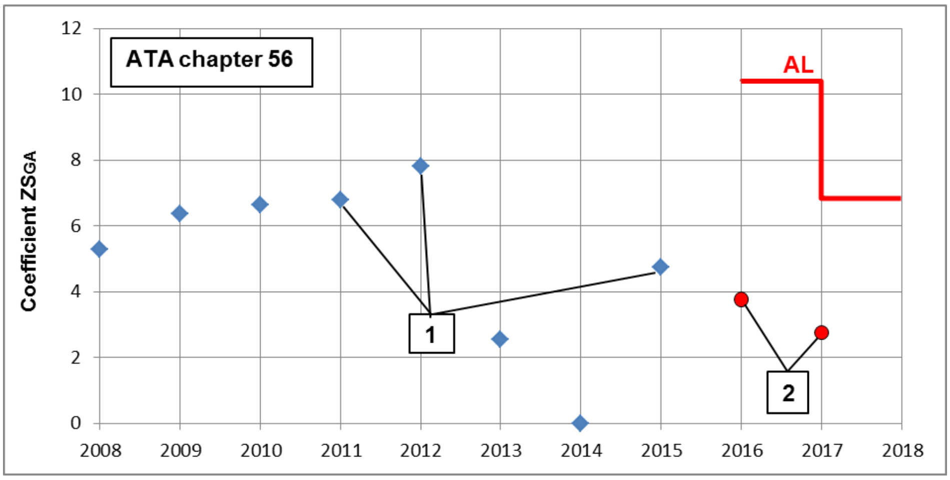

Fig. 7. Annual and forecasted value of ZS_{GA56} coefficient for gliders windows, 1 – current year coefficient value, 2– forecasted mean, AL –calculated predicted alert level

Events in this ATA-100 chapter mainly occurred on gliders (90%); caused by self-opening canopies. 60% of such occurrences happened on SZD – 50 "Eagle-owl" and SZD – 9 "Stork" gliders. Although most of the canopy opening events took place during a slide slip manoeuvre this cannot be an explanation for this phenomenon. The fact is that canopy is big and therefore not sufficiently stiff, it can be stated that it is too flexible. During situations of the airframe high stress, canopy's deformation may occur, and thus the possibility of release its locks. Probably engineers should consider changing the design of the locks. This does not change the need to accurately perform a pre-flight check and make sure before the glider operation of the correct position of the lock elements in relation to the slide-ways.

5. Conclusions

Statistical analyses and forecasts would be more accurate and more objective, if data on the flight hours and the number of flight operations at airfields was available. Aviation authority should take necessary measures in order to improve reporting system from aviation organizations.

For aircraft with MTOM<5700 kg failures of the airframe and propulsion systems are predominant (see. Fig. 2). Next come the events associated with an abnormal runway contact (ARC). This category also includes emergency landings out of the airfields, causing mostly airframe damages, mainly affecting the safety of the crew (the crew of aircraft in this class consist of 1 or 2 persons). Dominated events are related to the training and the competitions.

The intensity of the reported events increases when it is "flying weather", and decreases when the summer is, for example, rainy. This is apparent in the number of reported events when in the first quarter of the year the number of events is usually minimal (see. Fig. 8).

Some structural defects should be detected during testing procedures. The observed tendency, however, is to limit the testing of new designs, i.e. reducing the time of the final design formation and costs. This affects the number of failures detected during airplanes and gliders operations, often produced by small companies seeking a quick profit.

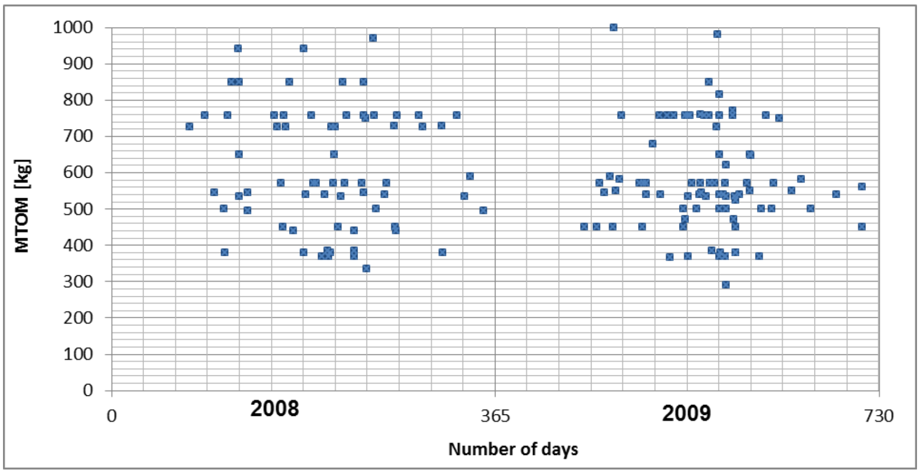

Fig. 8. Number of reported events for MTOM<1000kg aircraft in the subsequent days of 2008 and 2009 (example of seasonality in light aircraft operations)

Statistical analyses implementation, which include the impact of aging aircraft components on safety should also be foreseen, particularly those that are produced using advanced technologies (e.g. composites).

Acknowledgement

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