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# Analysis of Operating Loads on an Aircraft's Vertical Stabilizer on the Basis of Recorded Data

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Structural health monitoring of aircraft is a necessary topic especially with aging fleets. In general, it means tracking the structural integrity and keeping the risk of not detecting hazardous cracks low. Traditionally fatigue analyses from collected data have been carried out in a flight-by-flight basis. However, simultaneous good-quality recordings of most relevant flight parameters with calculated fatigue damage synchronized with recordings enable a more thorough analysis. Using an adequate collection of time stamped flight parameter signals, this paper aims at analysing mileage sequences of loads on the horizontal stabilizer.
In order to ensure the safety of the supporting structure, software for detecting flight loads exceeding limits has been developed. The aim of this study was to analyse the completed data from flight recorder KAM-500. The task was to approximate passes of horizontal stabilizer's loads by using a set of parameters recorded by the flight data recorder TESTER-U3Ł. For each of the analyses all available collections stored in the archives were used. Several measuring points on both left and right horizontal stabilizer of aircraft were considered.
The aim of this study was to determine the number of load cycles without knowing the distributions of load passes on the horizontal stabilizer. The algorithm is designed to detect the cycles in which the flight loads were significantly exceeding limits. Cycles with lower values were found to be insignificant in the context of further strength analysis of horizontal stabilizer. The effectiveness of the algorithm's detection based on calculation is estimated to be 90-95 %.

## 1. Introduction

Structural health monitoring of aircraft is a necessary topic especially with aging fleets. In general, it means tracking the structural integrity and keeping the risk of not detecting hazardous cracks low. Traditionally the fatigue analyses from the collected data have been carried out in a flight-by-flight basis.
However, simultaneous good-quality recordings of the most relevant flight parameters with the calculated fatigue damage synchronized with the recordings enable a more thorough analysis.
The presented damage distributions demonstrate a new ability to monitor the health of an aircraft stabilizer using collected data from flight. The performed analysis is based on actual results whereas good-quality records are available. Individual aircraft tracking approach concept was used based on the literature (Gallagher et al., 1984).
The proper execution of the analysis allows to establish the fatigue of the aircraft horizontal stabilizer. Considered area is under particular interest due to numerous defect (Klimaszewski et al., 2005). Consequently, this approach may reduce the required number of inspections, which involved non-destructive testing checks. Currently, these tests are carried out relatively frequently and entail significant costs.
A brief summary of the paper is as follows. At the beginning the description of input data is shown. The next section considers a fundamental question about how to estimate fatigue life of the aircraft stabilizer whereas there is no sufficient data. Then the process of flight recordings data mining is discussed. The presented experiments illustrate the idea of the data mining concept. Finally, conclusions are drawn.

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## 2. Description of input data

Research that provided the input data required for this analysis were performed on the airframe. Preparation for the research included gathering data measuring-recording equipment KAM-500. For each of the analyses all available collections stored in the archives of the Air Force Institute of Technology (AFIT) placed in Poland were used (Leski et al., 2007).
During flight tests, the measuring-recording equipment was collecting data from twenty strain gauges, placed both on left and right horizontal stabilizer. Mainly the data collected from four out of twenty strain gauges were taken into account. Previous preliminary analysis of all data leads to the conclusion that there is no need to examine collected data from all sensors. Scientific explanation for this choice is a high correlation between the results read from all of strain gauges. A choice of four has been justified as a necessity of observing both stabilizers with additional replacements on each stabilizer.
The mounting position of the interest strain gauges has been shown on the figure 1. The precise arrangement was described in table 1.

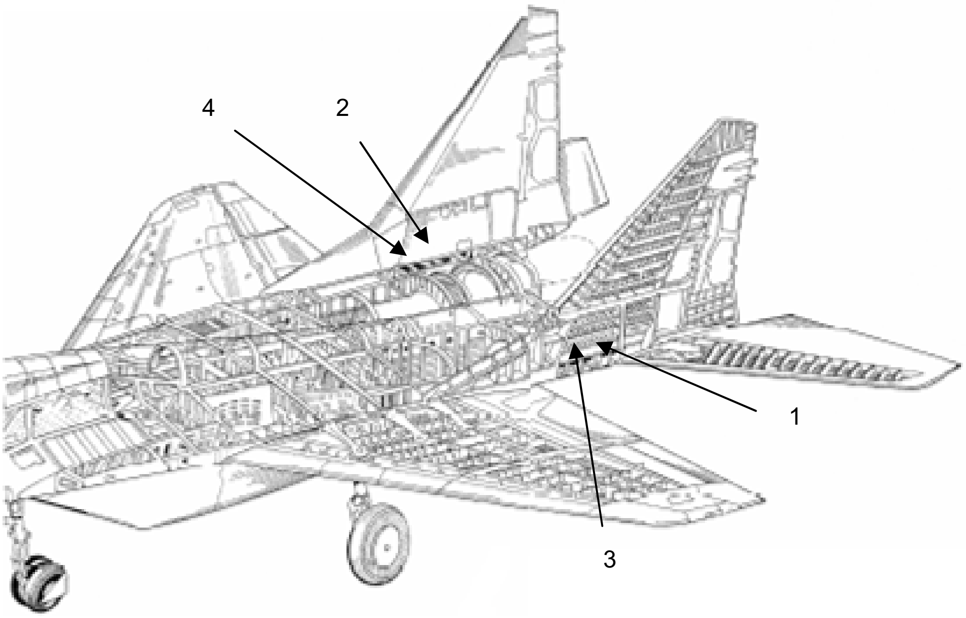


*Figure 1: Strain gauges' arrangement*

*Table 1: Precise arrangement of strain gauges*

| No. | Localization |
|---|---|
| 1 | The frame wall No. 7B of left horizontal stabilizer superstructure |
| 2 | The frame wall No. 7B of right horizontal stabilizer superstructure |
| 3 | The frame belt No. 7G of left horizontal stabilizer superstructure |
| 4 | The frame belt No. 7G of right horizontal stabilizer superstructure |

The technical specification of the used strain gauges is TFrx – 6/350.

## 3. Algorithm

The flight data recorder TESTER-U3Ł with encoder 1IM is the strip chart recorder. In contrast to the measuring-recording equipment KAM-500 its purpose is to collect most useful data during the flight. During regular exploitation aircrafts are usually not equipped with strain gauges, which can collect fatigue data from the stabilizers.

It has been observed that there is a sufficient correlation between strain gauge recorded data by measuring-recording equipment KAM-500, and the data from a set of parameters recorded by the flight data recorder TESTER-U3Ł with encoder 1IM. This concatenation leads to the algorithm presented in this section. The designed algorithm needs the following flight data recorders parameters, as presented in table 2.

*Table 2: Input data*

| Symbol | Full name | Units |
|---|---|---|
| $v_p$ | airspeed | km/h |
| Alfa | angle of attack | ° |
| Teta | angle of inclination | ° |
| $n_x$ | longitudinal load factor | - |
| $n_y$ | lateral load factor | - |

We can find that cycles may occur for aircraft velocities between 380-500 km/h if the lateral load factor during that period of time is greater than 4. If the algorithm manages to find that specific cycle it is possible to predict that the stress on stabilizer was significant. Although if the load factor will stay on the same level, the presence of cycles may be also noticed.
If the value of load factor will be greater than 4.8, we can also predict growth of values from four strain gauges. Whereas we can be sure that founded the cycle is correct when the aircraft speed is also growing during that period of flight.
Whilst the angle of attack is greater than 18°, the value of lateral load oscillates between 2 ÷ 5, the value grater then 0.8 of longitudinal load factor occurs, one can be sure, that there has also been a strain cycle on the horizontal stabilizer.
The last case, which can cause the rise of recorded values, is when the aircraft velocity remains over 300 ÷ 350 km/h for at least 50 sec.
A scheme of the algorithm is presented on Figure 2.

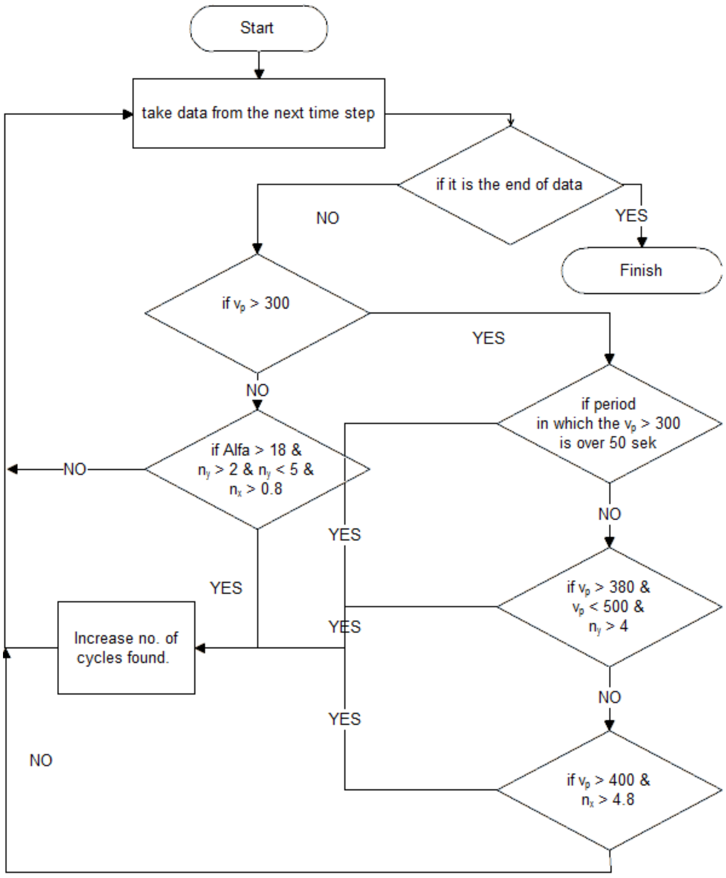


*Figure 2: Algorithm*

The results of the algorithm are time periods in which cycles of strain gauges registered parameters can occur.
The method for detection of cycles was derived from the concept of separate maneuver and gust load factors from measured acceleration (Rustenburg et al., 1999).

## 4. Results

In order to verify the correctness of the used algorithm 26 experimental flights have been analysed. Research flights were performed towards the establishment of a representative load sequence created based on the measured results (Leski, 2010). Efforts were carried out to choose the flights so that they were diverse in terms of maneuvers performed.
Figure 3 illustrated the examples of the results for one of the flights.

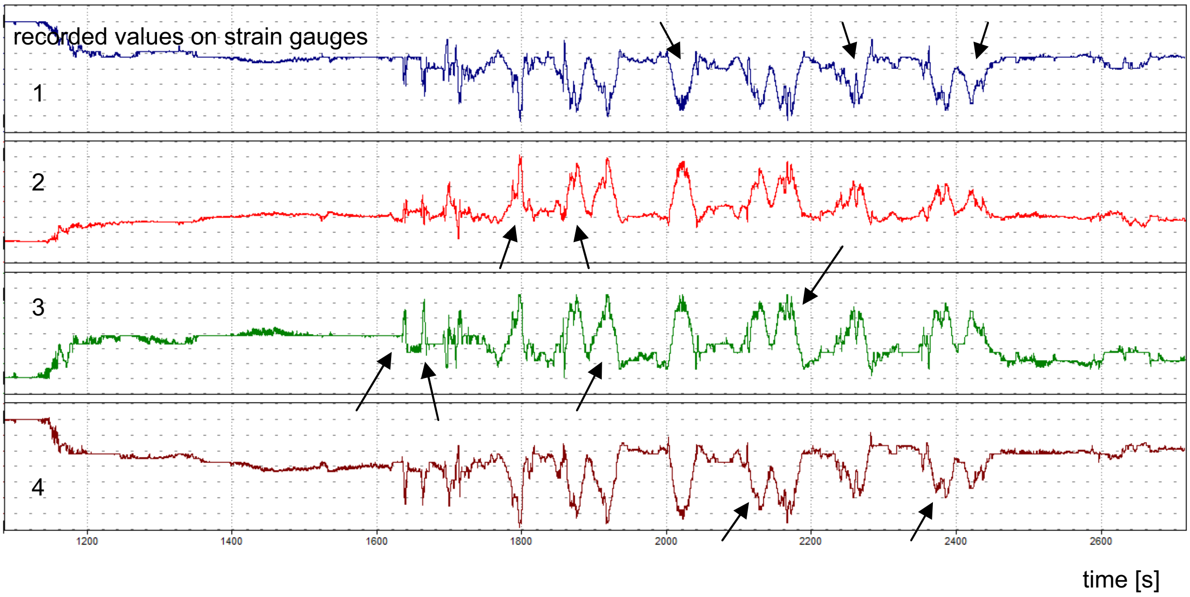


*Figure 3: Recorded values on strain gauges with algorithm results obtained marked*

Although the results of the algorithm are the time periods in which cycles of strain gauges registered parameters can occurs, in Figure 4, different recorded values from strain gauge graph cycles were marked. These marks were used in order to better illustrate the results from used algorithm.
For flight presented the following time intervals, displayed at table 3 were found.

*Table 3: Time periods obtained*

| No. | from [s] | to [s] |
|---|---|---|
| 1 | 1638.22 | 1641.12 |
| 2 | 1664.05 | 1667.12 |
| 3 | 1696.04 | 1741.15 |
| 4 | 1795.43 | 1803.95 |
| 5 | 1864.04 | 1883.91 |
| 6 | 1915.63 | 1926.18 |
| 7 | 2018.49 | 2031.54 |
| 8 | 2118.48 | 2138.37 |
| 9 | 2163.9 | 2177.06 |
| 10 | 2244.29 | 2272.87 |
| 11 | 2370.83 | 2393.04 |

Detailed analysis of the data visualized on Figure 5 shows the previously mentioned correlation between the signals coming from different strain gauges.

In Figure 4 plots from AMXER software have been placed. Plots represent successively the values obtained from the first strain gauge, airspeed, angle of attack, angle of inclination, lateral load factor and longitudinal load factor.

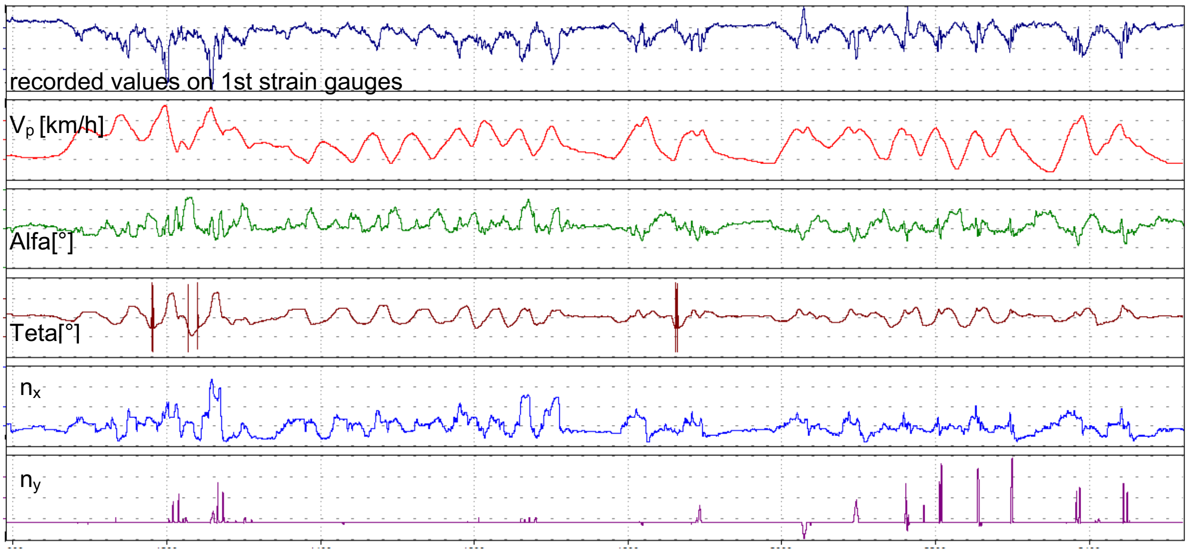


*Figure 4: Values recorded on strain gauge compared to the data from recorder TESTER-U3Ł*

The foregoing figure is a good example of correlation between registered values from strain gauges and values from the channels, as described in table 2, such as, airspeed, angle of attack, angle of inclination, lateral load factor and longitudinal load factor.

## 5. Conclusions

Previously this kind of the fatigue analyses for aircraft stabilizer hasn't been performed. There have not yet been discovered appropriate tools for fatigue analyses. This paper presents an automated data mining procedure for calculated mileage sequence of loads on the horizontal stabilizer from the flight recording.
The proposed algorithm is effective at exploring the positions and numbers of fatigue loads at horizontal stabilizer. The value of load from the four strain gauges has been taken into account. It has been proven that the loads from the strain gauge sensors placed on the stabilizer are correlated. Because of this the paper focuses on results from only four of twenty strain gauge sensors. Both, right and left horizontal stabilizer, during the flight have been exposed to the same loads.
The algorithm is written in an universal manner. It can be transferred to another aircraft with two vertical stabilizers. For this purpose a study to determine the limits of values of relevant parameters should be performed.
The aim of the designed algorithm was to detect the cycles with significant levels. Cycles with lower values were found to be insignificant in the context of further fatigue analysis. The effectiveness of the cycle detection algorithm is estimated to be 90-95 % on the basis of the calculation. This effectiveness has been checked for all available results of research flights, for which detailed analysis has been performed. It is not possible to determine the accuracy precisely, since the boundary designating which cycles are important for analysis is soft.
Such an approach leads to establishing the fatigue of a stabilizer. This new analysis capability supports fleet management by providing detailed information about horizontal stabilizer condition. Consequently, this approach may reduce the required number of inspections, which involve the non-destructive testing (NDT) checks with crack detector, Shearography Q-810 and System MOI use.
Therefore, such approach will lead to saving time and resources required during complex reliability analysis.

## References

Gallagher J., Giessler F., Berens A., Engle R., 1984, USAF damage tolerant design handbook: Guidelines for the analysis and design of damage tolerant aircraft structures, Dayton, Ohio.

Klimaszewski S., Leski A., Dragan K., 2005, NDI approach for Structural Integrity Evaluation of MiG-29 Aircraft, ASIP Conference, Memphis, USA.

Leski A., Baraniecki R., Kurdelski M., Raczyński E., Jakielaszek Z., Bryl M., 2007, Skalowanie czujników tensometrycznych zamontowanych na samolocie MiG-29 nr fabryczny 2960525115 (nr boczny 4101), Air Force Institute of Technology, Poland (limited access).

Leski A., 2010, An Algorithm of Selecting a Representative Load Sequence for a Trainer, 2$^{nd}$ International Conference on Engineering Optimization, Lisbon, 1-8.

Rustenburg J., Skinn D., Tipps D., 1999, An Evaluation of Methods to Separate Maneuver and Gust Load Factors From Measured Acceleration Time Histories, Report No. DOT/FAA/AR-99/14, Virginia.