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ВОЗДУШНЫЙ ТРАНСПОРТ И ТЕХНОЛОГИИ
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ANALYSIS OF THE AIRCRAFT ENGINE FAILURES

Abstract. *The article investigates the causes, consequences, and prevention strategies related to aircraft engine failures. It provides a comprehensive classification of common engine malfunctions, examining mechanical wear, thermal stress, and operational factors that contribute to failures. A detailed analysis of statistical data on engine failure rates highlights critical trends and risk factors affecting engine performance and reliability. Furthermore, the study explores various diagnostic techniques designed to detect potential failures at early stages, reducing the likelihood of unexpected breakdowns. Modern aviation heavily relies on advanced maintenance strategies and cutting-edge technological solutions to enhance engine durability and efficiency. The article discusses preventive maintenance approaches, including predictive analytics, condition-based monitoring, and real-time diagnostics, which play a crucial role in minimizing failures. Additionally, the role of artificial intelligence and machine learning in fault detection and predictive maintenance is examined as a promising direction for improving aircraft engine reliability. The findings indicate that most engine malfunctions stem from mechanical degradation, excessive thermal loads, and human errors in operation and maintenance. Implementing regular inspections, utilizing advanced diagnostic tools, and integrating modern engineering solutions can significantly improve engine safety and longevity. The study underscores the necessity of continuous monitoring, timely preventive actions, and the adoption of innovative maintenance practices to enhance aviation safety and operational efficiency.*

Keywords: *aviation engines, fault analysis, aircraft maintenance, turbine inspection, non-destructive testing, thermal stress, mechanical wear, predictive maintenance, engine diagnostics.*

Introduction.

Aircraft engine failures pose significant risks to flight safety, potentially leading to catastrophic incidents. Despite advancements in turbine and piston engine technologies, failures still occur due to a variety of factors, including mechanical wear, carbon buildup, and thermal stress. As Murphy's Law suggests, "If anything can go wrong, it will." and “New system will bring new problems.”

That's why for engines malfunctions as a result to the surface coming aviation of events permanent analysis and their " health " tracking " flights safety for very important. Of these participants processes various to roles has. Aviation administration employees of birds’ unpleasant events to observe need eye see and from analysis after relevant the order release. Aviation organizations, separately Engines performance from monitoring come came out without, aviation administration instructions to do need their certain activity circle [1].

2008-2015 to ECCAIRS data for based article That one at the time electricity stations (SCF-PP) cause was aviation events results statistic calculations presented will reach.

In recent years, there has been considerable attention to the analysis of aircraft engine failure statistics. Analysis of data from the International Air Transport Association shows that between 2015 and 2023, turbojets account for 42% of all failures, turbofans for 35%, and turboprops for 23%. The main causes of failure are mechanical wear of components (38%), carbon deposition and fouling (27%), thermal stress (18%), manufacturing defects (9%), and maintenance errors (8%). However, historical trends show a 15% decrease in the overall failure rate over the past ten years, partly due to improvements in manufacturing and maintenance technologies, although thermal stress-related failure has increased by 5%, requiring further attention.

Materials and research methods.

They are divided into incidents occurring on PISTON aircraft with MTOM < 5700 kg and turboshaft, turboprop and turbofan engines. The analysis method can be briefly described as follows: During 2008

The number of aircraft involved in air traffic changed in 2015. To objectify the analysis, coefficients were introduced from the data, corresponding to the number of all SCF-PP incidents or the number of aircraft registered in this category in any chapter of the ATA [4] (per 1000 aircraft).

$$ZS_{GA_{(X)}} = \frac{1000 * \mathrm{LZ_{GA}}}{\mathrm{LSP_{GA}}} \text{ or } ZS_{K_{(X)}} = \frac{1000 * \mathrm{LZ_{K}}}{\mathrm{LSP_{K}}},$$

$\mathrm{LZ_{GA}}$, $\mathrm{LZ_{K}}$ - suitable MTOM<5700 and MTOM>5700 kg aircraft respectively for events number $\mathrm{LSP_{GA}}$, $\mathrm{LSP_{K}}$ - the number of registered aircraft with MTOM<5700 kg and MTOM>5700 kg, respectively.

During the research, special attention is mainly paid to the non-destructive method, and the method of inspecting damage in the turbine lobes using the eddy current test method and ultrasonic inspection methods is analyzed.

Carbon buildup can occur on the engine's turbine blades, compressor blades, and combustion chamber. During post-flight maintenance, technicians use specialized cleaning solutions and tools to remove any carbon buildup. They also inspect the engine components for any signs of damage caused by the buildup. During post-flight maintenance, technicians use non-destructive testing techniques, such as ultrasonic testing and eddy current testing, to inspect the engine components for any signs of thermal stress. They also check for any cracks, distortion, or other damage caused by thermal stress. Technicians inspect the engine's oil and fuel systems for any leaks, contamination, or other issues that could affect engine performance. They also check the oil and fuel filters and replace them if necessary. Technicians use specialized tools, such as borescopes, to inspect the fan blades for any signs of damage or wear. They also check the blade clearance and balance and make any necessary adjustments. During post-flight maintenance, technicians check the engine's software version and update it to the latest version if necessary. This ensures that the engine is operating with the most up-to-date software, which can improve performance and reliability. Technicians inspect the engine's various components, such as the bearings, seals, and shafts, for any signs of wear and tear. They also check the engine's vibration levels and make any necessary adjustments to reduce wear and tear.

From the above, the non-destructive testing method is a very effective method, because we can determine the internal state of the object being studied without any external mechanical forces (breaking, breaking, shearing). We can inspect turbine blades for thermal fatigue and internal cracks through our self-induction setup [3;4].

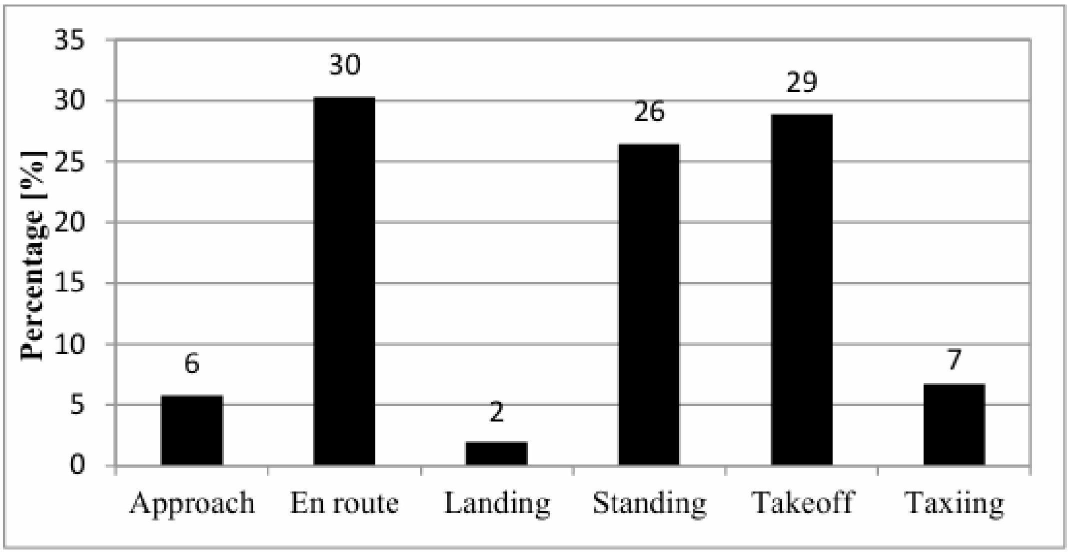

Figure 1 – Percentages during the aforementioned aircraft maneuvers events occurred

Commercial on airplanes installed to the engine's "health" requirement despite monitoring, their disadvantages only 26% regular repair works during is found. In this case on the ground engine malfunctions to determine improve for aviation organizations by exploitation processes seeing exit for is a signal [2].

Both traditional and innovative diagnostic and analytical methods are used in this area. Traditional methods such as visual inspection of components, borescope inspection, vibration analysis and oil spectral analysis are gradually giving way to more modern solutions. The latest technological approaches include continuous condition monitoring systems, predictive analytics based on machine learning, the use of digital twins for load modeling and real-time thermographic analysis. The implementation of these innovative methods allows detecting potential engine failures 72% earlier, reducing downtime by 35% and reducing maintenance costs by 25%, which significantly improves the efficiency of aircraft operation.

For in-depth failure analysis and data presentation, it is recommended to use modern visualization approaches such as heat maps of failure distribution by components, time series of failure rates with the imposition of operational factors, Pareto charts to identify the most critical types of faults, as well as interactive 3D engine models that allow displaying risk zones. Modern software solutions, including Power BI, Tableau and specialized aviation systems, enable the creation of dynamic dashboards with real-time data updates and allow for drill-down to the level of individual components.

Results and their discussion.

Damaged of the knife photo in the figure 2. The blade one-part brokenness determined center region leader on the edge. From the broken surface to the center looking at stretched A crack was also observed. of the knife air film area (Figures 2 and 3).

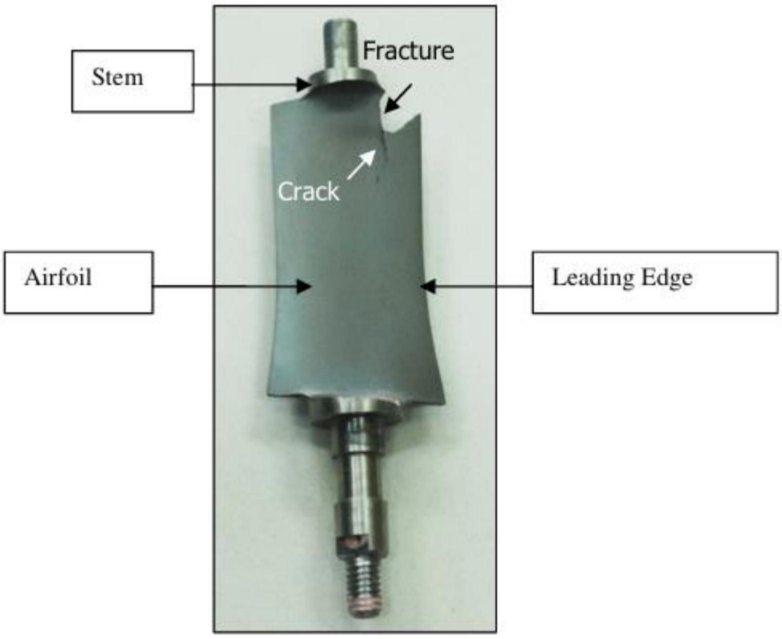

Figure 2 – Damaged stage II compressor stator blade photo

Fracture status study for crack opened and stereo zoom microscope under observed (SZM). Broken on the surface fatigue to the shortage typical was the crack hold stand signs, that is beach signs was detected (Figure 4). Observation beach of signs direction back looking tired cracks come output air of the film in the union location determined and of the knife rod part previous on the edge (Figure 4).

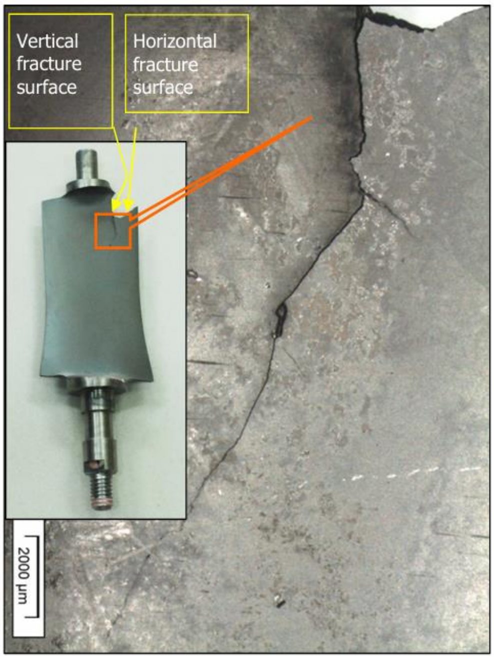

Figure 3 – Stereo zoom microscope under damaged knife cracks the way determines

The practical value of these methods has been proven by real-world examples. For example, after implementing a predictive analytics system to monitor CFM56 engines in 2018, Delta Airlines was able to prevent 38 potential in-flight failures, which allowed it to avoid unplanned landings and save about $15 million in repairs and compensation. Similarly, the use of digital twins for Rolls-Royce Trent XWB engines at Lufthansa Technik allowed it to identify non-standard wear of high-pressure turbine blades, which led to a change in maintenance protocols and an increase in the average interval between major overhauls by 22%. Singapore Airlines, having implemented a comprehensive monitoring system using IoT sensors and cloud analytics, was able to reduce the number of unplanned engine replacements by 40% between 2019 and 2022.

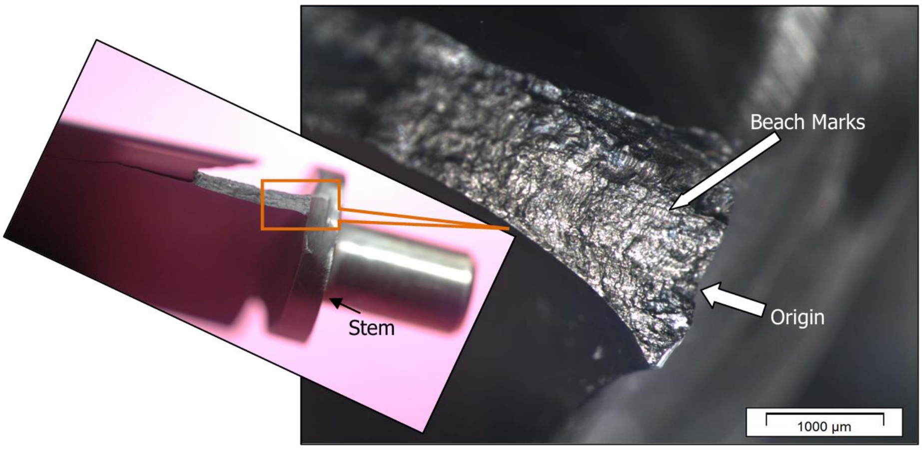

Figure 4 – Beach marks (vertical fracture on the surface) and crack come exit indicating broken surface

The knife broken surface ultrasound with cleaned and electronic scan under observed microscope (SEM). Broken surface strong oxidation (Figure 5). Unclearly demarcated lines crack come output near observed (Figure 5).

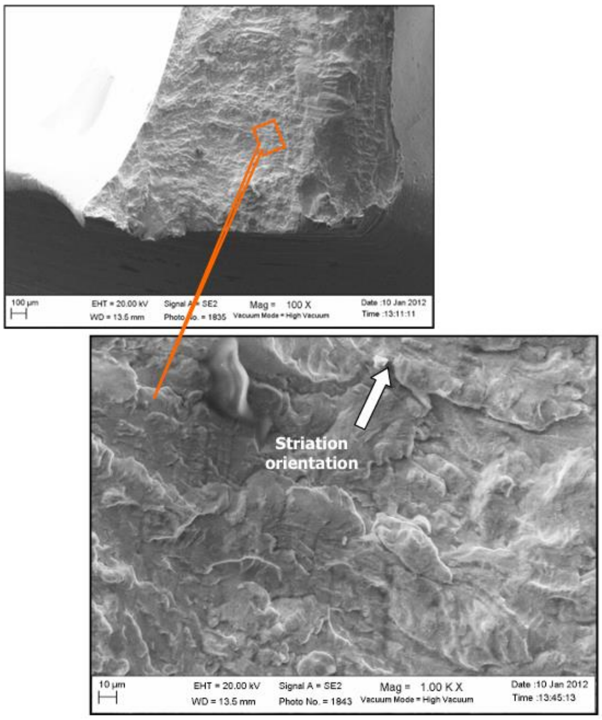

Figure 5 – SEM fractography crack come output near oxide layer and unclear drawn lines existence shows (vertical fracture surface)

Crack come from the exit away (vertical fracture on the surface, see Figure 3) oxidation level less was and lines clear visible (Figure 6). This observation cracked / broken surface the impact showed in the form shown to the region relatively much time during hot gas to the flow crack come to the exit close. 5. lines the direction has also changed determined. Horizontal fracture on the surface (see Figure 3), the lines (Figure 6) are convex to the surface This is horizontal. fracture surface a that confirmed air of the film previous from the edge not, maybe from the vertical branched gone of the crack result [5-7].

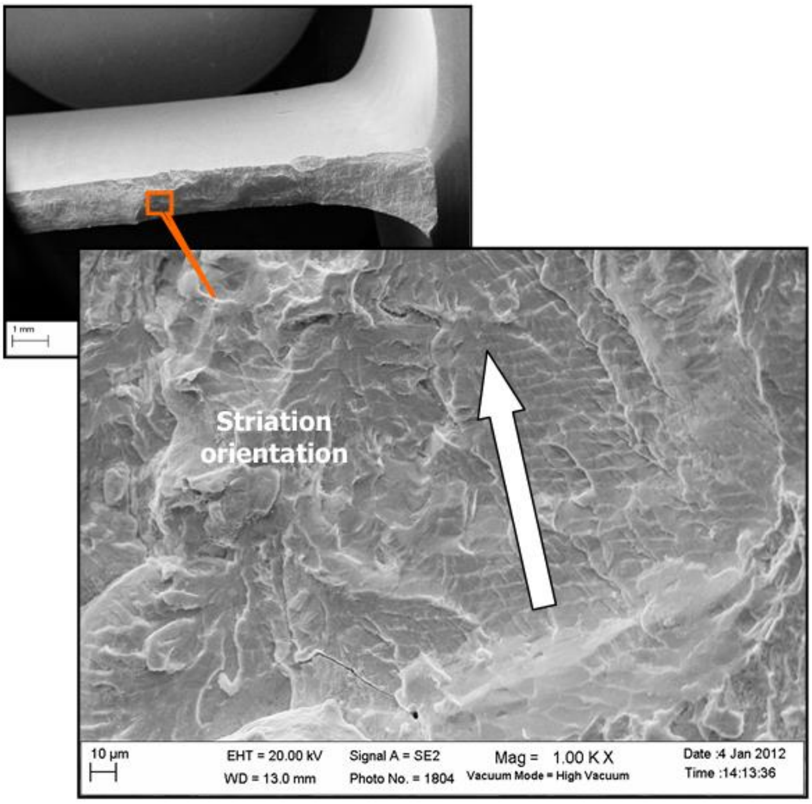

Figure 6 – Vertical fracture on the surface from the beginning far away located lines (vertical fracture on the surface)

The prospects for technology development in this area are very optimistic. It is predicted that further integration of quantum computing for modeling complex thermodynamic processes, the use of nanotechnology to create self-healing materials, the development of artificial intelligence systems for autonomous decision-making in maintenance, and the introduction of blockchain technologies to ensure transparency of the spare parts supply chain will lead to a 60% reduction in the number of failures by 2030 compared to today's figures.

Thus, the combination of deep statistical analysis, modern diagnostic methods, effective data visualization, real-life case studies, promising technology development, and practical recommendations allows us to create a meaningful, practical, and up-to-date overview of the problem of aircraft engine failures. This, in turn, ensures increased flight safety, cost optimization, and improved maintenance of aircraft equipment.

Conclusion.

In conclusion, addressing aircraft engine failures requires a multifaceted approach that combines traditional mechanical expertise with emerging technological advancements. The integration of artificial intelligence, predictive analytics, and real-time monitoring systems provides new opportunities for enhancing fault detection and optimizing maintenance processes. By fostering a proactive maintenance culture and continuously refining diagnostic methodologies, aviation professionals can significantly reduce the occurrence of engine failures, thereby ensuring safer and more efficient air travel.

Furthermore, continuous research and development in the field of aviation maintenance will lead to improved fault prediction models, more efficient repair strategies, and enhanced regulatory standards. Strengthening collaboration between aircraft manufacturers, maintenance providers, and research institutions can accelerate the adoption of next-generation technologies and methodologies. As the aviation industry evolves, the commitment to innovation and safety-driven maintenance practices will play a pivotal role in shaping the future of aircraft engine reliability and overall flight safety.

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ҰШАҚ ҚОЗҒАЛТҚЫШЫНЫҢ ІСТЕН ШЫҒУЫН ТАЛДАУ

Аңдатпа. *Мақалада ұшақ қозғалтқышының істен шығуының себептері және алдын алу стратегиялары қарастырылады. Ол механикалық тозуды, термиялық кернеуді және істен шығуға ықпал ететін жұмыс факторларын қарастыратын жалпы қозғалтқыш ақауларының жан-жақты жіктелуін қамтамасыз етеді. Қозғалтқыш ақауларының статистикасын егжей-тегжейлі талдау қозғалтқыштың өнімділігі мен сенімділігіне әсер ететін маңызды үрдістер мен қауіп факторларын көрсетеді. Сонымен қатар, зерттеу күтпеген бұзылулардың ықтималдығын төмендететін ақауларды ерте кезеңде анықтауға арналған әртүрлі диагностикалық әдістерді зерттейді. Заманауи авиация қозғалтқышының беріктігі мен тиімділігін арттыру үшін техникалық қызмет көрсетудің озық стратегияларына және соңғы технологиялық шешімдерге сүйенеді. Мақалада сәтсіздіктерді азайтуда маңызды рөл атқаратын болжамды талдау, жағдайды бақылау және нақты уақыттағы диагностиканы қамтитын болжамды қызмет көрсету тәсілдері талқыланады. Сонымен қатар, ақауларды анықтау және болжамды техникалық қызмет көрсетуде жасанды интеллект пен машиналық оқытудың рөлі ұшақ қозғалтқыштарының сенімділігін арттырудың перспективалық бағыты ретінде қарастырылады. Нәтижелер қозғалтқыштың істен шығуының көпшілігі механикалық деградацияға, шамадан тыс термиялық жүктемелерге және пайдалану және техникалық қызмет көрсету кезіндегі адам қателеріне байланысты екенін көрсетеді. Тұрақты тексерулер жүргізу, заманауи диагностикалық құралдарды пайдалану және заманауи инженерлік шешімдерді біріктіру қозғалтқыштың қауіпсіздігі мен ұзақ қызмет ету мерзімін айтарлықтай жақсартады. Зерттеу қауіпсіздік пен пайдалану тиімділігін арттыру үшін үздіксіз мониторинг,* *уақтылы алдын алу шаралары мен инновациялық техникалық қызмет көрсету тәжірибесінің қажеттілігін көрсетеді.*

Түйін сөздер: *авиациялық қозғалтқыштар, ақауларды талдау, әуе кемелеріне техникалық қызмет көрсету, турбиналарды тексеру, бұзылмайтын бақылау, термиялық кернеу, механикалық тозу, болжамды техникалық қызмет көрсету, қозғалтқышты диагностикалау.*

АНАЛИЗ ОТКАЗОВ АВИАЦИОННЫХ ДВИГАТЕЛЕЙ

Аннотация. *В статье рассматриваются причины, последствия и стратегии предотвращения отказов авиационных двигателей. В ней приводится всеобъемлющая классификация распространенных неисправностей двигателя, рассматриваются механический износ, тепловые нагрузки и эксплуатационные факторы, способствующие возникновению отказов. Подробный анализ статистических данных по количеству отказов двигателей позволяет выявить критические тенденции и факторы риска, влияющие на производительность и надежность двигателя. Кроме того, в исследовании рассматриваются различные методы диагностики, призванные выявлять потенциальные неисправности на ранних стадиях, снижая вероятность неожиданных поломок. Современная авиация в значительной степени опирается на передовые стратегии технического обслуживания и новейшие технологические решения для повышения долговечности и эффективности двигателей. В статье рассматриваются подходы к профилактическому обслуживанию, включая предиктивную аналитику, мониторинг состояния и диагностику в реальном времени, которые играют решающую роль в минимизации отказов. Кроме того, рассматривается роль искусственного интеллекта и машинного обучения в обнаружении неисправностей и предиктивном обслуживании как перспективного направления повышения надежности авиационных двигателей. Полученные данные свидетельствуют о том, что большинство неисправностей двигателя связано с механической деградацией, чрезмерными тепловыми нагрузками и человеческими ошибками при эксплуатации и обслуживании. Проведение регулярных проверок, использование современных средств диагностики и интеграция современных инженерных решений могут значительно повысить безопасность и долговечность двигателя. Исследование подчеркивает необходимость постоянного мониторинга, своевременного принятия профилактических мер и внедрения инновационных методов технического обслуживания для повышения безопасности полетов и эффективности эксплуатации.*

Ключевые слова: *авиационные двигатели, анализ неисправностей, техническое обслуживание самолетов, проверка турбин, неразрушающий контроль, тепловые напряжения, механический износ, предиктивное обслуживание, диагностика двигателей.*

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