In-Service Flaw Detection and Quantification on the MiG-29 Composite Vertical Tail Skin

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Abstract. Nondestructive testing results for the composite vertical tail skins on Polish Air Force MiG-29 aircraft are presented in this article. The inspections and assessments were conducted using the optical DSight™ technique using the DAIS® system. In addition, automated ultrasound and resonance C-scan techniques were performed using the MAUS IV/V® system.
These inspections were the first efforts to characterize the in-service condition of the MiG-29 composite structures. This article presents the inspection approach for data collection and assessment, and outlines problems encountered during the inspections. The article describes concerns regarding the detection of non-standard damage classes, and analysis approaches to define the structural implications of this damage.

1. Introduction

MiG-29 is the basic fighter jet used in Polish Air Force. Two main criteria in the maintenance approach of MiG-29 are service life based on hours (so called Hour Service Life – HSL) and service life based on years (so called Calendar Service Life - CSL) [1]. The new maintenance approach called On Condition Maintenance (OCM) was introduced in connection to possibility of extending service life of some airplanes. One of the primary tasks was NDT (Non Destructive Testing) work for critical components, as well as corrosion inspection program for MiG-29 aircraft. Activities connected with NDT and corrosion inspection program are also delivered for other aging aircraft of Polish Armed Forces. In this article only part of NDT work will be presented the one related to composite skin of vertical tail of MiG-29. The MiG-29 is the aircraft with double vertical tail construction. Vertical tail consists of aluminum substructure (so called “keson”) and composite skin made of CFRP (Carbon Fiber Reinforced Plastic) [2]. Skin is monolithic with thickness range 1.8 mm – 3.2 mm and it’s joined to substructure with use of bolts and adhesive [2]. The main effort, during vertical tail inspection, was focused on CFRP skin and damages classified as :

- Delaminations;
- Disbonds;
- Foreign object inclusions;
- Porosity.

The article will present both the approach for inspection with the use of DSight™ and Ultrasound Pulse Echo as well as approach for inspection, collected data and encountered problems.

2. Techniques used for inspection

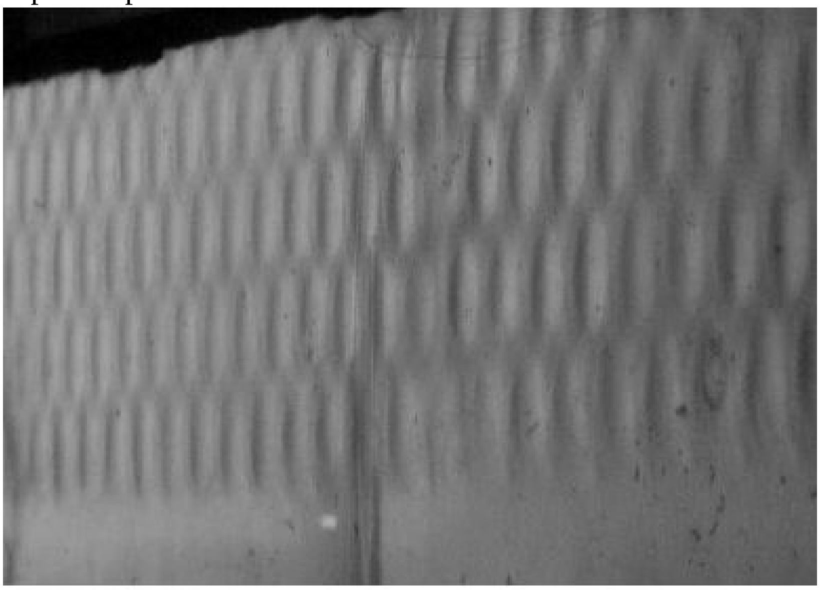
Two main techniques were used for inspection of MiG-29 vertical tail composite skin. At the beginning DSight™ inspection was delivered. That inspection was supported with the use of DAIS® system.

2.1 DSight™ inspection approach

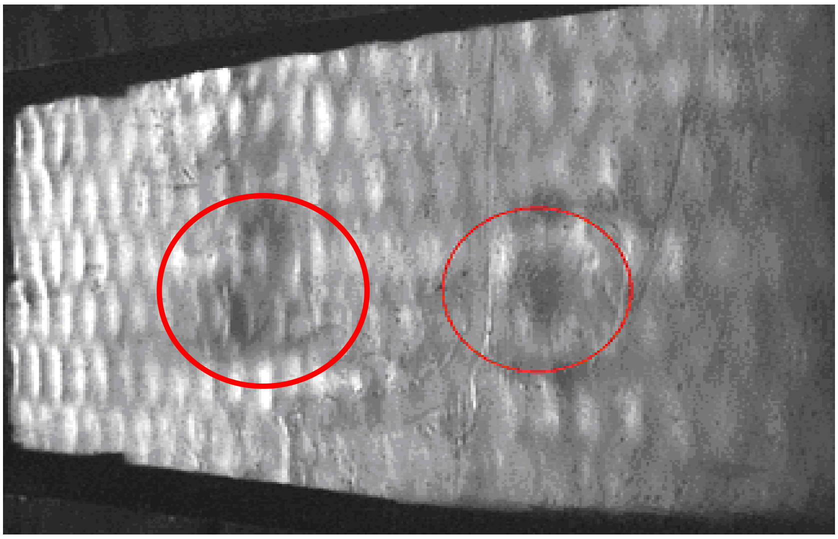
DSight™ inspection is based on the use of Double Pass Retroreflection phenomenon [3,4]. The light goes from the light source and reflects from the surface under the inspection. Part of the light reflects from the surface and goes back to the picture analyzer (CCD camera) located slightly off the light source. Part of the light is reflected in another direction (according to reflection law). That part of the light beam reflects back from the mirror, located on the opposite site of the light source. Light beam reflects again from the mirror and again from the inspected surface and goes to the camera. Based on that phenomena the complete system was constructed. That system uses DSight™ phenomenon and was called **DAIS®** (**D**Sight **A**ircraft **I**nspection **S**ystem).

The system consists of light source (white light source) and special chamber (sensor) to cut off measurement area from the external light source. Reflected light goes to the CCD camera or it is turned to mirror (retroreflective screen). Screen is built up from very small beads with diameter about 60 μm. That surface imperfection causes reflected beam slightly divergent (creates light cone). Again, light beam is reflected from the surface and goes to CCD camera. Such a phenomena causes that even very small surface distortions are visible on the recorded picture. Sensor is connected with the PC computer in order to send and save collected data for further analysis. That approach enables the post measurement data analysis. The next important issue is the fact that data is stored in the database which makes possible to monitor the technical condition of selected aircrafts or elements. That is especially important during OCM of aircrafts.

Data analysis is based on visual assessing of recorded images and extracting of key features of damages on inspected surface. Some key features of: surface without distortion and surface with distortion caused by the low energy impact damage on the composite honeycomb sample are presented below.



Pic.1 Key feature of DSight™ images – surface without distortion

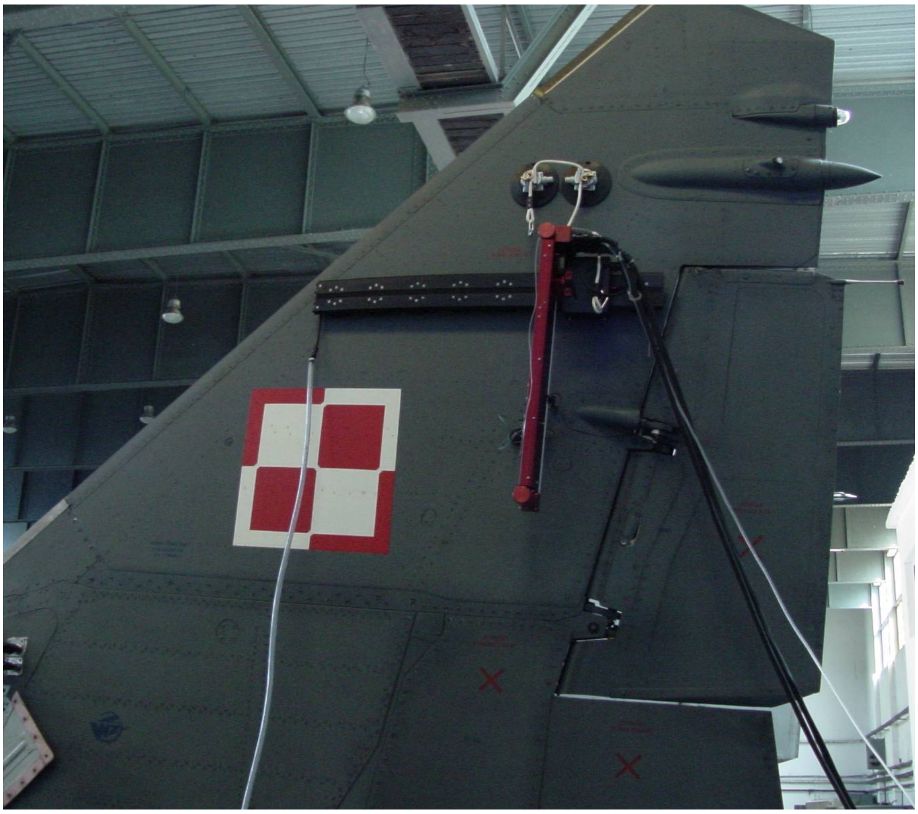


Pic.2 Key feature of DSight™ images – surface with disbands

As we can notice the surface without distortions (Pic.1) gives smooth light distribution. Whereas damages caused by low energy impacts show areas with different gray scale value (Pic.2). The most important feature of data assessing using DAIS® system is the fact that detectable damages have got surface distortions. The main purpose of applying enhanced visual test with the use of DSight™ for composite skin of vertical tail, was to asses number of low energy impact damages. The next step in that approach was to deliver ultrasound test.

2.2 Ultrasound inspection with the use of MAUS® system

To perform structural integrity inspection of airplane composite vertical tail, ultrasound testing was conducted. The total surface area for inspection was approximately 11 sq. meters per one aircraft. The aircraft population selected to tests was 22. So total area for inspection equaled 242 sq. m. Due to the fact that classical tests (applying manual hand scanning) were very difficult or impossible (because the work was performed on the airplane) the automated scanning procedure was delivered. MAUS® IV/V system was used. **MAUS®** system (**M**obile **AU**tomated **S**ystem) is a hybrid construction and makes it possible to inspect vertical tail using such techniques as: ultrasound, eddy current, MIA, Pitch-Catch, Resonance and the Phased Array module for ultrasound. System is fully portable and enables inspection on horizontal and vertical inverted surfaces. That is possible due to flexible track system equipped with vacuum suction cups. On the picture below (Pic.3) inspection of vertical tail composite skin of MiG-29 is presented.

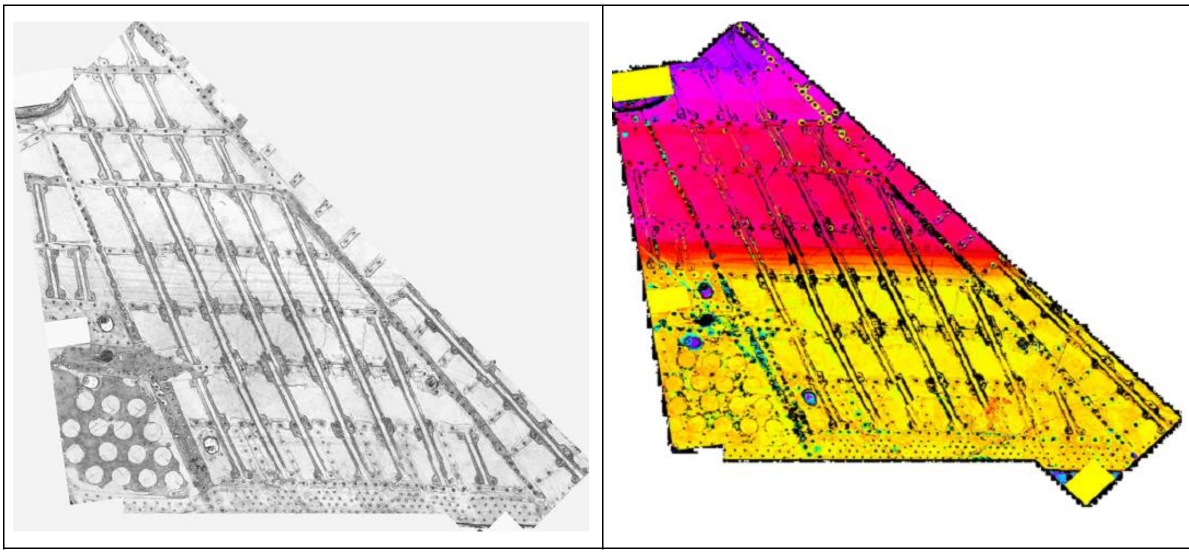


Pic.3 MiG-29 Composite Vertical Tail Inspection.

On the picture scanning arm and flexible track system are presented. Total thickness of composite skin of the vertical tail is between: 1.8 – 3.2 mm. The first step before inspection were specimen preparation and specimen tests. On that stage the damage classification was made. Based on prepared ‘step samples’, tests have been performed [5]. The tested samples gave idea that following damages of the composites could be detected:

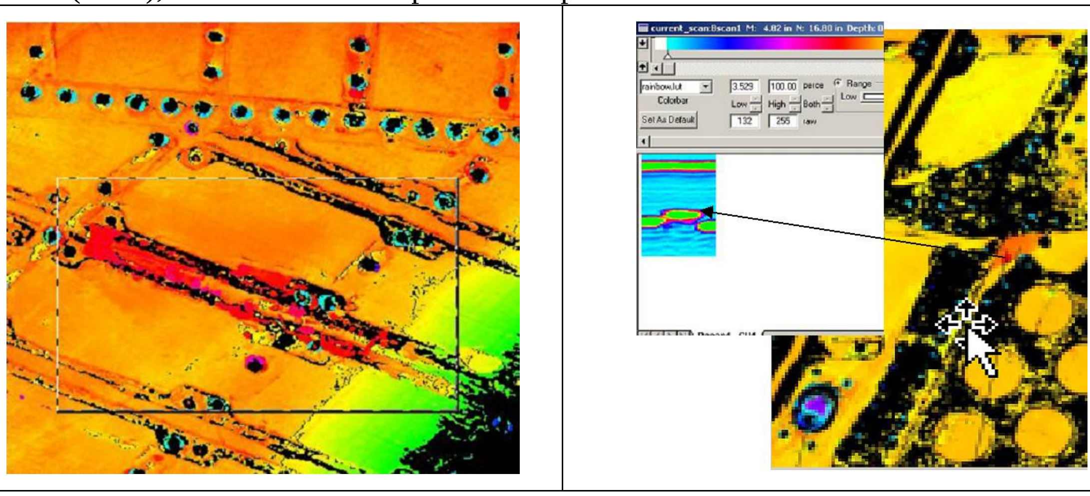
- disbonds (skin to substructure);
- delaminations;
- foreign object inclusions;
- porosity.

Based on that criteria the following tests were conducted. All composites skin of double vertical tail of 22 airplanes were inspected. C-scan data visualization mode was accepted as a base. In case of any damage occurrence additional full waveform capturing with B-scan visualization possibility was taken. MAUS® measurement interface, gives possibility for Amplitude and TOF (Time Of Flight) C-Scan data presentation. Below, on the picture (Pic.4), the completed C-scans (Amplitude and TOF) of MiG – 29 vertical tail are presented.



Pic.4 Collected C-Scan data Amplitude (left) and TOF (right) of MiG-29 vertical tail.

All areas of composite skin were inspected. On the amplitude data different colors are connected with different signal attenuation. Color range in the TOF data gives information about different composite skin thickness as well as damage depth. That system of data presentation is very helpful for damage description as well as for finding damage location. Single sensor Pulse-Echo technique was used with the one side access. Below, on the picture (Pic.5), some results of inspection are presented.



Pic.5 Damages in the composite skin of vertical tail.

As we can notice on the left picture delamination area is presented over the longeron structure. That signal is very distinguished with higher reflection amplitude and depth of damage lower than thickness of composite skin. On the right picture foreign object inclusion with C-scan and B-Scan data is presented. That results are only some selected areas of the vertical tail. During the inspection the most often damages such as disbonds and delamination (especially around fasteners) were found. Also, both foreign object inclusion as well as porosity happened.

3. Results obtained during inspection

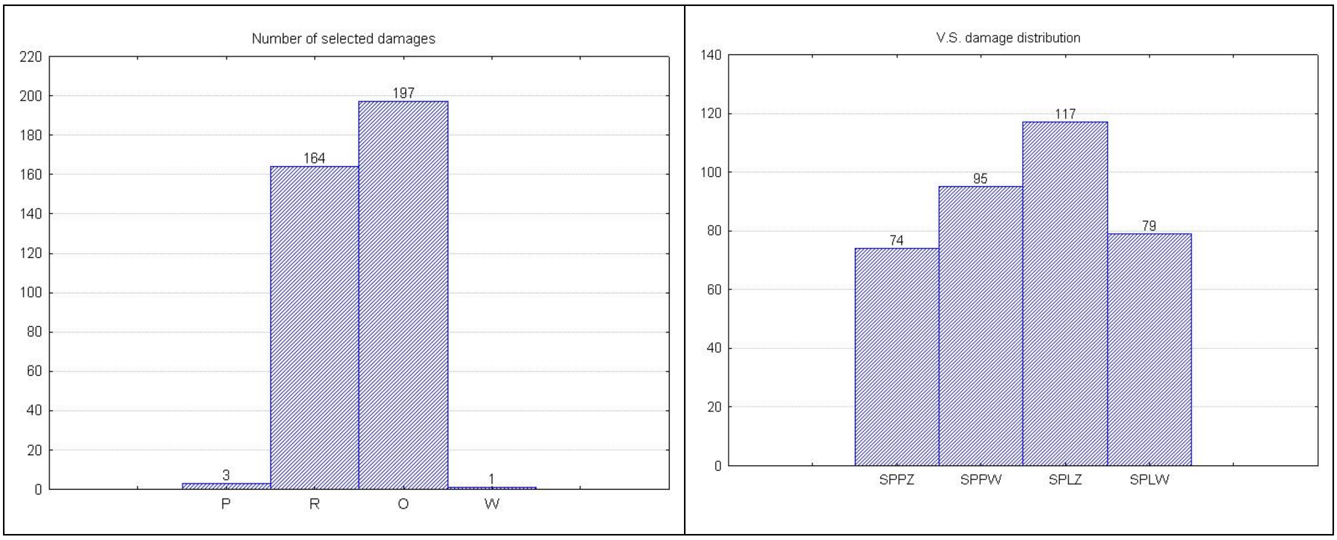
The total population of 22 aircrafts was inspected. In that population the following numbers of damages occurred:

- O- disbonds (197);

- R - delaminations (164);
- P - porosity (3);
- W - foreign object inclusions (1).

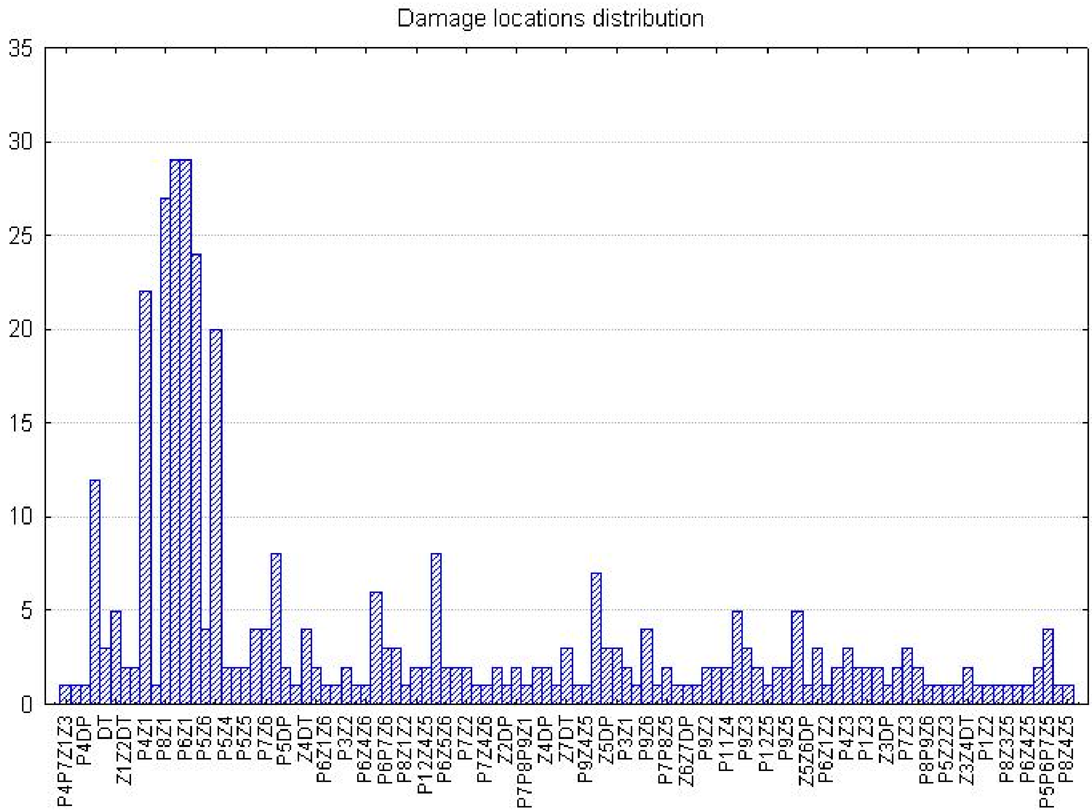
The total number of damages was found and equaled 366. The distribution of the damages placement regarding to the side of the vertical tail (internal and external) as well as left or right tail have approximately normal distribution. The total number of damages is following:

- SPLZ - external side of left tail – 117;
- SPLW - internal side of left tail – 79;
- SPPZ - internal side of right tail – 95;
- SPPZ - external side of right tail – 74.



Pic.6 Number of selected damages and damage distribution placement of vertical tail.

The observed damage distribution in the structure of composite skin of vertical tail does not show repeatable character of locations (except disbonds). The areas of damage occurrence are more random as we can notice on the chart (Pic.7).



Pic.7 Damage distribution in the vertical tail structure.

Only few more locations repeat for disbond. Only for disbonds we can describe placement more necessary for inspection. For other damages distribution of their location is random. Therefore it is crucial to inspect the whole area of vertical tail composite skin.

4. Future Planes

Bearing in mind that the increasing measurement possibilities and new technologies, such as Phased Array and shearography they also will be used for such inspections. Both of these techniques have got big potential and both are also portable and capable of doing in service inspection. The main concern is time reduction necessary for inspection. Shearography as well as Phased Array are much faster than classical single sensor UT. Phased Array can reduce time necessary for inspection even up to 4 times. Shearography can use different loading possibilities such as: vacuum and thermal. That can also extend measurement possibilities for another damage detection such as e.g. water ingress in the honeycomb structures like flaps.

5. Summary

The approach for inspection as well as some obtained results are presented in this article. All performed inspections were ISI (In Service Inspection). The main problem was the work on the vertical surfaces with bolt and rivets areas disturbing to attach flexible track system. Gained experience during aircraft inspection and amongst other for composite skin gave good basis for OCM.

Automated inspection increased reliability and speed of inspection, reducing at the same time the so called "human factor". As one can notice in the chart presenting damages location distribution, they occurred in random locations. From that point of view there is necessity for periodical inspection of composite skin of vertical tails. Taking into consideration future planes connected with Air Force development, our gained experience gave us potential to work with new aircrafts introduced to Polish Armed Forces.

6. References

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