

INVESTIGATIONS INTO LOAD SPECTRA OF LIGHT-WEIGHT UAV'S

Mirosław RODZEWICZ*, Dominik GŁOWACKI*

***Warsaw University of Technology**

Institute of Aeronautics and Applied Mechanics

Nowowiejska 24, 00-665 Warsaw, Poland

Keywords: *UAV loads, load spectrum, manual control, autopilot*

Abstract

Popularity of Unmanned Aerial Vehicles (UAVs) is a result of significant progress in the field of modern technology (including information technology). The stimuli for UAVs development are the needs coming from military and civilian economy. The most important civilian applications are: aerial monitoring, photogrammetry, video-reporting of public events, etc. Bearing in mind the safety of flight - unmanned aerial vehicles for civilian use must be subjected to very strict regulations. In order to be able to answer questions concerning the fatigue life of structure, reliability and security, there is a need for research into the determination of loads that occur in real time during the flight. Aim of this study is to determine and analyze the load factor changes during UAVs' flights in various control modes to obtain the necessary data to validate the fatigue life of the structure of the aircraft. In order to solve this issues, the authors of the paper presents the results of own study in a field of determining operational loads spectra that occur during flight of some chosen UAVs. Under consideration was an impact of the type of control and atmospheric conditions on the resulting loads. The work provides a method for separating the measured spectrum of the loads from the portions resulting from the control and external disturbances (including the turbulent atmosphere)

1. Introduction

In recent years the development of civilian UAVs is very significant. UAV-users can be found in different sections of economy such as land surveying companies, meteorological institutions, universities, government departments, etc. The potential applications include: monitoring the borders, observations during natural disasters, monitoring of forests,

plants and animals, communication paths, aerial video-reporting of public events, photogrammetry etc. The increase of operational abilities offered by the UAVs leads to increasing number of users. Important role in UAVs development plays research institutes and universities. In Poland significant achievements in this field has Warsaw University of Technology, where a family of long endurance UAVs designated for aerial monitoring purposes and prepared for photogrammetry missions has been built, (Fig.1).



Fig. 1. PW-ZOOM 1 – the UAV designed in Warsaw University of Technology for photogrametric purposes

Constructing and entry to service of new aircraft types must be preceded by studies on safety during operation. A major problem in the implementation of new aircraft is to determine the safe service life. A crucial significance for this purpose has the knowledge about the load spectrum. The paper presents the investigations into load spectrum of the UAV's performed by the authors for several UAV's of different weights and sizes (see Fig. 2).

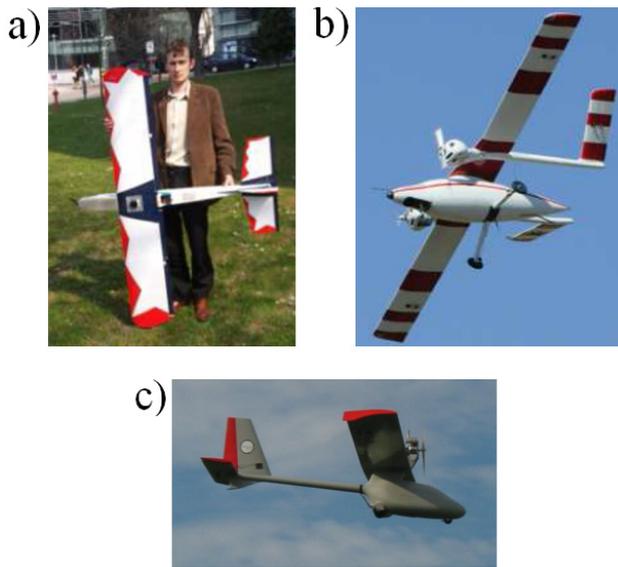


Fig. 2. UAVs made in the WUT:
a) WorldStar, b) Samonit, c) PW-ZOOM)

Table 1

Technical data			
	WorldStar	Samonit	PW-ZOOM
Purpose	Trainer for programming autonomous flight-missions	Aerial monitoring missions	Photogrametry missions
Wingspan	1.7 m	4.4 m	3,17 m
Length	1.35 m	2.3 m	2 m
Empty weight	3,3 kg	33 kg	16 kg
MTOW	3,3 kg	88 kg	20 kg
Min. Speed	40 km/h	90 km/h	45 km/h
Max. Speed	100 km/h	150 km/h	120 km/h
Powerplant	Electric motor	2 x I.C. Komatsu Zenoah G800BPU	DLE-40 2-stroke gas engine

In practice, two ways of determining the life of the aircraft are in use. The first method is based on operating experience gained during the use of similar type of UAV. It is just an estimation, thus less reliable. The second method is based on the fatigue-stand tests of aircraft, in which anticipated loads on the aircraft are being imposed in an accelerated way. In order to estimate the fatigue life either by calculation (Fig.3) or in an experimental way, load spectra of the airframe must be known.

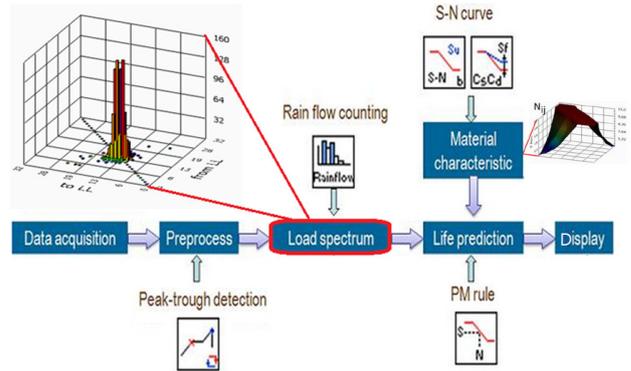


Fig. 3. Calculating schema of fatigue life

LabVIEW software (Laboratory Virtual Instrument Engineering Workbench) - developed by National Instruments has been used for all analyzes. LabVIEW uses a graphical programming language called "G". This software is often used in research centers, tests in industry and in places, where measurements are taken and collected data is analyzed. The code consists of connected icons, and execution of the program determines the flow of data between the two icons. Some screenshots of programs for visualization and data processing developed in LabVIEW are shown in Figure 4.

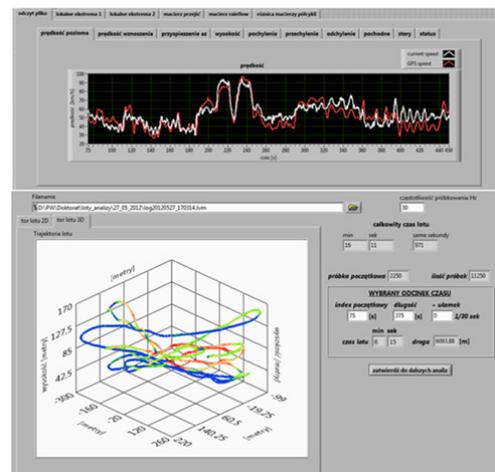


Fig. 4. Examples of screenshots from program developed to analyze UAV's loads in the LabVIEW environment

LabVIEW enables to present the 3-D images of the flight trajectory in which the color indicates the airspeed or load factor. Another possibility is the graphic presentation of the steering (control) modes used during the whole flight (fig.5) [1].

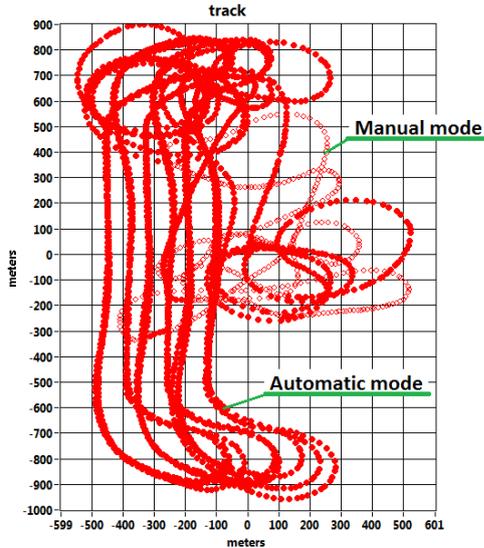


Fig. 5. Visualization of the flight path during photogrametry mission and indication of control modes

The LabView algorithms designed in the WUT allow not only for analysis and presentation of data directly recorded in the log, but also allow deriving additional and very useful information such as the wind speed and gust distribution measured during the flight.

2. Half-cycles array as a tool for load-signal analysis

The first step for load spectrum determination is a standardization of the load signal. For this purpose the operational range of the load factor has been divided into 64 levels (called Load Levels LL) with the values n_{z_min} corresponding LL = 62, and n_{z_max} corresponding to LL = 6. Levels LL = 1, 2, 3, 4, 5 and LL=63, 64 are treated as a reserve in case the loads occurring during the flight are larger than the permissible load (Fig.6). Scaling equation for $n_{z_min} = -3$ and $n_{z_max} = 6$ is as follows: $LL = -6.222n_z + 43.333$

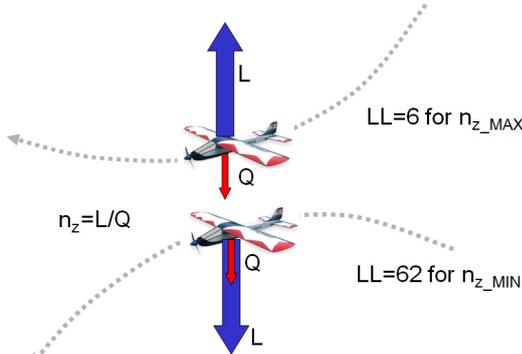


Fig. 6. Correlation between Load levels and a load factor

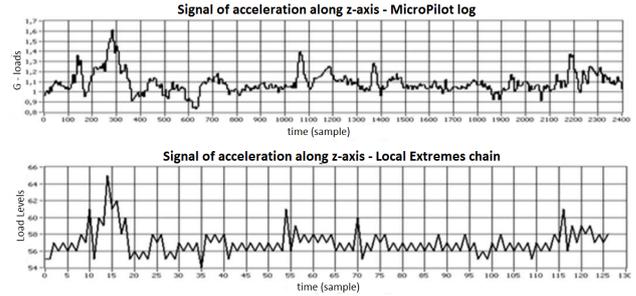


Fig. 7. Comparison of the raw signal of a g-acceleration and the signal reduced to the chain of local extremes

Load spectrum can be presented as a half-cycle array (HC-array), which presents the numbers of load increments counted according the rule: “from LL_i – to LL_j , where $i = 1, 2, \dots, 64$ and $j = 1, 2, \dots, 64$. Creating such an array is associated with the use of the "Rainflow counting algorithm" developed in 1969 by Matsuishi and Endo, which is one of the most effective methods allowing to determine full load cycles (i.e. load oscillations resulting from several consecutive load changes). The name “half-cycle array” comes from the assumed rule that the each single load cycle consists of two half-cycles (increasing and decreasing), which are displayed simultaneously over and under the diagonal-line of the HC-array.

A pre-processed signal in the form of local extremes (Figure 7) is used as the input for the load spectrum determination. Figure 8 shows the algorithm of preparing the local extremes vector. This algorithm allows also to track the speed of load variations. As the output there are generated 3 separate vectors, such as "local extremes," "time vector", "velocity vector" (Figure 8).

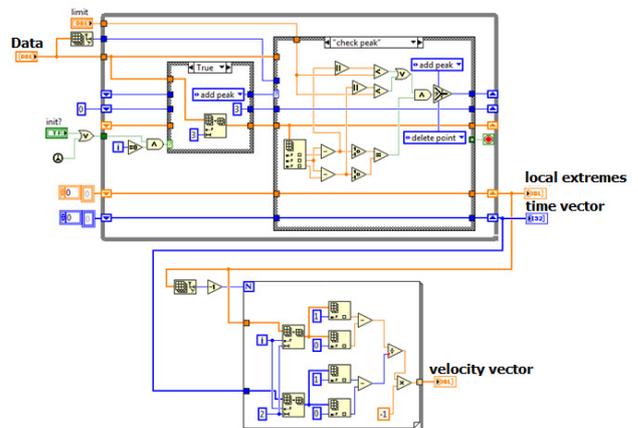


Fig. 8. Algorithm of preparing a chain of load signal local extremes associated with a time vector.

The outline of HC-array derivation based on the Rainflow counting algorithm is shown in Fig.9.

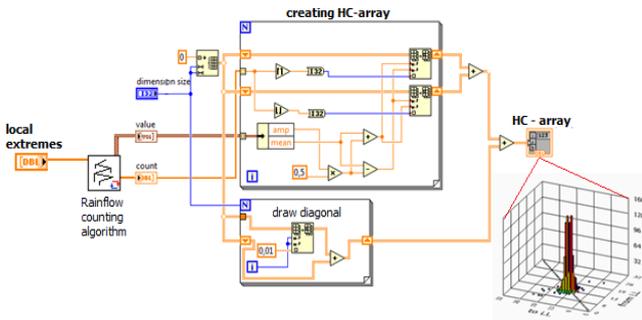


Fig. 9. Half-cycle array derivation algorithm

A very convenient way of load spectra comparison is so called incremental load spectrum (ILS). On the graph, it shows the number of occurrences for each load level. The ILS is formed from the summation of the values of the cells over and under the strip made along the main diagonal of the array as shown in Figure 10. The increase in the value of the load by at least one level is equal to the sum of all the values of the cells; the increase in the value of the load by at least the two levels is equal to the sum of all table cells without first cells adjacent to the diagonal. In order to calculate the number of occurrences for the next load levels, we need to move further away from the main diagonal of the array.

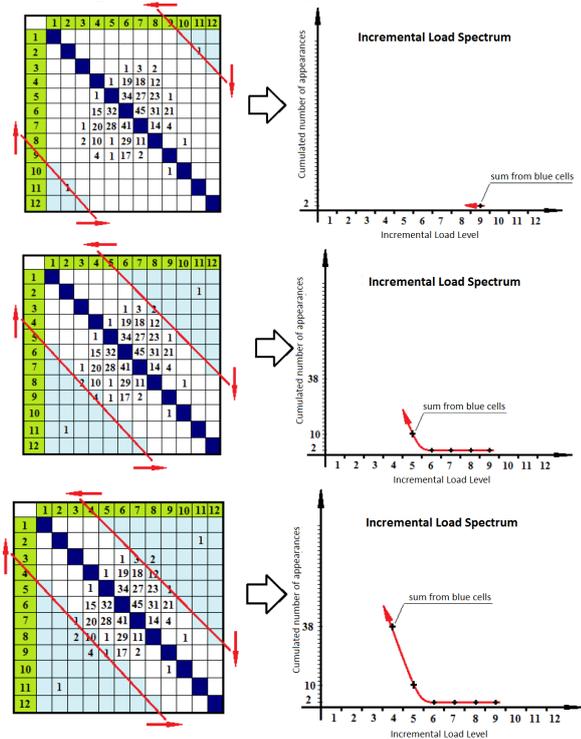


Fig. 10. Derivation of Incremental Load Spectrum

3. Load spectra for the UAV controlled in a manual or automatic way and during various weather conditions

The tools described in the previous section have been used to test the loads of UAVs during different weather conditions operating modes. The qualitative nature of the loads in the manual and automatic control mode is shown in Figure 11 and also in Fig. 12 and 13 on the pattern of the load envelope.

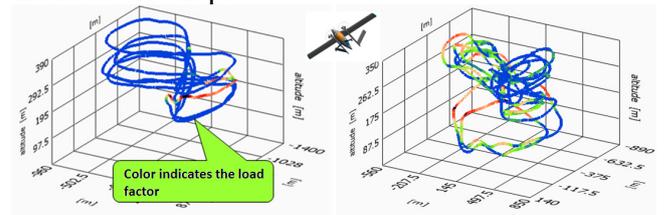


Fig. 11. Variability of the loads during automatic control mode and manual control mode of Samonit

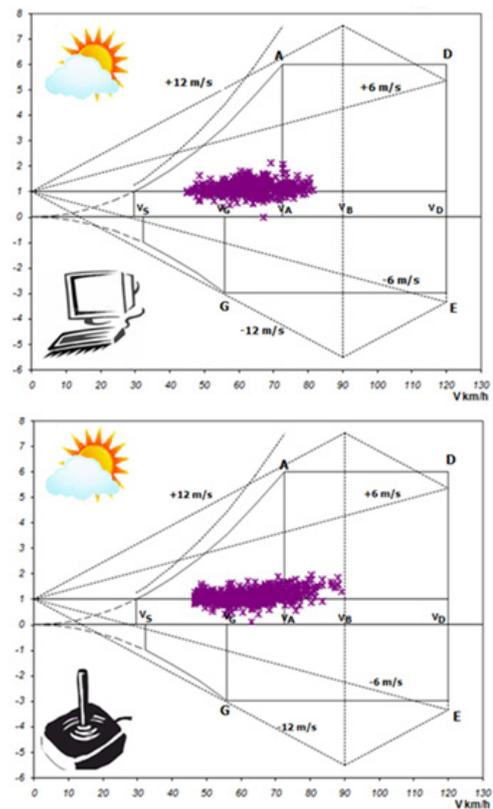


Fig. 12. Loads of the WorldStar in different control modes (automatic and manual) for the same flight mission

Loads caused by air turbulence are essentially independent of the manual control mode. Occurring atmospheric turbulence leads to changes in flow and transient increase or decrease of the angles of attack and thus leads to increase or decrease of aerodynamic forces.

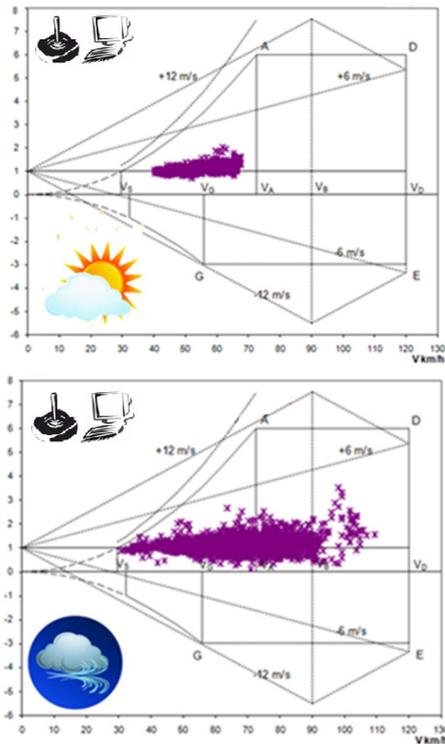


Fig. 13. Loads of the WorldStar in different weather conditions for the same flight mission

Most of the time an unmanned aircraft flight is controlled by an autopilot. However, there are situations in which an operator located on the ground controls an aircraft manually. By examining typical flight maneuver which is an aerodrome-circle, the incremental difference spectra has been prepared and are shown in Fig.14. When the airplane is controlled by an autopilot, the amount of small amplitude load-increments is greater than in case of manual control. In case of manual control fewer amount of low amplitude load-increments is taking place, but load-increments with higher variations occur more frequently (Fig.14).

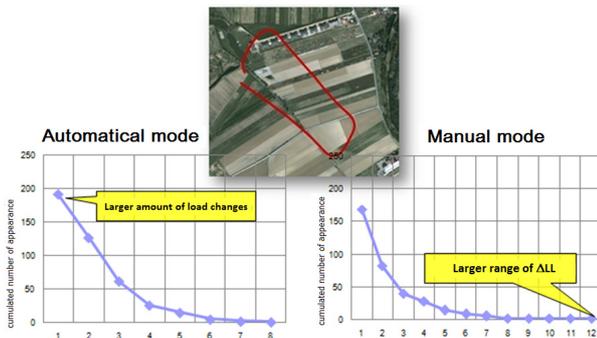


Fig. 14. Load spectrum dependent on automatic and manual mode

It is possible to derive the representative load spectra (RLS) for each kind of light mission (or flight mission part). These are formed as a mean value for the number of occurrences offset vertically by three standard deviations [2]. In the same way the highest value of the load-increment is offset horizontally (see Fig. 15). As the example there are shown in Fig.15 The RLS for the aerodrome-circles flown by the WorldStar.

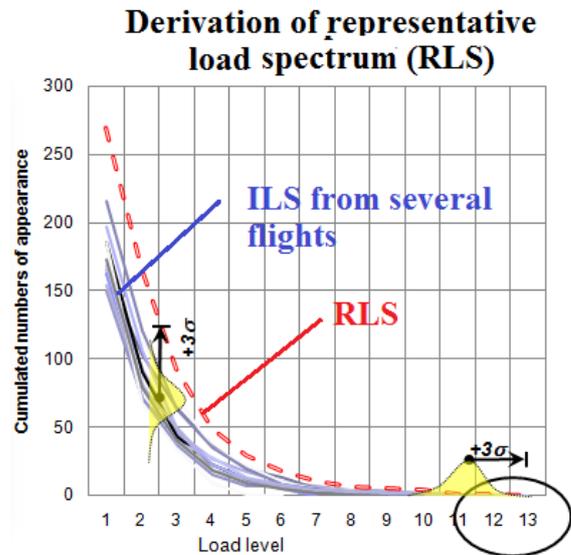


Fig. 15. Representative load spectrum for analyzed flights and estimated life-times with respect to control modes

The authors developed the method of separations of the load spectrum derived from control and the level from external, atmospheric turbulence. For this purpose, a simulation model described by a transfer function has been built. The input signal was the angle of the elevator deflection, whereas the output was the load factor. Transfer function (transmittance) was determined by flight-testing in a calm weather in which the plane was subjected to sudden change of elevator angle and then vertical acceleration corresponding to them has been recorded. Transmittance identification was based on a special procedure developed in the LabVIEW. Having the transmittance and taking the elevator deflection recorded in the flight-log as the input signal - it is possible to simulate the load-signal caused purely by the manual control. Then comparing the simulated load-signal with

the real load-signal recorded in the flight-log it is possible to separate loads caused by the manual inputs and loads caused by the turbulence (or from other sources). Both incremental load spectra have been placed for comparison in Figure 16. Visible difference between the measured signal and one being simulated is due to external turbulences and non-linearity of the model.

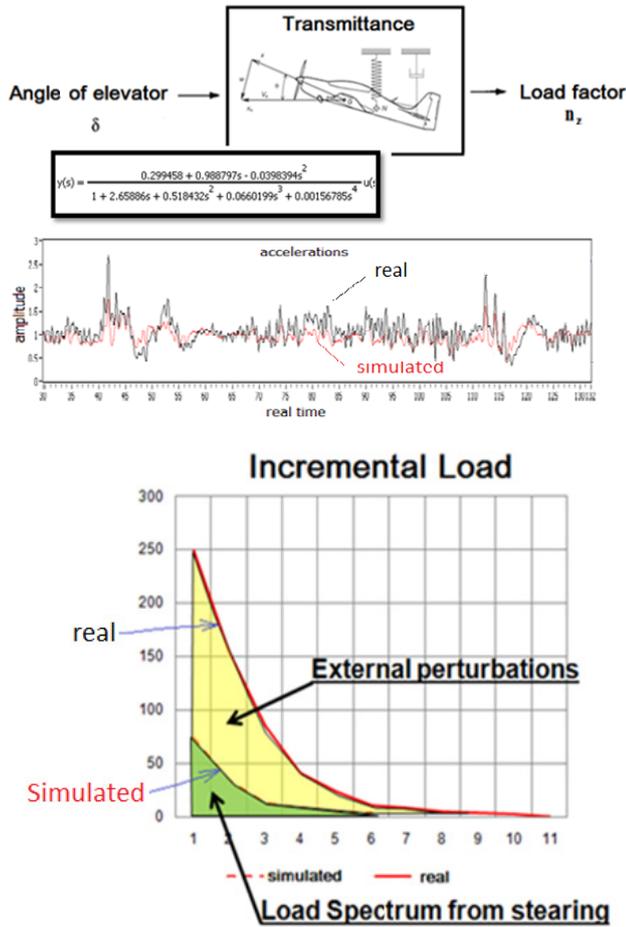


Fig. 16 Comparison of simulated and measured Output signal

Fig.17 presents an example of a path from a photogrammetric mission of PW-ZOOM. In this flight the wind blew from the West, the average speed of the wind was approximately 6m/s.



Fig. 17. Visualization of the flight path during the photogrammetric mission

Fig.18 focuses on a g-acceleration and shows the derived load spectrum (ILS) of the UAV in the same flight.

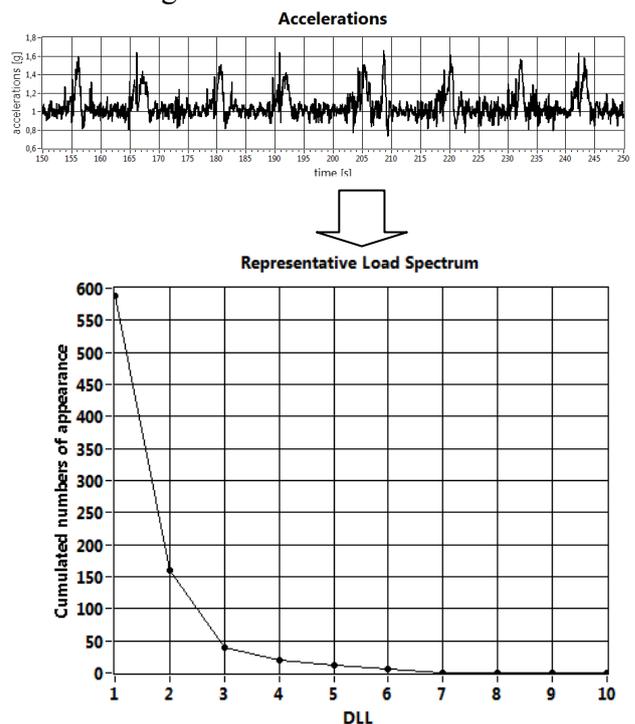


Fig. 18. load spectrum for analyzed flights during photogrammetric mission

In this flight a maximum increment of LL was equal to 6 and it appeared 5 times. Using load level standardization formula (see Fig. 6) and recalculating it into load factor increment it means that maximum value of Δn_z did not exceed 1. Such a “calm” flight is very important

in photogrammetry missions, because the quality of photos taken during this mission depends on accelerations acting on the camera in the air.

5. Summary

- The basis for Load Spectra estimations is statistical analysis of several similar flight missions and consideration of statistical analysis of possible dispersions of two main parameters: Number of Appearances for each Load Level increment and dispersion of maximum load increments values.
- Control mode has a large influence on the Load Spectrum. It was found that significant differences in load spectrum could be observed between manual and automatic control modes of the UAV. Those differences may have strong influence on the fatigue life of the UAV structure.
- Determination of UAVs load spectra has a crucial importance for the process of airworthiness requirements elaboration for this category of aircraft. In order to determine airworthiness requirements regarding fatigue safety of the UAV structure – it is necessary to increase the number of analyzed flights – taking into consideration different flight scenarios, different weather and terrain conditions, different pilots, etc.

Acknowledgements:

Thanks to the project No 197810 "A novel approach to monitoring the impact of climate change on Antarctic ecosystems" in the Research Programme of the EEA/Norway Grants Framework

References

- [1]. M.Rodzewicz, D.Głowacki *Investigations into load spectrum and strength tests of an UAV structure*. The READ 2012 Conference (Research and Education in Aircraft Design) – October 2012 Brno
- [2]. M. Rodzewicz *Determination and extrapolation of the glider load spectra*. Volume 80 Issue 5 of

Aircraft Engineering and Aerospace Technology, pp. 487 – 496,

- [3]. M. Rodzewicz *Fatigue evaluation of high-loaded aeronautical composite structures*. Aircraft Engineering and Aerospace Technology, Vol 81, No 5, pp 452 – 460;
- [4]. Rodzewicz M., Czerwiński G., Kubica B. J. *Load spectrum – archiving, analysis and load sequences reproduction* - (in Polish). Proceedings of XIII Conf. Mechanics in Aviation, PTMTS ML-XIII 2008, vol. 1, pp.43 - 55;
- [5]. Owczarek W., Rodzewicz M. *Investigations into glider chassis load spectrum*. Fatigue of Aircraft Structures Monographic Series, Issue 2009, pp 150 – 170.

Contact Author Email Address

Mirosław Rodzewicz: miro@meil.pw.edu.pl

Dominik Głowacki: dglowacki@meil.pw.edu.pl

Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS 2014 proceedings or as individual off-prints from the proceedings.