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# Analysis of operational damage and their impact on the work of the contact surfaces in the axial compressor stage

## Analiza uszkodzeń eksploatacyjnych oraz ich wpływ na pracę powierzchni kontaktowych w stopniu sprężarki osiowej

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**During the operation, rotating parts of aircraft turbine engines are exposed on different types of damage. These damages mostly ensure from the difficult work conditions of this components. The article presents examples of failure of aircraft engines resulting from damage to the compressor elements. The influence of exemplary damages in the area of the blade on the work of contact surfaces in the disk rim part and the blade footer was analyzed. The distribution of stresses and pressures was determined on assuming different ranges of rotational speed as well. Numerical analyzes were performed using the ANSYS software.**
**KEYWORDS: turbine engine, damage of rotating parts, stress analysis**

Modern compressor units of turbine jet engines are systems that must maintain a high level of reliability at very high loads. These loads result from the need to obtain a large compression (now a 50-fold increase in pressure) at high values of air flow, which in turn translates into the efficiency of the drive unit. Due to these issues, the design process of axial compressor assemblies is very complex. We are looking for a configuration that will increase their durability and performance, as well as effective methods of detection, elimination and prevention of damage occurring during the operation of these components. Methods using numerical simulations or experimental methods that can help in the diagnosis of these components are still being developed. A popular and constantly developed research direction is the analysis of the impact of damper blades' vibrations on the vibration level and the viability of these elements (for example, crack propagation is examined). Works [1–3] analyzed the impact of damage geometry, as well as the impact of its location (including on the leading edge) on natural frequency or fatigue strength. On the basis of numerical and experimental analyzes, it was shown that the fatigue strength of the blade decreased in the case of damage located close to the blade lock [2].

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The usefulness of numerical methods in damage analysis is also confirmed by papers [4,5]. The first one presents the CFD analysis of compressor efficiency with a damaged blade (with the tip of the blade tip curled), and in the second – the analysis of the effects of a foreign object debris (FOD) collision.

This article is to explain the causes of damage occurring during the operation of compressors. In addition, it presents an analysis of the impact of selected damage to the blade of a high-pressure compressor blade on the work of contact surfaces in the lock.

### Damages and their causes

Compressibility of compressors for various types of operational damage results from difficult working conditions and the location of these components in the whole structure. The blades of the steering wheel rims and the impeller rims are most exposed to damage. Damage can also result from improper repairs, insufficient inspections and external factors, including from collision with ice cubes, birds or so-called foreign bodies (FOD) sucked through the inlet from the surface of the runway. Working in dusty conditions causes a large amount of dust to be sucked into the flow channel of the engine, which leads to erosive wear of components, mainly compressors and bearings [6, 7]. Other typical operational damage of the compressor elements may include: scratches causing material cracking, bruising, dents, rips and losses of material caused by cracking of the surface, creases and distortions of the surface, changing the initial shape or outline of the element (fig. 1).

Fig. 1. Exemplary damages of air compressor blades of a turbine engine

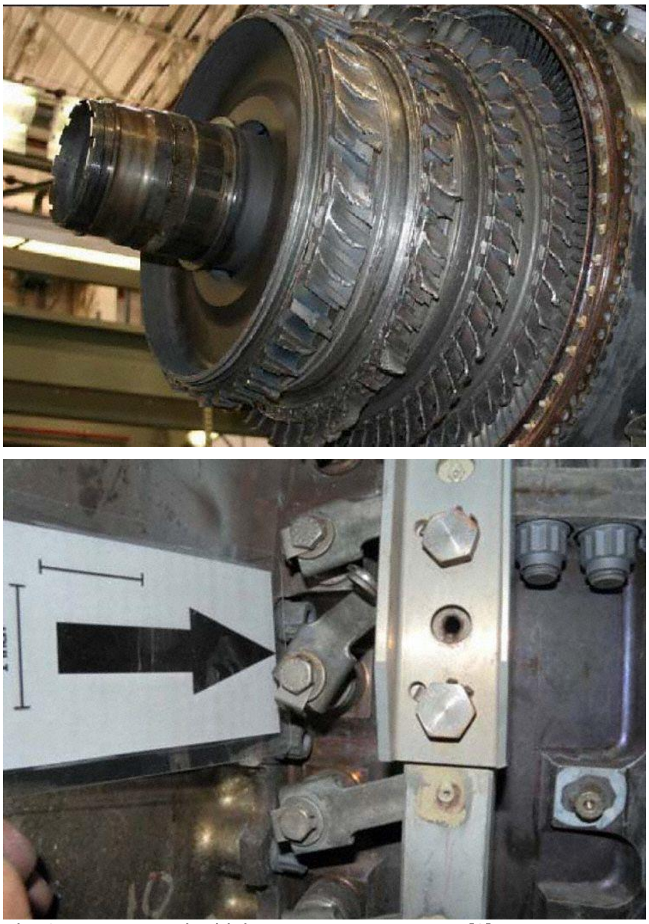

Fig. 2. Damage to the high-pressure compressor [8]

Because the technical condition and efficiency of the compressor affect the performance and life of the engine, it is important to carry out regular inspections of the rotor unit. The engine manufacturers in the service manuals precisely define the types and sizes of acceptable damage, as well as the possibilities and possible repairs. In the case of compressor sets, consisting usually of several stages connected together, the inspection ranges and damage sizes are characterized individually for each stage. The data show that the smallest damage qualifying the element to be replaced is damage on the leading or trailing edge. Such damage, such as nicks or defects of the material, cannot reach a depth of more than 1.0 mm, while dents – to a depth of more than 1.5 mm.

Here are three examples of compressor failures (from the last 10 years) involving civil aircraft:

- August 2008 – Airbus A321 with a V2533 engine – damage to the sixth degree of a high pressure compressor as a result of the so-called engine being sucked in by the engine. foreign body (FOD) [8].
- July 2010 – Boeing 777-200 with PW 4090 engine – damage to all four stages of the low-pressure compressor and three of five stages of the high-pressure compressor. According to the JTSB (Japan's Transportation Safety Board) report, the cause of the compressor's destruction was the closure of the IGV (inlet rim of the steering wheels) during the construction of the aircraft, which caused airflow disruption and vibration-critical components of the compressor (fig. 2) [8].
- November 2016 – Boeing 787-900 with Trent 1000 engine – damage to the first stage of the medium pressure compressor. The cause of the damage was fatigue (break in the region of the lock) of one of the blades [8].

The presented damage cases are one of many that occur during the operation of drive units. According to ICAO (International Civil Aviation Organization) [9] data, in 2012–2016 engine failures or malfunctions (SCF-PP category, i.e. System/Component Failure or Malfunction – Powerplant) accounted for 15% of all incidents, while serious accidents – 11.11% (fig. 3). Most accidents and serious incidents of the SCF-PP occurred mainly during the take-off and flight phase of the route [10].

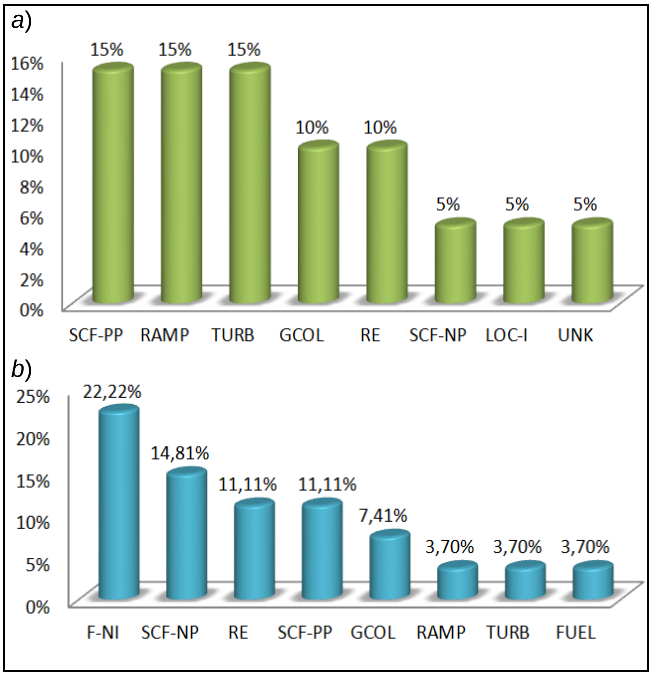


Fig. 3. Distribution of accidents (*a*) and serious incidents (*b*) as a percentage on the incidence category in 2012–2016 [10]

## Numerical analysis

The numerical FEM analysis was subjected to a blade section with blades. The undamaged model and model with shoulder damage were examined. The geometrical model of the element was created using the reverse engineering process based on the real geometry of the blade (fig. 4).

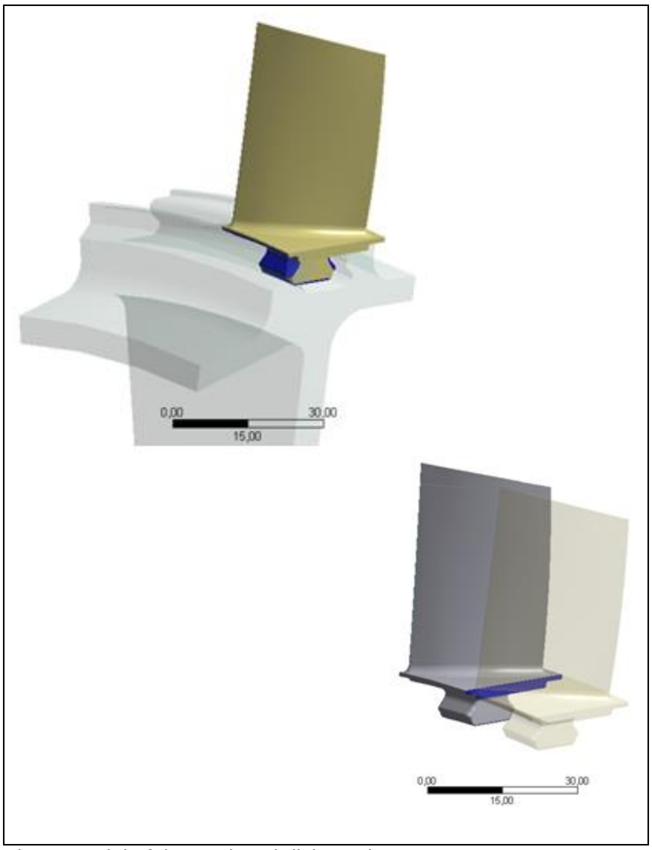


Fig. 4. Model of the analyzed disk section

Three cases of damage to the blade's blade were selected for the analysis. They are presented in fig. 5. These damages differ in the degree of material loss on one of the three blades (middle blade) of the considered slice (see table).

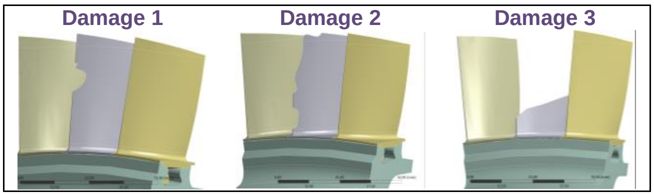


Fig. 5. Types of blade damage taken into consideration: damage 1 – local loss of the feather material, damage 2 – loss on the whole leading edge, damage 3 – significant loss of the blade pen

**TABLE. Degree of blade weight loss**

| | Undamaged | Damage 1 | Damage 2 | Damage 3 |
|---|---|---|---|---|
| Mass, kg | 0.01371 | 0.01365 | 0.01351 | 0.01039 |
| Weight loss, % | – | 0.47 | 1.46 | 24.23 |

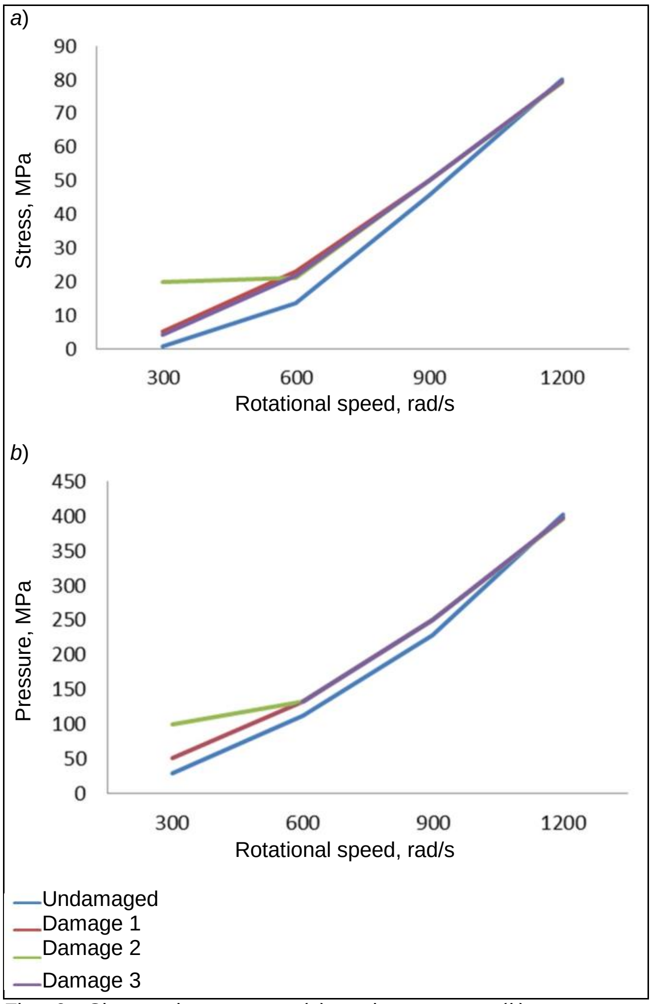


Fig. 6. Change in stresses (*a*) and pressures (*b*) on contact surfaces as a function of rotational speed

Ti-6Al-4V titanium alloy used in this type of real constructions was used for calculations. The structure load is the inertia forces resulting from the rotational speed set in relation to the axis of rotation, and thermal loads. The adopted rotational speed varies from 300 to 1200 rad/s. The analyzes included 16 different cases. The distributions of maximum stresses and pressures on contact surfaces of the blade-disc were determined. Three types of damage were considered and – for comparison – a model with an undamaged blade. Distributions of stresses and pressures at varying rotational speed are shown in fig. 6.

The analyzes carried out allowed to assess how much damage to the blade pen affects the work of the contact surfaces of the lock-rim (including the damaged blade and the blades adjacent to it in the disk). It can be seen that for damage 2 (i.e. weight loss along the entire leading edge) higher stresses and pressures (pressures) were obtained at a low speed range (300÷600 rad/s) than for the other considered cases. Other damages caused only a slight increase in stresses on the contact surfaces, e.g. at 900 rad/s – from 45 MPa for an undamaged blade to approx. 49÷50 MPa for the damaged blade. At 1200 rad/s, comparable stress values (at 80 MPa) were obtained for all failures.

## Conclusions

Low rotational speed may sometimes have a more critical effect on the cooperating elements of the compressor rotor than the speed from the standard operating range of such constructions. As a consequence, fatigue damage can occur in the area of the rim or shoulder blade. Damage to compressor assemblies is complex and it is still necessary to know the causes of failure of drive units of modern turbine engines. The development of new technologies, materials and research methods and the introduction of additional inspections is still not enough, which is very well illustrated by the statistics presented by ICAO.

Problems of damage to drive units, in particular rotor units, are still a field for development and research.

REFERENCES

1. Rygiel P., Obrocki W., Sieniawski J. “Numerical vibration analysis of turbine engine compressor blades depending on geometry and position of the damage”. *Advances in Manufacturing Science and Technology*. 41, 1 (2017): pp. 43–55.
2. Obrocki W., Setkowicz A. i in. „Wpływ uszkodzenia krawędzi natarcia łopatek sprężarki silnika lotniczego na ich wytrzymałość zmęczeniową”. *Mechanik.* 3 (2018): pp. 205–209.
3. Witek L. “Vibration analysis for detecting failure of compressor blade”. *Engineering Failure Analysis*. 25, 1 (2012): pp. 211–218.
4. Yanling Li, Abdulnaser Sayma. “Effects of blade damage on the performance of a transonic axial compressor rotor”. *ASME. Turbine Technical Conference and Exposition*. Vol. 8, 2012: pp. 2427–2437.
5. Guan Yupu, Zhao Zhenhua i in. “Foreign object damage to fan rotor blades of aeroengine. Part II: Numerical simulation of bird impact”. *Chinese Journal of Aeronautics.* 21 (2008): pp. 328–334.
6. Kozakiewicz A. „Analiza uszkodzeń turbinowych silników odrzutowych”. *Prace Instytutu Lotnictwa*. 213, 22 (2011): pp. 224–234.
7. Szczepankowski S., Szymczak J. „Wpływ zapylonego otoczenia na charakterystyki i parametry pracy lotniczych silników turbinowych*”. Journal of KONBiN.* 17, 1 (2011): pp. 257–268.
8. www.avherald.com.
9. “*MID Annual Safety Report*”. MID Annual Safety Report Team, Second Meeting (MID–ASRT/2), ICAO, 2018.
10. “*Aviation Occurrence Categories, Definitions and Usage Notes* (4.2)”. Montreal: Common Taxonomy Team, ICAO, 2011. ■

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