INVESTIGATIONS INTO LOAD SPECTRUM AND STRENGTH TESTS OF AN UAV STRUCTURE

Mirosław Rodzewicz
Warsaw University of Technology – Institute of Aeronautics and Applied Mechanics
Nowowiejska 24,
00-665 Warsaw, Poland
miro@meil.pw.edu.pl

Dominik Głowacki
Warsaw University of Technology – Institute of Aeronautics and Applied Mechanics
Nowowiejska 24,
00-665 Warsaw, Poland
dglowacki@meil.pw.edu.pl

Abstract. The paper concerns investigations undertaken in order to support the process of UAV airworthiness requirements determination, especially requirements concerning fatigue aspects. A very important for it is the knowledge regarding UAVs load spectra. There are presented in the paper the results of preliminary research in this matter. A description of the load spectrum processing is given, starting from filtering the input-data, and then either counting the load signal transfers or implementing the Rainflow Counting algorithm end presenting the results in form of transfer array or half-cycles array. This description is illustrated by three examples regarding test flights of 4-meters class UAV, which was design in Warsaw University of Technology. They concerns flights controlled in manual and automatic way, in order to show the differences between the LSs for such control modes. Besides the LS processing, there is also shown the method of statistical analysis of load spectra from several flights, because the problem of LS dispersion is very important and should be taken into account. In the end there are shown the examples of UAV structure elements tests, for which the load spectra may have a crucial importance.

Keywords. UAV loads, load spectrum, manual control, autopilot.

1 Introduction

A significant growth of applications of the UAVs is observed during last two decades– mostly in military domain. At the same time the economical aspects involve rise of interest for application the UAVs also in civilian economy. The potential possibilities of such applications are for example: terrain monitoring during disasters, monitoring of forests and plants, monitoring of communication tracks, media or energy transfer lines ect. With any doubts it would be cheaper in comparison of GA category aircrafts application. The main obstacle here is the lack of law-requirements concerning legal airspace use by UAV aircrafts. It follows from it, that until now no airworthiness requirements are specified for the UAVs. Therefore it should become a challenge for the scientists community– to make the UAVs accessible for civilian purposes. The paper concerns preliminary investigations regarding strength and fatigue safety of the UAV structure. Those investigations were connected with the program of UAVs development, which was conducted in the WUT under leadership of prof. Z. Goraj. The object of investigations was SAMONIT 1 – the UAV destined for from-air monitoring missions. The basic data of this aircraft are displayed in Fig.1.

Fig. 1 SAMONIT 1 – the UAV and its technical data

The SAMONIT is controlled either in a manual way (by a RC devise) or in an automatic way – by an autopilot type MicroPilot L-2128 (Fig.2). The attentions focused on the load spectrum induced by both ways of the UAV control. The knowledge about load spectrum is necessary for defining the requirements regarding fatigue durability of the UAV-structure, to include them to airworthiness requirements.

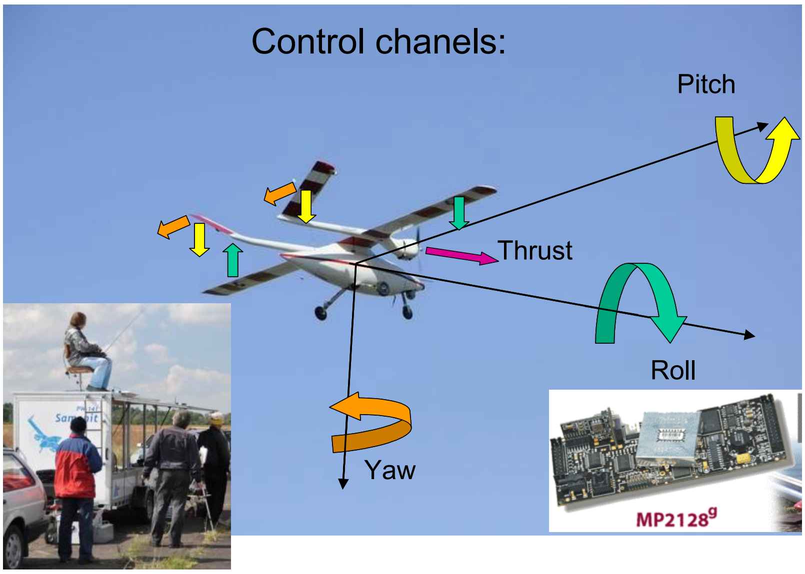


Fig. 2 SAMONIT 1 – control channels

The main function of the autopilot is the aircraft control, but the other useful feature of this devise is the acquisition of the flight data (all together: 52 channels). Those data contains a lot of information, which might be useful for flight dynamic analysis, and load spectrum derivation as well.
Figure 3 presents the screen-shot of the MicroPilot software for data-log viewing. The upper window contains the signals chosen as the example: airspeed, altitude and acceleration in the *z*-axis direction (i.e. perpendicular to the wing-plane), while the lower window contains the GPS-track. The analysis described in this paper was focused on the a_z acceleration signal, because it may be easily recalculated into the load factor n_z as a ratio of a_z/g , where g is the earth gravity.

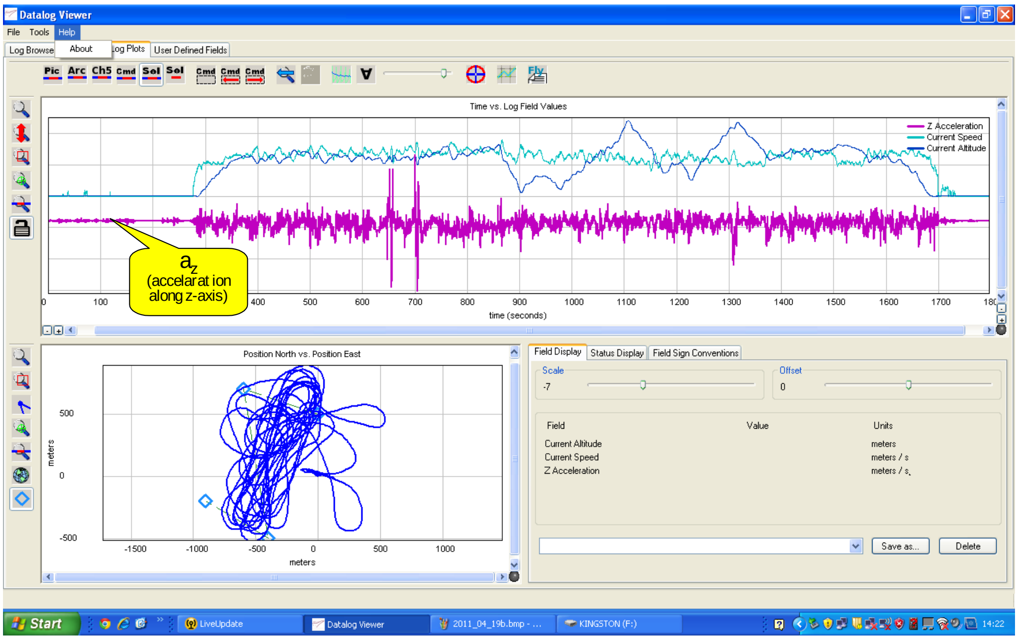


Fig. 3 Data-log Viewer – screen-shot of MicroPilot software

Much more powerful tool for flight log analysis is the LabView program. Especially it allows for more informative presentation of the recorded data. Let focus the attention on the track of the flight, which is presented on the Google Earth map (see Fig. 4). Using LabView it may be presented for example as the 3-D imagination of the flight trajectory with a color indication of the airspeed. It may also be presented with graphical indication of the mode of control, which is necessary to know - how was controlled the UAV in each point of the track.

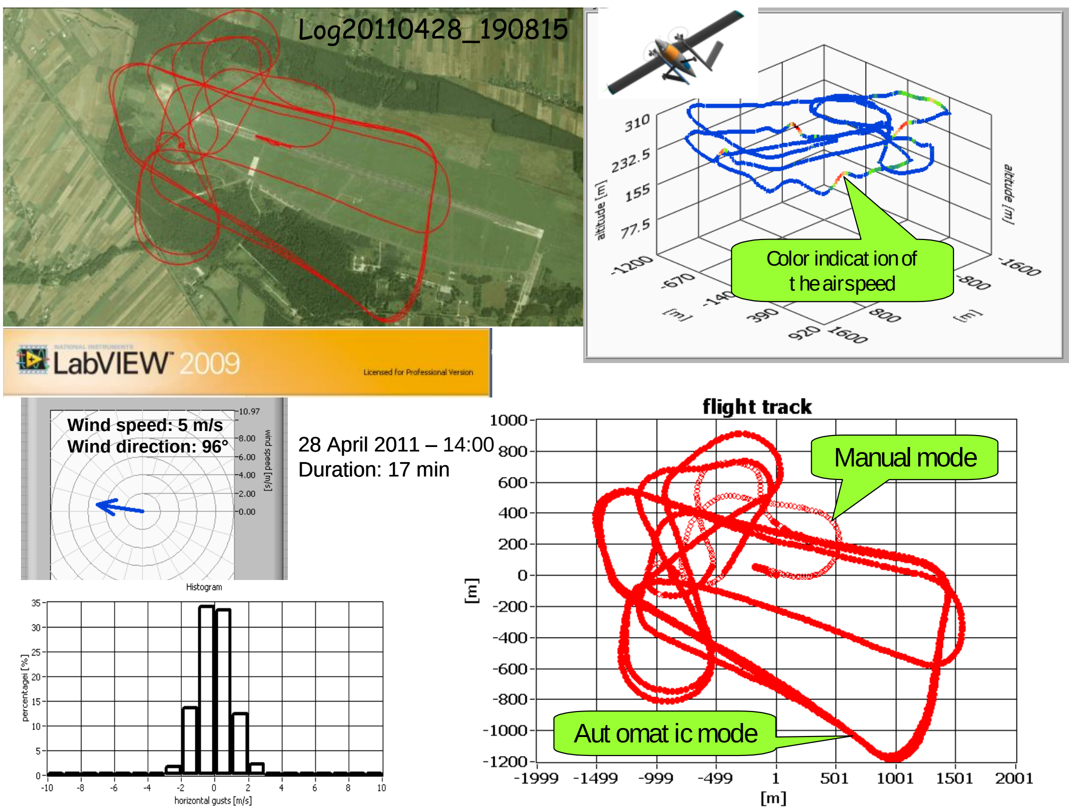


Fig. 4 Presentation of log-data by the LabView tools

The LabView algorithms designed in the WUT allow not only for analysis and presentation of data directly recorded in the log, but also allow to derive additional and very useful information: for example the wind speed and gusts distribution during the flight.

2 Transfer arrays as a tool for load-signal analysis

As a tool for load signal analysis there were used Transfer and Half-Cycles arrays. The transfer arrays (**T**-arrays) contain an information regarding number of signal transfers from each particular level to another level (as it is shown in the slide). For scaling the signal there was applied a standard correlation formula between the load factor n_z and the load level *LL* (i.e. *LL*= 3 for maximum design value of the n_z, and *LL*=31 for minimum design value of the n_z.). To be able to count signal transfers – the load signal should be at the beginning reduced to the form of local extremes chain. The important feature of a Transfer Array is, so called an operational zone, i.e. the square-envelope of all cells having non-zero values. This envelope defines the range of signal variability.

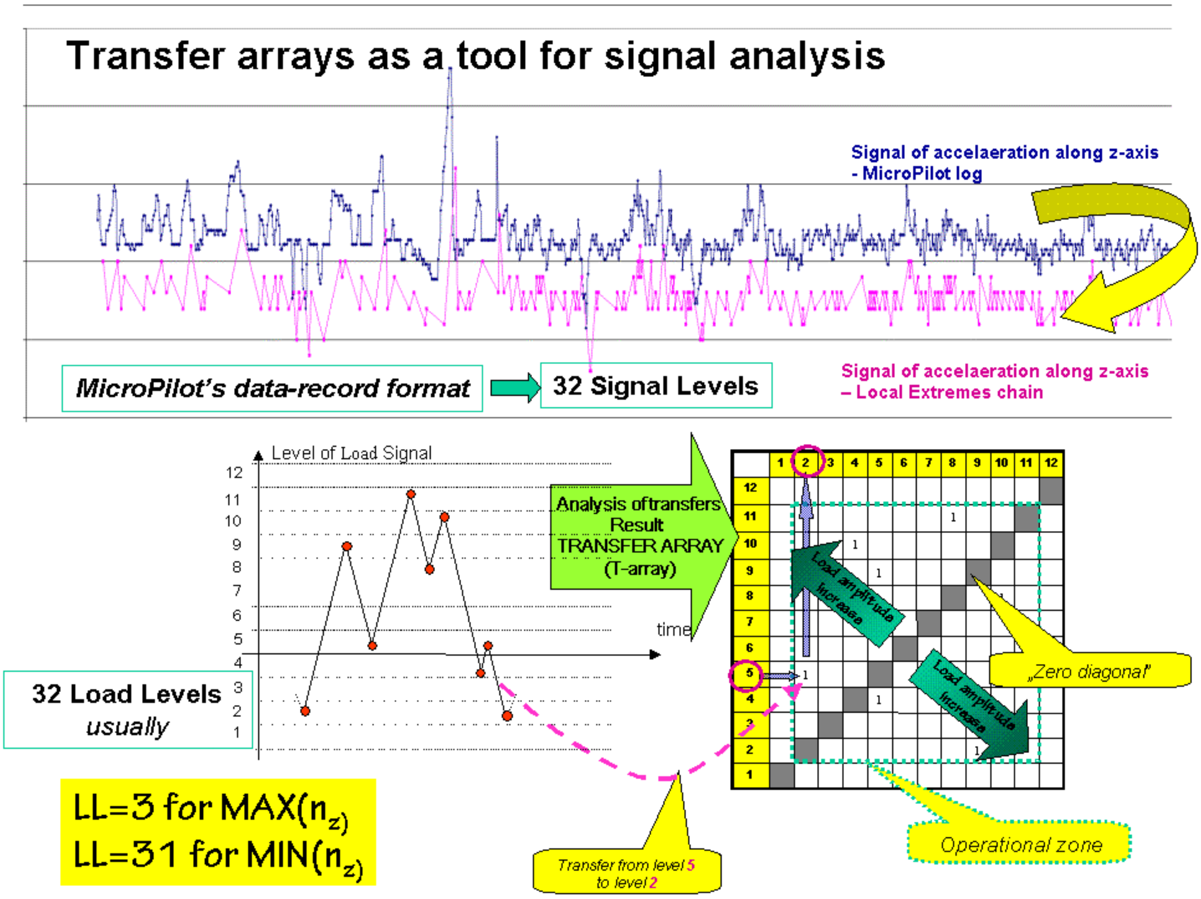


Fig. 4 Signal elaboration and Transfer-array determination

The Transfer Array contains the information about all load signal transfers, but they are not sufficient for fatigue damage calculations, because the algorithm applied here is too simple and causes the omission of the resulting changes of the load signal levels after several transfers. Therefore there was applied another more sophisticated algorithm, which is known as the Rainflow Counting (see Fig. 5). The result obtained with Rainflow Counting is a specific transfer array, which is called as a half-cycles array (**HC**-array). Operational zones of the **T**-array and the **HC**-array derived from the same signal have equal dimensions, but only in the **HC**-arrays appear the values representing high increments of the loads, which are compound from several transfers of the load signal.

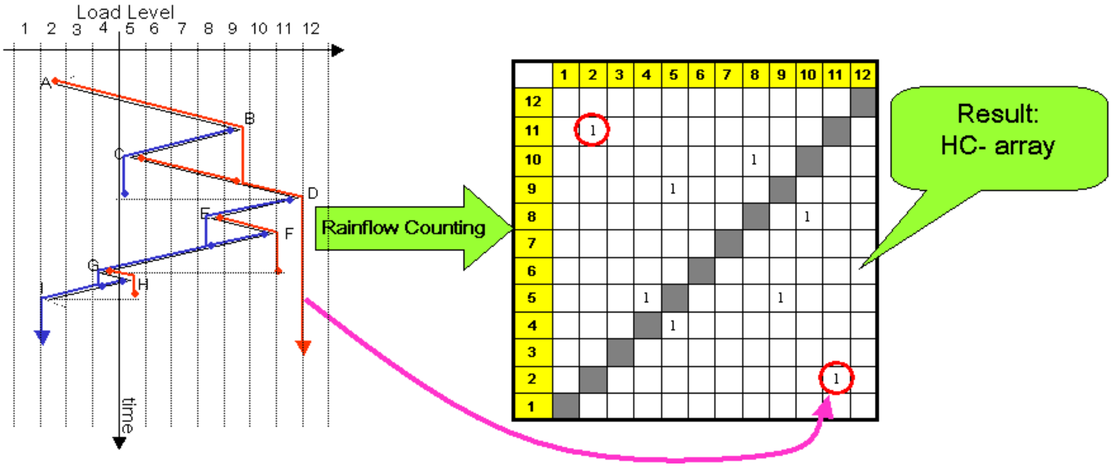


Fig. 5 Half-Cycle array as a result of Rainflow Counting algorithm application

On the basis of **HC**-arrays there is possible to create the incremental form of load spectra (Fig.6). While in the past it was a basic form of load spectrum presentation, today they have inconsiderable meaning for fatigue calculations, but still can be used for comparative analysis of different load spectra.

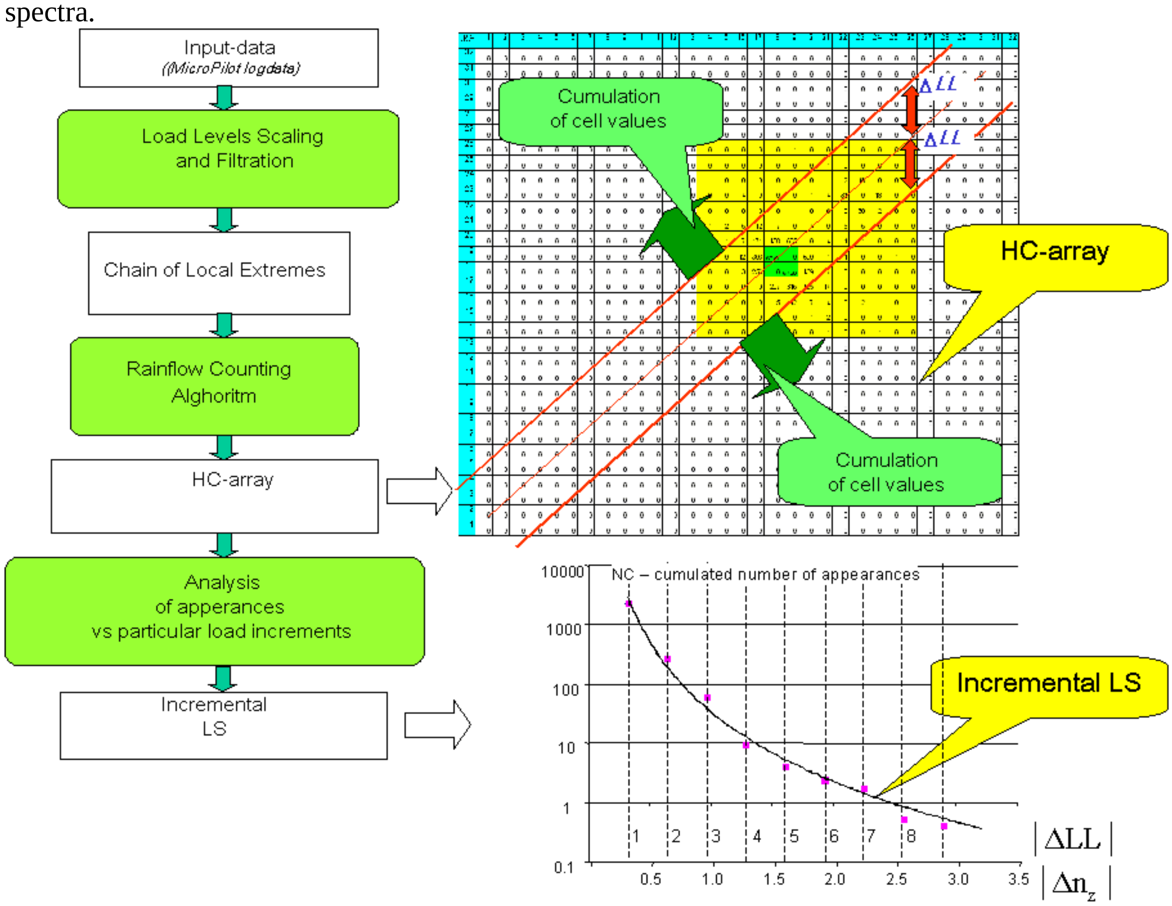


Fig. 6 The procedure of incremental load spectrum derivation

Fig. 7 presents the example of the load spectrum derived from the data-log of our Samonit 1, which was obtained using own procedures written in the LabView. The UAV was controlled in this flight partly in an automatic and partly in a manual mode. The track length was about 41 km and the duration was about 950 s.

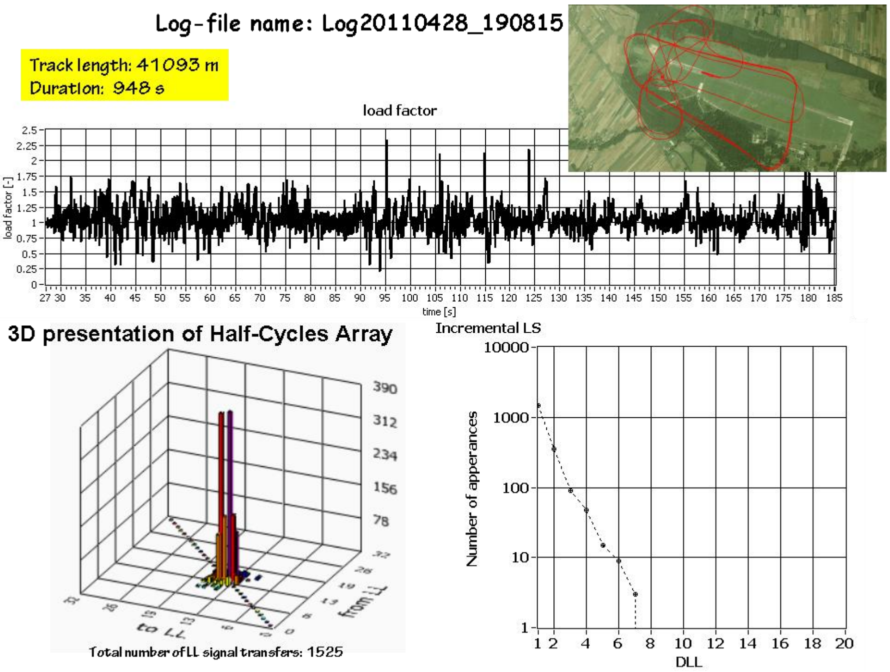


Fig. 7 Examples of load spectrum processing in the LabView

3 Load spectra for the UAV controlled in a manual or automatic way

The tools presented in previous chapter were used in the analysis made with special respect to the control modes of the UAV. Fig. 8 presents two next flight tests of the SAMONIT 1: The flight presented in the upper part of the figure was made in a manual mode, while the flight presented below was mainly controlled by the autopilot. Both flights were made at the same airfield in similar weather conditions. In order to compare those load spectra – from both data-logs there were cut the segments of equal flight duration and almost equal flown distance.

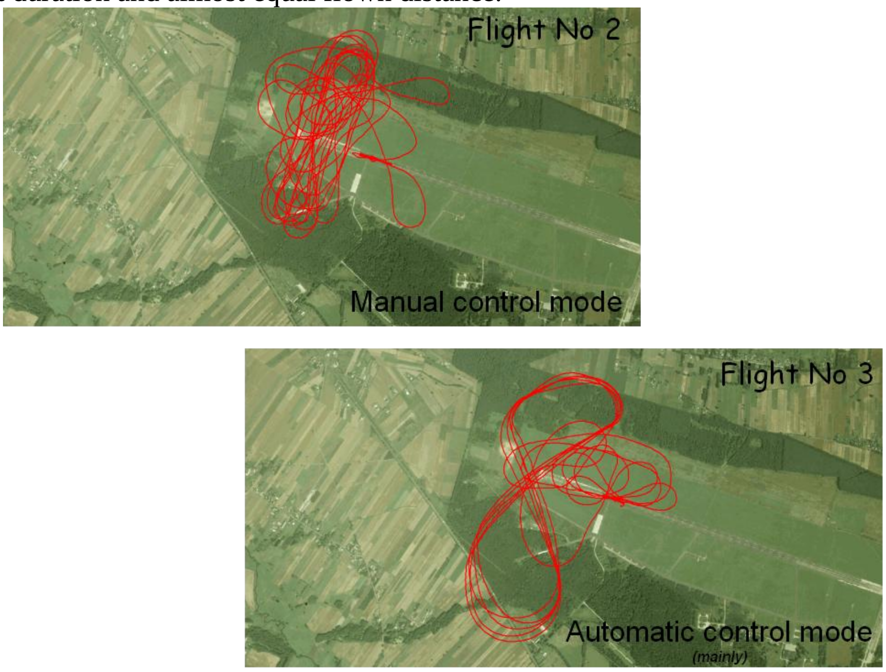


Fig. 8 The tracks of flight No 2 & 3

The results obtained for a manual mode of control are presented in Fig. 9. There is the evidence of load signal increment equal to 18 Load Levels, which is identical with load factor increment equal to 5.7). It is significant variation, having in mind the fact that the UAV did not make any aerobatic evolutions in this flight.

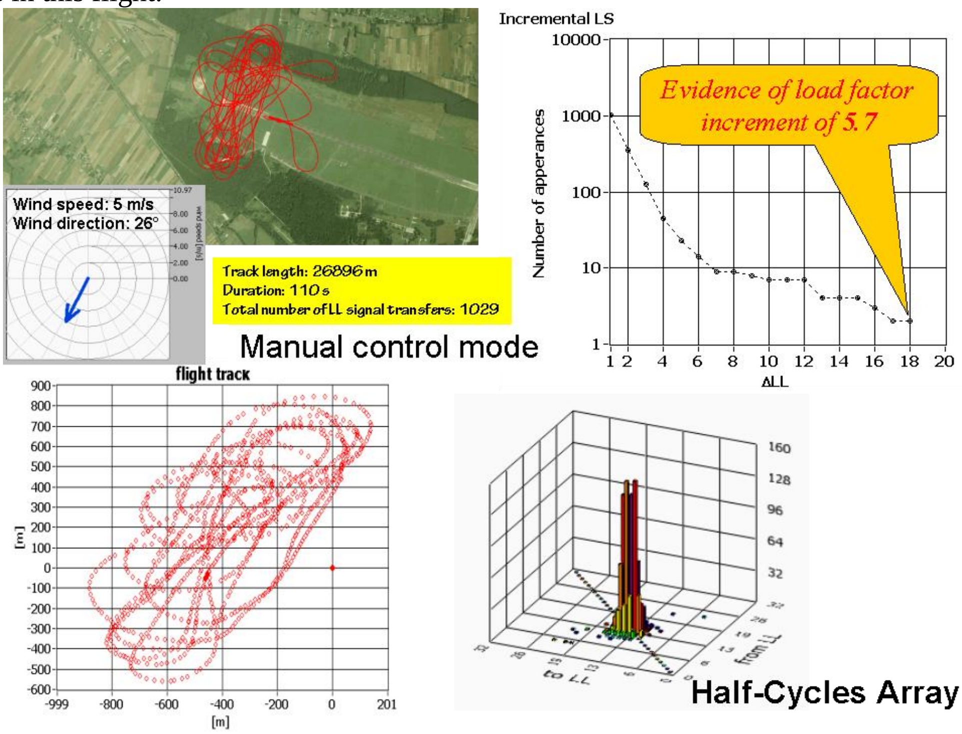


Fig. 9 HC-array from flight No 2 (manual control mode)

The results for automatic mode of control are presented in Fig. 10. In a current case of flight – controlled by the autopilot the maximum load factor increment was equal to 2.9.

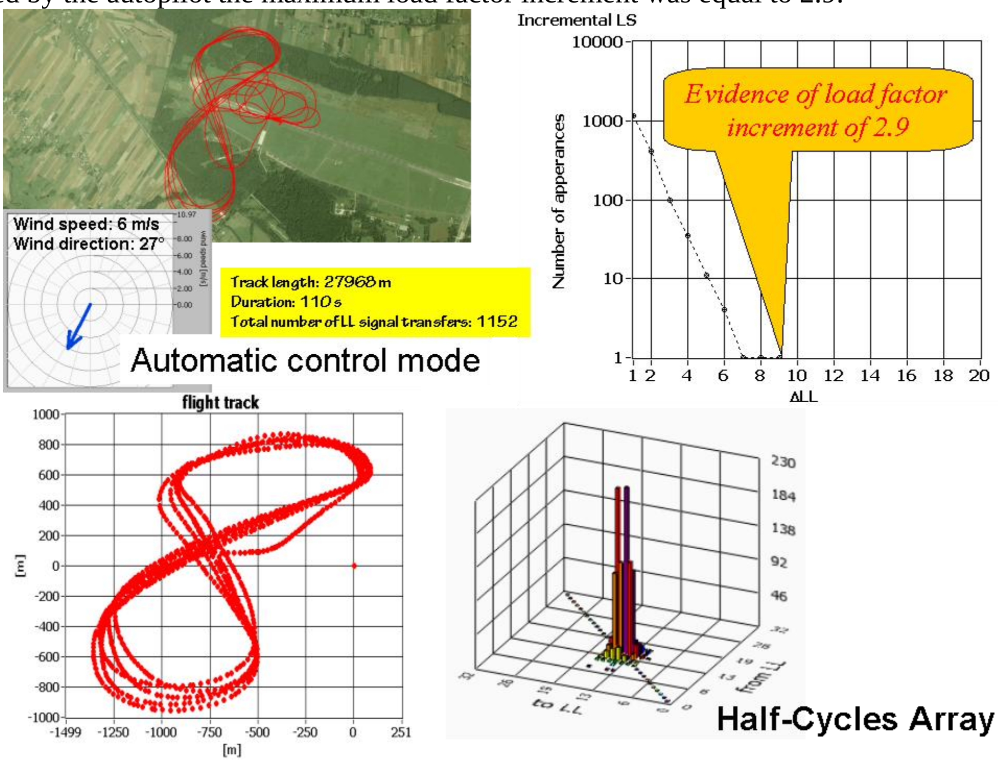


Fig. 10 HC-array from flight No 3 (autopilot control mode)

The conclusion, which comes from this analysis is that the autopilot produced softer load spectrum than manual mode of control (see Fig. 11). The question which is appearing here is: what a consequence for the UAV structure follows from this fact?

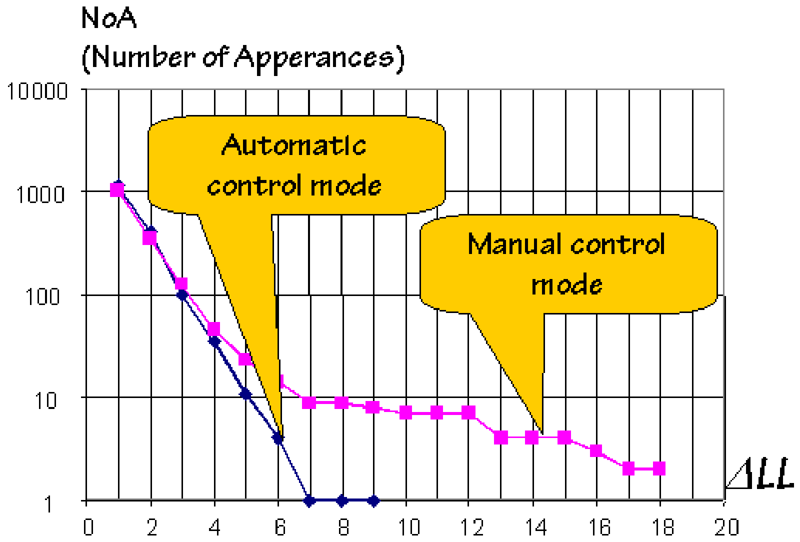


Fig. 11 Comparison of incremental load spectra generated by manual and automatic control modes

To be able to answer this question let's assume that the fatigue properties of a composite structure are given by the High diagram shown in Fig. 12. It is possible to present those properties in the form of the array showing number of half-cycles to failure.

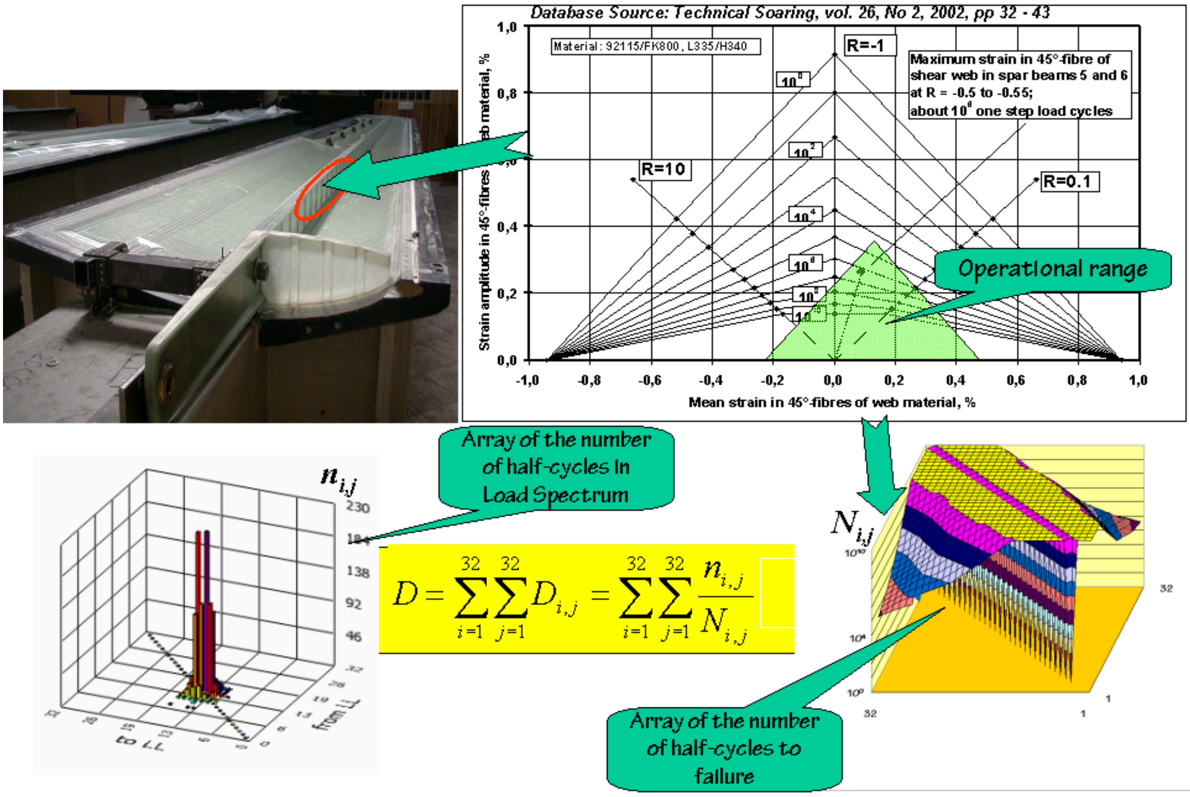
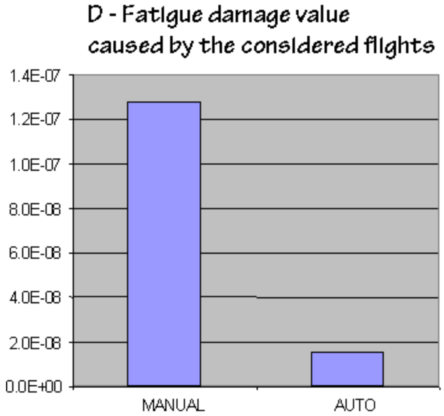


Fig. 12 Example of fatigue properties of composite structure and explanation of modified Palmgren-Miner formula

By applying modified Palmgren- Miner formula (Fig. 12) the following results were obtained (Fig. 13):



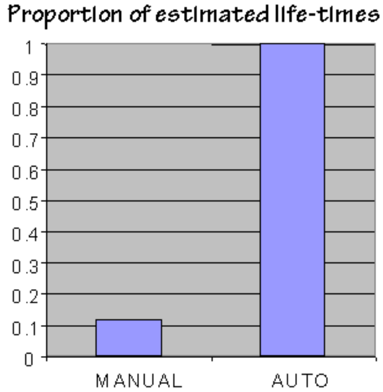


Fig. 13 Comparison of fatigue damage and fatigue life-times for a manual and automatic mode of the UAV control

Generally – to be able to determine effectively the UAV load spectrum – it is necessary to increase the number of analyzed flights – taking into consideration a different scenarios, different weather conditions, terrain conditions, different pilots, etc. It would enable the statistical analysis of particular load increments occurrences. The chart in the upper part of Fig. 14 presents two curves: mean values and the values shifted up of 3 standard deviations. In case of this curve there are taken into account possible dispersion of load increments occurrences (i.e. number of appearances in relation to the flight times). On this basis it is possible to determine for example: the coefficients, which should be applied for multiplication of the values existing in the **HC**-array compound from all analyzed flights in order to obtain more generalized result.

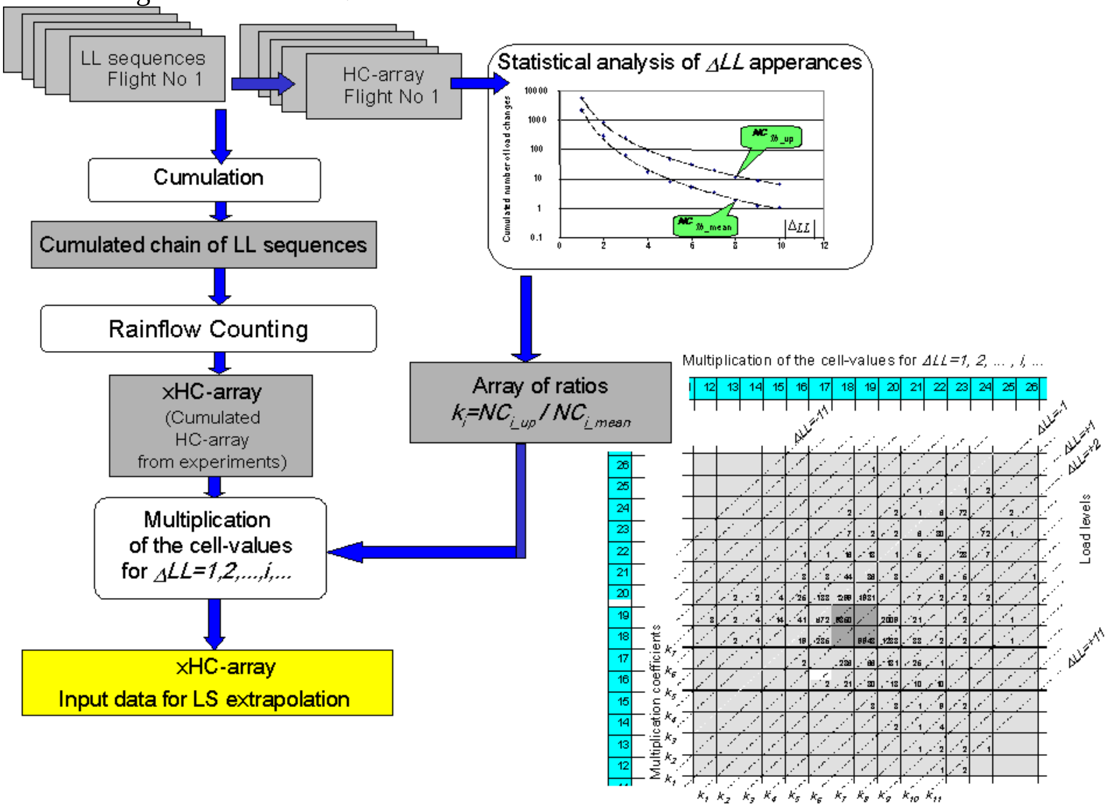


Fig. 14 Algorithm of data processing for model-load spectra – general case

This slide presents the result of statistical analysis of the load spectra produced during the same flight-path figures. Here we have 5 flight-path loops made in an automatic mode of the UAV control. For each loop there was determined the load spectrum, which is presented in the form of the **HC**-array and below in the form of the incremental LS. Taking into consideration the standard deviations of the *NoA* numbers for each Load Level increment, and also taking into consideration the standard deviation of maximum ΔLL values for each flight – it is possible to determine a new curve with extended ΔLL range. Having in mind the airworthiness requirements regarding safety margin – such a load spectrum would be representative for considered here flight maneuvers.

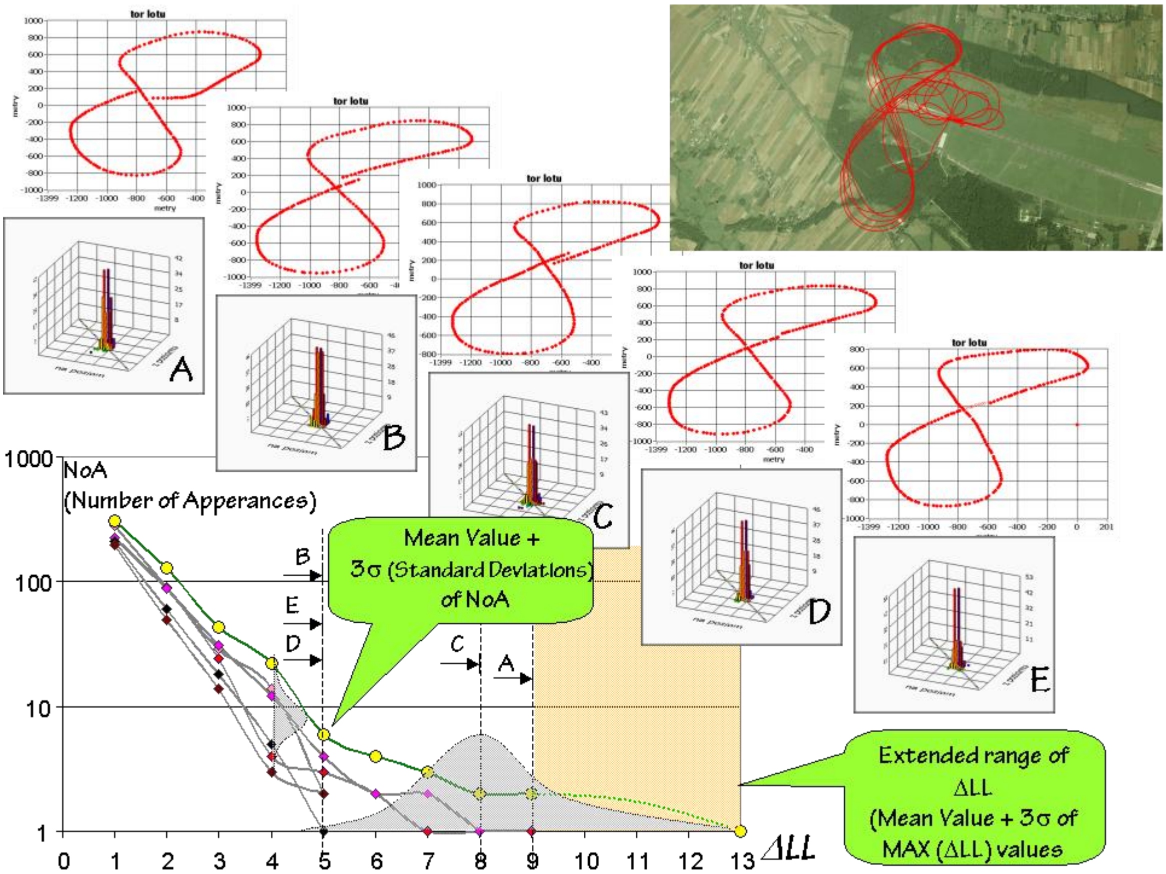


Fig. 15 Example of statistical analysis of the *NoA* and maximum ΔLL values

There are shown in Fig. 16 both: the original Load Spectrum derived from the data-log and extrapolated Load Spectrum with respect to possible load increments dispersions. As one can see: such a load spectrum applied on the fatigue stand would be more strong proof of the fatigue life of our UAV.

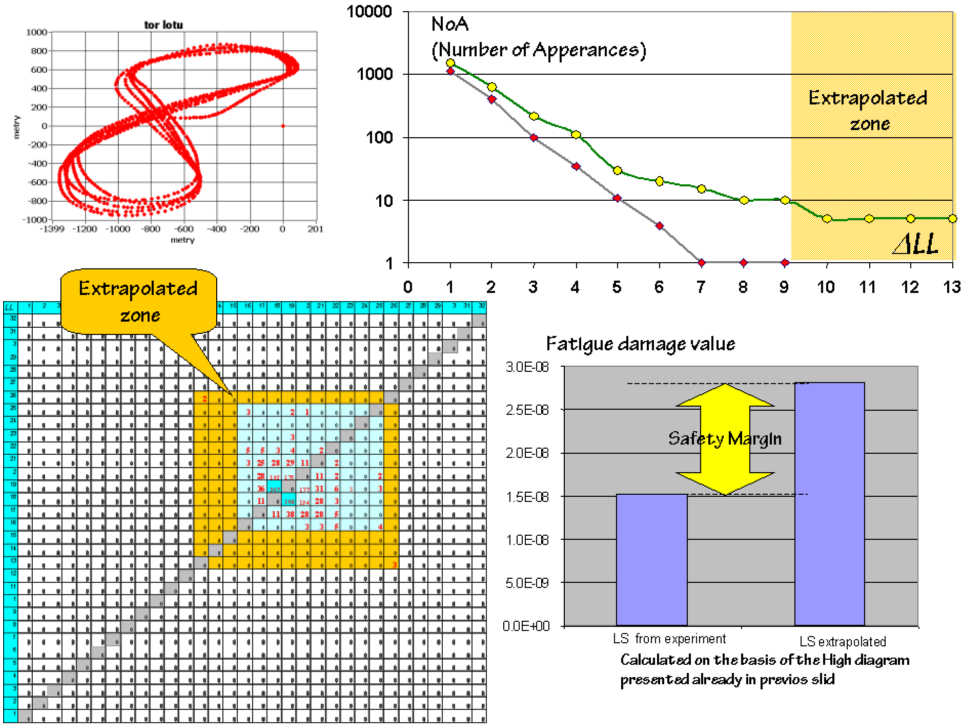


Fig. 16 Demonstration of safety margin obtained by the procedures of LS derivation - presented in the paper

4 Conclusions

- Determination of UAVs load spectra has a crucial importance for the process of airworthiness requirements elaboration for this category of the aircrafts.
- It was found that significant differences in load spectrum could be observed between a manual and an automatic control mode of the UAV. Those differences involve strong influence on the fatigue life of the UAV structure.
- Elaboration process of the model load spectra for fatigue testing of the UAV structure should be based on statistical analysis of possible dispersions of two main parameters: Number of Appearances for each Load Level increment, and dispersion of maximum load increments values.
- 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 a different flight scenarios, different weather and terrain conditions, different pilots, etc.

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