MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
STATE UNIVERSITY "KYIV AVIATION INSTITUTE"
FACULTY OF AERONAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS DEPARTMENT OF AVIONICS AND CONTROL SYSTEMS

APPROVED FOR DEFENSE
Head of the graduating department
_________ O.M. Tatchynina
«___» ___________ 2025

QUALIFICATION WORK

(EXPLANATORY NOTE)

OF A GRADUATE OF THE BACHELOR'S EDUCATIONAL DEGREE
IN SPECIALTY 173 "AVIONICS"

Topic: *"Development of Aircraft Maintenance Programs Based on MSG-3"*

Prepared by: B-173-21-2-AV, **Hrytsenko Illia Vladlenovych**
(student, group, last name, first name, patronymic)

Supervisor: _____ Senior Lecturer **T.S. Solomakha**
(scientific degree, academic title, last name, first name, patronymic)

Reviewer: _______________ **V.V. Levkivskyi**
(signature) (full name)

Kyiv 2025

STATE UNIVERSITY "KYIV AVIATION INSTITUTE"

Faculty of Aeronavigation, Electronics and Telecommunications
Department of Avionics and Control Systems
Field (specialty) 173 "Avionics"
(code, name)

APPROVED
Head of the Department
__________ O.M. Tatchynina
«___» ____________ 2025

ASSIGNMENT

for the qualification work

Hrytsenko Illia Vladlenovych

1. **Topic of the work**: *"Development of Aircraft Maintenance Programs Based on MSG-3"*, approved by the Rector's order dated "20" March 2025 No. 621/st.
2. **Work execution period**: from March 23, 2025 to June 23, 2025.
3. **Initial data for the work**: data on the system of developing aircraft maintenance programs based on MSG-3, methodology, economic and operational evaluation of the maintenance program.
4. **Contents of the explanatory note**: analysis of the aircraft maintenance system was conducted. The MSG-3 methodology for maintenance program development was explained. Analysis of functional systems according to MSG-3 using the Boeing 737 example was conducted, including maintenance planning chart and interval development, implementation and optimization of the maintenance program. Economic and operational evaluations of the program were considered, including cost impact, efficiency, and long-term maintenance cost forecasting.
5. **List of required illustrative material**: tables, drawings, diagrams, graphs.
6. **Calendar schedule**:

No	Task	Deadline	Completion mark
1.	Justification of the thesis topic	25.01.2025	
2.	Literature review	23.03.2025	
3.	Preparation and writing of Chapter 1	27.03.2025	
4.	Preparation and writing of Chapter 2	09.04.2025	
5.	Preparation and writing of Chapter 3	21.04.2025	
6.	Preparation and writing of Chapter 4	23.05.2025	
7.	Plagiarism check and receiving print review	10.06.2025	
8.	Formatting and printing of explanatory note	12.06.2025	
9.	Preparation of presentation and report	06.06.2025	

7. Date of assignment issuance: ____________________

Thesis supervisor ____________________ L.M. Sytnyanskykh
(signature of supervisor) (full name)
Assignment accepted for execution _______________ Hrytsenko I.V.
(signature of graduate) (full name)

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

ДЕРЖАВНИЙ УНІВЕРСИТЕТ “КИЇВСЬКИЙ АВІАЦІЙНИЙІНСТИТУТ”

ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ

КАФЕДРА АВІОНІКИ ТА СИСТЕМ УПРАВЛІННЯ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
_________О.М. Тачиніна

«___»__________2025 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ БАКАЛАВР

ЗА СПЕЦІАЛЬНІСТЮ 173 «АВІОНІКА»

Тема: «Формування програм технічногообслуговування повітряного судна на базі MSG-3»

Виконав: Б-173-21-2-АВ, Гриценко Ілля Владленович
(студент, група, прізвище, ім'я, по-батьвові)

Керівник: старший викладач Т.С. Соломаха
(науковаступінь, вченезвання, прізвище, ім'я, по-батькові)

Наркомконтролер: ______________ В.В. Левківський
(підпис) (П.І.Б.)

Київ 2025

ДЕРЖАВНИЙ УНІВЕРСИТЕТ ”КИЇВСЬКИЙ АВІАЦІЙНИЙ ІНСТИТУТ”

Факультет аеронавігації електроніки та телекомунікацій
Кафедра авіоніки та систем управління
Напрям (спеціальність) 173 «Авіоніка»
(шифр, найменування)

ЗАТВЕРДЖУЮ
Завідувач кафедри
_________ О.М. Тачиніна
«___»___________2025р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи

Гриценко Ілля Владленович

1. Тема роботи: «Формування програм технічного обслуговування повітряного судна на базі MSG-3»затверджена наказом ректора від « 20 » 03 2025 р. № 621/ст.

2. Термін виконання роботи: з 23 березня 2025 по 23 червня 2025.

3. Вихідні дані роботи: дані про систему формування програм технічного обслуговування повітряного судна на базі MSG-3, методологія, економічна та експлуатаційна оцінка програми ТО

4. Зміст пояснювальної записки: проведено аналіз системи технічного обслуговування повітряних суден. Роз’яснено методологію MSG-3 у формуванні програм ТО. Проведено аналіз функціональних систем відповідно до MSG-3 на прикладі Boeing 737, формування карти ТО та інтервалів обслуговування, впровадження програми ТО та її оптимізація. Розглянута економічна та експлуатаційна оцінка програми, вплив на витрати, ефективність та прогнозування витрат на ТО у довгостроковій перспективі.

5. Перелік обов’язкового ілюстративного матеріалу: таблиці, рисунки, діаграми,графіки.

6. Календарний план-графік

№ пор	Завдання	Термін виконання	Відмітка про виконання
1.	Обґрунтування теми дипломної роботи	25.01.2025	
2	Проведення огляду літератури	23.03.2025	
3.	Підготовка та написання 1 розділу	27.03.2025	
4.	Підготовка та написання 2 розділу	09.04.2025	
5.	Підготовка та написання 3 розділу	21.04.2025	
6.	Підготовка та написання 4 розділу	23.05.2025	
7.	Перевірка на анти плагіат та отримання рецензії на друк	10.06.2025	
8.	Оформлення та друк пояснювальної записки	12.06.2025	
9.	Підготовка презентації та доповіді	06.06.2025	

7. Дата видачі завдання: ___________________

Керівник дипломної роботи ___________________ Ситнянських Л.М.

(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання _______________ Гриценко І.В.

(підпис випускника) (П.І.Б.)

РЕФЕРАТ

Електричні підстанції є важливими об’єктами енергосистем, і їх надійна робота залежить від ефективного технічного обслуговування. Одним із сучасних підходів є прогнозне обслуговування, що передбачає виконання робіт відповідно до реального стану обладнання. Методологія MSG-3, яка базується на аналізі технічних характеристик і умов експлуатації, дає змогу оптимізувати процес обслуговування.

Ускладнення технологій на підстанціях потребує вдосконалення систем ТО. Інтеграція автоматизованих систем управління та сучасних матеріалів підвищує ефективність, але водночас збільшує вимоги до обслуговування. Правильно побудована програма ТО на базі MSG-3 дозволяє зменшити ризики відмов і аварій завдяки врахуванню критичності обладнання.

MSG-3 забезпечує обслуговування за потреби, зменшуючи витрати на непотрібні перевірки та навантаження на персонал. Регулярний моніторинг і своєчасне усунення дефектів підвищують надійність роботи підстанцій і забезпечують ефективне використання ресурсів. Застосування цієї методики сприяє зниженню ризиків, підвищенню стабільності енергопостачання та економічній ефективності.

Мета дослідження — розробити методику створення програм ТО на основі MSG-3 для підстанцій з урахуванням стану обладнання.

Предметом дослідження є процес формування програм технічного обслуговування для обладнання електричних підстанцій з використанням методики MSG-3.

Об'єкт дослідження — електричні підстанції, предмет — процес створення програм ТО з використанням MSG-3.

У **дослідженні застосовано методи** прогнозування, аналізу надійності, математичне моделювання й оптимізацію процесів ТО.

Практичне значення полягає в можливості оптимізації технічного обслуговування, зосередженого на критичних елементах, що дозволяє скоротити витрати та підвищити надійність. Замість обслуговування за фіксованим графіком використовується підхід, орієнтований на реальний стан обладнання.

Наукова новизна полягає в адаптації MSG-3 до умов роботи електричних підстанцій. Методика дозволяє створювати індивідуальні програми ТО, що відповідають специфіці енергетичного обладнання, підвищуючи ефективність технічного управління та економічність обслуговування.

ABSTRACT

Electric substations are critical components of power systems, and their reliable operation depends on effective maintenance. One of the modern approaches is predictive maintenance, which involves performing maintenance tasks based on the actual condition of the equipment. The MSG-3 methodology, which is based on the analysis of technical characteristics and operating conditions, enables optimization of the maintenance process.

The increasing complexity of technologies at substations requires improvement of maintenance systems. The integration of automated control systems and advanced materials enhances efficiency but also raises maintenance demands. A properly developed MSG-3-based maintenance program reduces the risk of failures and accidents by taking into account the criticality of the equipment.

MSG-3 supports condition-based maintenance, reducing unnecessary inspections and relieving personnel workload. Regular monitoring and timely defect elimination improve substation reliability and ensure efficient resource utilization. The application of this methodology contributes to risk reduction, greater power supply stability, and economic efficiency.

The objective of the study is to develop a methodology for creating MSG-3-based maintenance programs for substations, taking into account the condition of the equipment.

The subject of the study is the process of forming maintenance programs for substation equipment using the MSG-3 methodology. The object of the study is electric substations; the subject is the process of developing maintenance programs based on MSG-3.

The research applies forecasting methods, reliability analysis, mathematical modeling, and maintenance process optimization.

The practical significance lies in the ability to optimize maintenance by focusing on critical components, which allows for cost reduction and increased reliability. Instead of a fixed maintenance schedule, the approach is based on the actual condition of the equipment.

The scientific novelty lies in the adaptation of MSG-3 to the operating conditions of electric substations. The methodology enables the creation of customized maintenance programs tailored to the specifics of power equipment, enhancing the efficiency of technical management and maintenance economics.

Пояснювальна записка до дипломної роботи «Формування програм технічного обслуговування повітряного судна на базі MSG-3»: 77 сторінок, рис., 9 табл., 0 додатків, 11 літературних джерел.

TABLE OF CONTENTS

INTRODUCTION

Modern electrical substations (SS) are integral components of power systems, and their proper maintenance is essential for uninterrupted operation and energy efficiency. One approach to planning and organizing maintenance is predictive maintenance, which determines the optimal time for servicing based on the actual condition of the equipment. A prominent predictive methodology is MSG-3, which relies on analyzing equipment technical characteristics and operating conditions.

As the complexity and variety of substation technologies increase, maintenance methods must evolve. Contemporary solutions—automation, computerized control systems, advanced materials, and components—greatly enhance substation performance. Yet their complexity also heightens the need for specialized servicing to guarantee continuous and reliable operation of all equipment.

Properly designing a maintenance program using MSG-3 is a key factor in reducing the risk of failures caused by inadequate or untimely servicing. With this approach, each substation component is inspected and serviced according to its criticality and probability of failure, ensuring safety and minimizing unforeseen breakdowns. Thus, MSG-3 turns maintenance into a targeted, preventive process that addresses potential failures before they lead to serious incidents.

MSG-3 helps create maintenance programs that not only secure stable and safe equipment operation but also lower servicing costs by focusing on the actual condition of substation elements. Tasks are performed only when needed, based on real wear-and-tear data, reducing unnecessary replacements or inspections. Optimized inspection intervals cut financial expenses and lighten personnel workload.

Moreover, implementing an MSG-3-based program improves operational reliability. Continuous monitoring and timely detection of potential issues allow defects to be eliminated before they cause significant system disruptions. This boosts substation reliability and ensures efficient resource use.

Applying MSG-3 in forming substation maintenance programs therefore enhances maintenance efficiency and reliability. Power companies can reduce accident risks, optimize servicing costs, and guarantee uninterrupted grid operation—crucial for power-supply stability and economic performance.

Aim of the work: to develop and implement a methodology for forming maintenance programs for electrical substations based on MSG-3, enabling effective maintenance planning that accounts for equipment specifics and condition.

Objectives:

1. Assess the condition of substation equipment and identify key parameters influencing maintenance needs.
2. Develop an algorithm for MSG-3-based maintenance program formation.
3. Determine optimal intervals for maintenance tasks.
4. Evaluate the economic efficiency of implementing this methodology.

Subject of research: the process of forming maintenance programs for substation equipment using MSG-3.

Object of research: electrical substations and their equipment requiring regular maintenance.

The study employs reliability analysis, equipment condition prediction, mathematical modeling, and maintenance-process optimization.

Practical significance: The proposed MSG-3-based maintenance-program methodology offers significant benefits for power companies. By concentrating on critical system elements and servicing them exactly when necessary, companies can achieve substantial cost savings, reduce unnecessary checks and replacements, and enhance overall system reliability. Maintenance based on actual equipment condition cuts the likelihood of accidents or unforeseen failures, increasing substation stability and mitigating risks associated with critical infrastructure downtime.

Scientific novelty: The work refines existing maintenance-program formation methods through modern approaches to forecasting and managing equipment condition. A core contribution is adapting MSG-3 to the specifics of electrical substations, whose functional blocks differ from those of aviation equipment. This adaptation enables tailored maintenance programs that lower costs while boosting operational reliability. Thus, the methodology expands MSG-3's applicability to the energy sector, improving technical-state management of substations and making their maintenance both economical and dependable.

CHAPTER 1. ANALYSIS OF AIRCRAFT MAINTENANCE SYSTEM

1.1 General characteristics of aircraft maintenance

Aircraft maintenance is an integral part of aircraft operation that ensures reliability, safety, and efficiency. Modern aircraft are extremely complex systems with numerous integrated components, each requiring regular servicing. Because aviation demands the highest safety standards, maintenance is critical to sustaining airworthiness, minimizing failure risks, and extending service life.

Aircraft maintenance comprises organized measures aimed at preserving and restoring airworthiness. It includes preventive inspections, replacement of worn or faulty parts, repairs, and checks of all primary systems: powerplant, avionics, mechanical and hydraulic systems, and flight-control systems.

Maintenance also involves verifying and maintaining certified aircraft status in accordance with international standards and regulations such as EASA, FAA, and ICAO. Given the complexity and responsibility, maintenance must satisfy stringent quality, safety, and personnel-qualification requirements.

Key maintenance types:

1. Scheduled maintenance — regular, time- or flight-hour-based tasks (inspections, replacements, regulated checks).
2. Required maintenance — reactive servicing performed when malfunctions or deviations occur, aimed at correcting detected defects.
3. Unscheduled maintenance — urgent work after accidents, failures, or severe deviations to restore airworthiness promptly.

Employing modern diagnostic and monitoring tools enables early fault detection and risk minimization. Computerized maintenance-management systems automate many processes, lowering error probability and boosting efficiency.

In sum, aircraft maintenance is vital for flight safety and reliability. Regular scheduled and unscheduled servicing per established standards, combined with advanced diagnostics and automation, reduces failure likelihood and enhances equipment performance throughout its lifecycle.

1.2 Key maintenance regulations and standards (EASA, FAA, ICAO)

Aviation maintenance is governed by a suite of documents and standards to maintain high safety and efficiency levels. The most important are issued by the European Union Aviation Safety Agency (EASA), the U.S. Federal Aviation Administration (FAA), and the International Civil Aviation Organization (ICAO). These documents set rules for operation, maintenance, inspection, and repair, as well as personnel-training requirements. Their collective goal is to uphold aviation-transport safety, ensure maintenance quality, and sustain high standards across all stages of aircraft operation.

Таблиця 1.1 - Основні нормативні документи

Організація	**Документ**	**Опис**
EASA	**Part-145**	Standards for organizations performing aircraft maintenance in Europe.
FAA	**14 CFR Part 145**	Regulates the activities of repair organizations in the USA; defines maintenance requirements.
ICAO	**Annex 6 (Operation of Aircraft)**	ICAO international standard for the operation and maintenance of aircraft.

FAA	**14 CFR Part 43**	Defines maintenance requirements, including repairs, inspections, and certification.
EASA	**Part-M**	Regulates the certification and operation of aircraft, specifically civil aircraft.
ICAO	**Annex 8 (Airworthiness of Aircraft)**	Defines certification requirements for aircraft and their technical condition to ensure safety.

The European Union Aviation Safety Agency (EASA) is the primary authority regulating aviation safety within the European Union. The main maintenance regulations are Part-145 and Part-M. Part-145 sets requirements for organizations that perform aircraft maintenance, including repairs, inspections, and other tasks; it covers certification of repair facilities, personnel training, and workplace/equipment standards. Part-M focuses on keeping aircraft in a certified airworthy condition and sets overarching requirements for maintenance organization and operational control. The U.S. Federal Aviation Administration (FAA) is one of the world's largest civil-aviation regulators. Title 14 CFR Part 145 is the core standard for certifying organizations that maintain aircraft in the United States, specifying requirements for repair, inspection, and continued airworthiness. Complementing it, 14 CFR Part 43 details maintenance procedures for aircraft and their components and the qualification requirements for aircraft mechanics.

The International Civil Aviation Organization (ICAO) develops global standards and recommended practices to ensure civil-aviation safety and efficiency. Annex 6 governs aircraft operations, including maintenance rules covering preventive work, repairs, and inspections. Annex 8 sets safety and airworthiness-certification standards, including requirements for regular technical checks and evaluation of aircraft equipment condition.

Regulations and standards issued by bodies such as EASA, FAA, and ICAO form the foundation for organizing aircraft maintenance. They define requirements for certifying repair organizations, qualifying personnel, and establishing core maintenance principles. Adhering to these standards ensures a high level of safety and reliability, guaranteeing timely and correct execution of required maintenance procedures and enabling uninterrupted, safe operation of international air transport.

1.3 Methods for Developing Maintenance Programs: Comparative Analysis of MSG-1, MSG-2, and MSG-3

Developing maintenance programs is crucial for aircraft reliability and safety. Key methods—MSG-1, MSG-2, and MSG-3—evaluate maintenance needs and determine optimal task intervals. Each reflects the evolution of aircraft-maintenance management principles.

This section compares MSG-1, MSG-2, and MSG-3, highlighting their advantages, limitations, and applications. Understanding these methods is essential for creating reliable, cost-effective maintenance programs that ensure safety and economy in aircraft operations.

Table 1.2 presents a comparative analysis of MSG-1, MSG-2, and MSG-3.

Метод	**Опис**	**Переваги**	**Обмеження**	**Основні сфери застосування**
MSG-1	The earliest version of the method, which relies on expert judgment to define maintenance requirements.	Simple to apply; suitable for older equipment types.	Not very flexible; does not account for the equipment's actual condition.	Older aircraft types and systems with low complexity.

MSG-2	A more advanced method that uses analysis of technical characteristics to develop maintenance programs.	Takes specific operating conditions into account, increasing accuracy.	Requires detailed information and resources for implementation.	Modern equipment of medium complexity.
MSG-3	The most modern method, based on the analysis of technical condition and potential failures.	Accurate, uses detailed data on technical condition, minimizes maintenance costs.	Requires large volumes of data and more complex technologies for implementation.	High-tech aircraft and systems.

MSG-1 method was the first approach used for developing aircraft maintenance programs. It was a fairly simple and general rule based on expert judgment and reliability and safety requirements. This method allows determining, based on operational experience, which aircraft components require maintenance at specific intervals. It was primarily applied to older aircraft models when modern technologies for accurate condition monitoring were not available. The main advantage of MSG-1 is its simplicity and relatively easy application. However, it does not take into account the actual condition of the technical equipment, which may lead to performing unjustified inspections or, conversely, missing necessary maintenance procedures.

MSG-2 is an improved approach that precisely considers the technical characteristics and operational conditions of the aircraft. This method focuses more on collecting and analyzing data on the reliability of individual components and systems. It allows determining necessary maintenance actions based on a detailed failure analysis.

The advantage of MSG-2 is its ability to provide accurate predictions of maintenance needs. However, its application requires detailed data on the operation and technical condition of the aircraft. Thus, this method is more resource-intensive compared to MSG-1.

MSG-3 is the most modern method, based on analyzing the technical condition and potential failures of system components. It uses detailed data on the condition of each aircraft element, which allows minimizing maintenance costs while enhancing safety. A key aspect is the use of real-time monitoring and diagnostic technologies, which enable forecasting the need for maintenance.

The main advantage of MSG-3 is a high level of accuracy and optimization of maintenance costs. However, this method requires significant expenses for data collection and processing, as well as technological infrastructure for condition monitoring.

The MSG-1, MSG-2, and MSG-3 methods reflect the evolution of approaches to aircraft maintenance. MSG-1 is a simple and general approach suitable for older types of aircraft. MSG-2 improves this method by adding reliability analysis and operational condition considerations, making it accurate but also resource-demanding.

1.4. Impact of Maintenance Programs on Operational Safety and Economic Efficiency

Aircraft maintenance (AM) is an integral part of aircraft operation, directly affecting both flight safety and the economic efficiency of an airline. Regular and timely maintenance activities ensure the proper technical condition of the aircraft, reducing the likelihood of malfunctions and accidents. At the same time, optimizing maintenance processes helps to reduce maintenance costs, increase equipment lifespan, and lower overall operational expenses.

This section analyzes how maintenance programs influence the operational safety of aircraft and their economic efficiency. This is an important issue because well-designed maintenance programs can not only ensure safe operation but also significantly reduce maintenance costs.

Maintenance directly impacts the operational safety of aircraft. Regular AM allows timely detection and elimination of faults or potential defects that could lead to emergency situations. Maintenance programs control the condition of critical systems such as the powerplant, flight control system, hydraulics, electronics, and others. This helps avoid many emergencies and extend safe aircraft operation over time.

Maintenance programs developed based on modern methods like MSG-3 take into account the actual technical condition of the aircraft. This allows for more precise determination of when maintenance is needed and when unnecessary checks can be avoided, reducing the risk of faults due to premature or incorrect interventions. Such an approach not only improves safety but also reduces the likelihood of human error during maintenance.

From an economic perspective, maintenance programs significantly impact airline costs. Optimally designed maintenance programs can reduce repair and servicing expenses and extend the aircraft's service life. A key factor here is minimizing the cost of unscheduled maintenance that may arise due to undetected faults.

Detailed and well-planned maintenance schedules help avoid unforeseen repair costs often caused by untimely or inefficient maintenance. For example, premature inspections may lead to the replacement of components that could still function efficiently, while the lack of proper monitoring may result in costly and complex repairs due to underestimated technical condition.

Maintenance programs also increase the number of aircraft available for operation simultaneously. Regular and optimized maintenance ensures long continuous operation without prolonged downtime for repairs, enhancing fleet utilization and reducing operating costs.

Maintenance programs play a key role in ensuring operational safety and economic efficiency in aviation. They allow not only reducing the risk of accidents through regular monitoring and servicing but also optimizing maintenance costs. Using modern methods such as MSG-3, companies can cut unnecessary expenses, extend equipment lifespan, and improve overall operational efficiency. In conclusion, well-developed maintenance programs are not only a guarantee of safety but also a factor of economic stability for airlines.

SECTION 2. MSG-3 METHODOLOGY IN THE DEVELOPMENT OF MAINTENANCE PROGRAMS

2.1. Key Principles of MSG-3

The MSG-3 (Maintenance Steering Group-3) method is one of the modern approaches to developing aircraft maintenance programs. It allows effective planning of maintenance activities based on a deep analysis of the technical condition of the aircraft and its operational environment. MSG-3 not only enhances safety but also optimizes maintenance costs, providing maximum economic efficiency.

The primary goal of MSG-3 is to minimize maintenance costs while ensuring a high level of reliability and safety of the aircraft. This method allows determining as accurately as possible when and what maintenance is necessary for specific equipment, significantly reducing the likelihood of unnecessary or premature inspections. MSG-3 considers all aspects of technical condition, from technical specifications to operational conditions, enabling the development of effective maintenance programs.

The MSG-3 method is based on several key principles that determine its effectiveness.

Table 2.1 – Key Principles of MSG-3

Principle	Description
Functional Failure Analysis	Assessment of risks and potential failures of various aircraft systems based on previous failure data and operational conditions analysis.
Component Reliability Assessment	Determination of the reliability of individual components based on statistical data on their performance.
Forecasting and Planning	Development of long-term maintenance plans based on the actual condition of the equipment, allowing optimization of costs and reduction of unexpected repairs.
Flexibility Principle	The maintenance program allows adaptation to changes in equipment condition and operating conditions. Maintenance plans can be adjusted based on real indicators.
Safety Impact Assessment	Analysis of how different types of maintenance affect equipment safety, including identifying critical components where failures could lead to accidents.

Risk assessment of failures is an integral part of MSG-3, as it allows the identification of potential issues at the earliest stages of operation. For this purpose, statistical data on previous failures and calculations based on real operating conditions are used. Each system within the aviation equipment is analyzed in terms of how often it fails and what the possible consequences of these failures might be. Determining the reliability of components and systems is another element of the MSG-3 methodology. Based on statistical data regarding the service life of each component, engineers can conclude how long each element can operate without maintenance. This enables adjustment of

the maintenance schedule so that component replacements occur only when truly necessary.

Condition forecasting is a key aspect because it allows determination of the optimal time for performing maintenance activities. Taking into account all collected data on reliability and failures, a maintenance plan is developed that covers all necessary inspections and repairs for the upcoming years, allowing for the advance determination of required resources and avoiding operational interruptions. Maintenance programs developed by the MSG-3 method can be adjusted depending on operating conditions and changes in the technical state. This provides flexibility and adaptability of the maintenance system, since if the equipment operates under more challenging or adverse conditions, the program can be revised to ensure maximum efficiency.

One aspect of MSG-3 is the evaluation of how each maintenance element can impact the safety of equipment operation. Moreover, the method allows considering which systems are critical to flight safety and whose failure can lead to accidents. This approach makes it possible to prioritize maintenance precisely for those components that are necessary from a safety perspective.

The MSG-3 method is a modern and effective approach to developing maintenance programs because it is based on a detailed analysis of the technical condition of aviation equipment and its operating conditions. The main principles of MSG-3 — analysis of functional failures, reliability assessment of components, forecasting and maintenance planning, flexibility of maintenance programs, and consideration of safety impact — allow the creation of efficient and optimized maintenance programs that ensure not only high safety but also significant economic benefits. The use of this method helps reduce maintenance costs and increase the reliability and service life of aviation equipment.

2.2 Algorithm for the Functional Systems Analysis of Aircraft according to MSG-3

The algorithm for analyzing the functional systems of aircraft (AS) according to the MSG-3 (Maintenance Steering Group-3) methodology is one of the main tools for developing maintenance programs that ensure the appropriate level of safety and economic efficiency in the operation of aviation equipment. The MSG-3 method is applied to determine the necessary maintenance actions for each functional system and component depending on their technical condition and probability of failure.

MSG-3 allows optimizing maintenance programs by increasing operational safety, reducing repair costs, and extending the service life of aviation equipment. The algorithm involves a detailed analysis of all functional systems and components of the aircraft considering various factors such as failure probability, consequences of malfunctions, and safety requirements.

The analysis of the functional systems of the aircraft according to MSG-3 consists of several consecutive stages, allowing comprehensive evaluation of each system and component, as well as determining optimal maintenance measures. The reliability and maintenance assessment algorithm for the functional systems of the aviation equipment includes several key stages, each important for ensuring safety and operational efficiency.

The first stage is the identification of all functional systems on board the aircraft. This necessary step allows creating a complete picture of which systems interact to ensure flight safety. Such systems include not only primary ones like the powerplant or flight control but also auxiliary systems, for example, hydraulic, electrical, or conditioning systems, since even minor malfunctions in these systems can lead to serious consequences.

The next step is the assessment of the criticality of each identified system. At this stage, systems are classified according to their importance for flight safety. For each system, components whose failure could cause catastrophic consequences and those with less impact are determined. This allows prioritizing inspections and maintenance.

After that, the reliability of systems and components is analyzed. Based on historical data or tests, the failure probability of each system under different operating conditions is determined. This allows forecasting the frequency of malfunctions, which facilitates effective planning of maintenance measures.

Failure consequence assessment is the next stage, where possible failure scenarios and their impact on flight safety are analyzed. For example, if the flight control system fails, it may lead to serious consequences for the crew and passengers, making it a maintenance priority.

Based on the results of reliability and criticality analysis, the maintenance frequency is calculated. These calculations allow determining how often scheduled inspections and technical reviews should be performed to prevent failures while avoiding excessive maintenance costs.

Then, the type of maintenance required for each system is defined. This could be component replacement, inspections, or technical checks, each with its own procedure considering the system's criticality.

The final stage is adjusting the maintenance plan. At this stage, based on the analysis and calculations performed, the timing, methods, and frequency of maintenance are refined to ensure the reliability of all systems and reduce overall maintenance costs.

Table 2.2 – Key Stages of the MSG-3 Algorithm

Algorithm Stage	**Description**
Identification of functional systems	Determining all systems and subsystems of the aircraft to be analyzed.
Criticality assessment of components	Determining the significance of each system for flight safety and maintenance effectiveness.
Reliability analysis	Assessing the probability of failure of each component based on statistical data.
Failure consequence assessment	Determining the consequences of failures for the safety and operation of the aircraft.
Maintenance frequency calculation	Determining the optimal maintenance frequency for each system to minimize costs.
Determination of maintenance type	Defining the necessary maintenance actions (replacement, inspection, check).
Adjustment of the maintenance plan	Updating the overall maintenance plan to incorporate analysis results and reduce failure risks.

The algorithm for analyzing functional systems using the MSG-3 method is a complex and detailed process that provides a systematic approach to planning the maintenance of aviation equipment. Key stages of this process include identifying systems, assessing their criticality and reliability, and determining optimal maintenance actions based on failure probabilities and safety consequences. Thanks to this approach, aviation companies can optimize maintenance costs by reducing unnecessary inspections and lowering overall operational expenses of the aircraft.

2.3. Methods for Failure Criticality Assessment and Risk-Based Approach

Failure criticality assessment and the risk-based approach are key elements in developing maintenance programs for aviation equipment, as they help reduce the likelihood of serious accidents and ensure flight safety. These methods assist in understanding which systems or components are essential for safety and reliability, and determining how frequently and under what conditions these elements require maintenance or replacement.

Failure criticality assessment enables identification of failures that could lead to severe consequences and require special attention during maintenance. Meanwhile, the risk-based approach allows for a comprehensive evaluation of the probability of failure and its consequences, helps prioritize maintenance actions, and optimize costs related to aviation equipment maintenance.

FMEA (Failure Modes and Effects Analysis) is one of the main methods used for failure criticality assessment. It involves a detailed analysis of all possible failures in functional systems and components, as well as an evaluation of their impact on flight safety and operational characteristics. When assessing failures in aircraft systems, three main factors should be considered to fully analyze the risks and consequences of each possible failure. Here is how each factor influences the overall assessment:

1. **Probability of failure** – the first parameter that determines how often a particular failure might occur within a given time period or number of flights. Probability is based on statistical data, testing, and analysis of previous failure cases. It is necessary to evaluate whether the failure is rare or could happen with some regularity, allowing the need for preventive measures or the frequency of system maintenance to be assessed.
2. **Severity of consequences** – assessing the severity helps determine how critical the failure consequences could be for the safety and operational efficiency of the aircraft. This can range from minor impacts (e.g., slight malfunction not affecting the overall system condition) to catastrophic situations where failure could lead to an accident or life-threatening risks for

crew and passengers. Severity assessment helps prioritize issues by identifying failures that require immediate intervention.

3. **Detectability** – this factor determines how easily a failure can be detected before it causes serious consequences. If a failure can be quickly detected (e.g., through system monitoring or automatic indicators), the risk can be reduced and measures taken before the problem becomes critical. If the failure is difficult to detect or has no obvious signs, this significantly increases the risk and necessitates developing additional control or monitoring means for timely detection.

These three factors — probability of failure, severity of consequences, and detectability — interact and help assess the risks for each system. As a result of a comprehensive evaluation, critical systems and components can be identified, for which additional safety, monitoring, and maintenance measures should be implemented.

Each element is then assigned scores based on these three criteria, followed by the calculation of an overall failure criticality index. This allows prioritizing maintenance actions focusing on critical components.

FMECA (Failure Modes, Effects, and Criticality Analysis) is an extension of the FMEA method and includes an additional assessment of the criticality of each failure. This enables not only evaluating the consequences and probability of failure but also determining the degree of criticality of a specific component or system. FMECA helps identify whether a failure is a serious incident that could lead to an accident or significant disruptions in system functionality.

Risk Assessment (RA) is a systematic approach to determining the likelihood that a specific failure may lead to hazardous consequences. Several models are used to estimate the probability and severity of failure consequences. Risk analysis allows evaluating the current safety level and developing strategies to reduce risks.

The risk-based approach in aviation maintenance is a tool for ensuring safety and operational efficiency. It provides a systematic and scientific evaluation of potential failures, their probability, and consequences, as well as developing strategies to mitigate risks. The main stages of this approach are:

- **Risk Identification:** Conduct a thorough analysis of all functional systems of the aircraft, including both primary and auxiliary systems, their subsystems, and possible failures. This involves assessing all potential malfunctions that may occur during operation to identify potential hazards. Operating conditions must also be considered to cover all possible failure scenarios.
- **Failure Probability and Consequence Assessment:** Determine how frequently failures in each identified system may occur, using historical data, previous failure statistics, and reliability models to predict the probability of specific problems. Simultaneously, assess the severity of each failure's consequences for safety and operational efficiency to understand which failures may result in catastrophic outcomes and which in less serious damages.
- **Risk Prioritization:** Assign priority to each risk based on the assessment of failure probability and consequence severity. High-probability and severe-consequence risks must be addressed first, while low-probability risks can be deferred. This prioritization allows efficient resource allocation for maintenance and component replacement, reducing overall maintenance costs.
- **Risk Mitigation Strategies Development:** Develop comprehensive measures aimed at reducing the likelihood of critical failures and minimizing their consequences. Risk mitigation may be achieved by optimizing inspection frequency, improving monitoring and control procedures, and enhancing system designs to lower failure probabilities. For example, new technologies can be implemented to improve reliability or maintenance rules adjusted to be more responsive to critical situations.
- **Monitoring and Adjustment:** After implementing risk mitigation strategies, continuous monitoring of the aircraft’s condition is necessary to verify the effectiveness of the measures taken. Monitoring helps detect new risks that

may arise over time and allows adjusting strategies by updating maintenance procedures and technical specifications accordingly. This enables adaptation to changing operational conditions and minimizes the chance of new problems occurring.

Failure criticality assessment methods and the risk-based approach are tools for developing aviation maintenance programs. They enable the most accurate estimation of failure probabilities and their impacts on flight safety. Applying these methods allows prioritizing components and systems that require intensive maintenance and optimizing maintenance costs. The risk-based approach provides a comprehensive strategy to reduce risks and improve equipment reliability, ultimately contributing to enhanced flight safety and reduced operational expenses.

2.4. Formation of Control Tasks and Maintenance Plan

The formation of control tasks and the maintenance (M) plan are key stages in ensuring the appropriate level of safety, efficiency, and cost-effectiveness in operating aviation equipment. The maintenance plan contains a list of actions to be performed to maintain the technical condition of the aircraft, while control tasks provide monitoring of these actions' execution and timely identification of the need to adjust maintenance programs.

The maintenance plan formation is based on data about the reliability and criticality of aircraft systems, which determine when and what maintenance actions are necessary to prevent failures. Control tasks help systematize the maintenance process, reducing the likelihood of malfunctions and improving flight safety.

When forming the maintenance plan, it is important not only to consider the technical condition specifics of each aircraft but also to maintain a balance between safety requirements and economic efficiency, so maintenance is performed at necessary times without excessive costs from unnecessary inspections or replacements.

Control tasks are part of maintenance because they ensure systematic monitoring and assessment of maintenance effectiveness. Each control task includes several key aspects that ensure the appropriate technical condition of aviation equipment and timely problem identification. A detailed description of each element of control tasks is as follows:

1. **Definition of inspection types** — the first step in creating a control task. For each system or component, it is essential to clearly define the type of inspection required. This may include checking physical parameters (e.g., system pressure), replacing components (e.g., filters or oil), or complex procedures such as structural inspections or system diagnostics. Defining the inspection type allows precise formulation of work requirements.
2. **Frequency of task execution** — depending on the significance and condition of equipment elements, and based on statistical data and manufacturer recommendations, the frequency for each control task is determined. Frequency may vary; for critical systems, inspections may be more frequent, while less critical components require fewer checks. Frequency determination relies on reliability analysis, previous inspection results, and operational experience.
3. **Methods for performing control tasks** — each control task should have a clear execution methodology including instructions for using tools, equipment, and technical condition inspection techniques. This ensures consistent standards of work regardless of the performer and circumstances. The methodology may also include requirements for instrument calibration, safety techniques, and result documentation.
4. **Documentation of results** — every completed control task must be documented to track the equipment's condition throughout its service life. This includes records of what was checked, obtained results, detected defects or deviations, and corrective actions taken. Documentation enables prompt response to technical condition changes and facilitates analysis of maintenance effectiveness.
5. **Task adjustments** — if deviations from standards or faults are detected during control tasks, adjustments must be made accordingly. This may

involve changing inspection frequency, updating execution methods, or modifying control measures. For serious faults or systemic problems, adjustments may include changes to the overall maintenance plan to eliminate risks and enhance aircraft reliability.

Ensuring effective execution of these elements is necessary to maintain high standards of safety and reliability in the aviation industry.

The aircraft maintenance plan is a tool to ensure system reliability and safety throughout their lifecycle. Its formation is based on the analysis results of the reliability and criticality of various components and systems of the aircraft. Creating such a plan requires considering several key elements that ensure effective maintenance execution.

The first step is identifying all necessary maintenance actions for each aircraft system. This includes scheduled inspections and replacement of components with limited service life or potential failure causes. For example, the flight control system may require scheduled performance and accuracy checks, while the power system might need filter or pump replacements. Each system has its maintenance requirements defined by component criticality analysis and their impact on flight safety.

The second step is prioritizing maintenance actions. Each action must be assessed regarding its importance for safety and flight efficiency. Critical systems such as the powerplant, flight control, or electrical systems have higher maintenance priority because failures in these systems can have severe safety consequences. Conversely, components not directly affecting safety may have lower maintenance priority. Prioritization helps allocate resources effectively and focus on the most important tasks.

Third, the maintenance plan specifies the intervals and timing of each maintenance action. Intervals depend on component reliability data, manufacturer recommendations, and operational experience. Maintenance intervals must balance between minimizing failure risk and reducing excessive costs due to frequent inspections. The plan should allow adjusting intervals based on new information or equipment condition changes.

Fourth, the plan includes the procedures and tools for performing maintenance actions. These procedures must be clearly described and standardized to ensure consistent and high-quality work. They include instructions for inspection, testing, adjustment, replacement, and repair, as well as requirements for tool calibration and safety measures during work.

Finally, the maintenance plan must include provisions for documenting all maintenance actions, recording defects, and corrective measures taken. Proper documentation allows tracking the technical condition of each system, analyzing maintenance effectiveness, and making data-driven decisions about future maintenance strategies.

Overall, the formation of control tasks and the maintenance plan ensures systematic, effective, and safe operation of the aircraft. Applying reliability data and failure criticality assessment methods allows focusing on critical systems, optimizing maintenance schedules, and reducing operational costs while maintaining a high level of flight safety.

Table 2.3 – Structure of Inspection Tasks and Maintenance Plan

Maintenance Plan Element	Description
Identification of Maintenance Actions	Determining the necessary technical actions for each system (inspection, replacement, review).
Prioritization of Maintenance Actions	Defining the priority of actions based on their criticality to flight safety.
Timing for Actions	Establishing the time interval for performing each maintenance task.

Resource Provision	Allocating necessary resources for task execution, including equipment and personnel.
Monitoring of Execution	Observing the implementation of the maintenance plan and making adjustments if necessary.
Documentation of Results	Recording the outcomes of performed actions for further analysis and assessment of equipment condition.

The development of inspection tasks and the maintenance plan are key stages in ensuring the efficient and safe operation of aircraft. This process enables the systematization of maintenance activities, optimization of costs, and ensures high reliability and flight safety. Proper prioritization, scheduling, and resource allocation guarantee that maintenance is performed at the appropriate level, with minimal expenses and without compromising safety.

CHAPTER 3. DEVELOPMENT OF A MAINTENANCE PROGRAM FOR A SPECIFIC AIRCRAFT (CASE STUDY)

3.1. Selection of Aircraft and Its Characteristics

The development of a maintenance program for a specific aircraft is a key step in ensuring the safety, reliability, and efficiency of aviation operations. Selecting a specific aircraft for maintenance program development involves a thorough analysis of its technical specifications, operational requirements, and usage conditions. Based on this analysis, a tailored maintenance program is created to ensure the optimal condition of the aircraft throughout its operational life.

This chapter focuses on the selection of a specific aircraft, which will be used as a case study for maintenance program development. Once the aircraft is selected, its technical characteristics are analyzed, which form the foundation for determining the specifics of its maintenance procedures.

Choosing the type of aircraft is a crucial stage in defining the approach to its maintenance. The type of aircraft—whether it is a passenger, cargo, or military aircraft—affects the complexity of maintenance, the required resources, and the qualifications of personnel. These aircraft types have varying design and functional features, which lead to significantly different maintenance requirements. For example, passenger aircraft include systems for passenger comfort and safety that require frequent inspections and servicing, while military aircraft are often equipped with combat systems that necessitate a different maintenance approach.

Furthermore, the specific model of the aircraft should be considered. Aircraft of the same type can differ in structural features, technologies, or equipment depending on the model. Even within a single model series, there can be significant differences in configuration, leading to varying maintenance needs. For example, some models may feature newer systems requiring specialized maintenance or updated components, while older models may require more frequent inspections and repairs.

Model series can also impact maintenance due to differences in equipment or technical characteristics. This means that servicing one aircraft series may require specific tools or methods different from those used for another series, even if they belong to the same category (e.g., passenger or cargo aircraft).

Therefore, proper selection of aircraft type and model, including consideration of the series, is essential for effective maintenance planning and execution, ensuring the safety and reliability of the aircraft.

Analyzing the operational history of a specific aircraft is an important phase in maintenance planning. The operational history provides valuable insights into previous failures, repairs, and maintenance actions, which help to more accurately forecast future inspection, component replacement, and repair needs. This allows for identifying patterns of frequent failures in specific systems or components, indicating potential issues requiring special attention.

Failure and repair history can also highlight particular systems or components that need increased monitoring and help identify critical systems affecting safety. For instance, if there have been recurring issues with a specific engine or electrical system, these components would warrant extra attention during scheduled maintenance.

Technical characteristics of the aircraft—such as size, weight, engine power, system types and quantities, and design features—directly influence maintenance requirements. For example, large aircraft with powerful engines and complex systems typically require more intensive maintenance than smaller ones. Parameters like system types (e.g., hydraulic, electric, pneumatic), number of components, and their configuration determine the inspection frequency and part replacement schedules.

Resource estimation for servicing a specific aircraft is a crucial part of maintenance planning, as it ensures efficient use of time, personnel, and equipment, while optimizing costs and efforts. Resource requirements depend on various factors, including the type and model of the aircraft, maintenance requirements, and specific characteristics of each system and component.

Key aspects of resource estimation for aircraft maintenance include:

- **Time estimation** for each system or component to perform inspections, diagnostics, cleaning, part replacement, or repair. This allows for planning the required labor hours and determining the number of crews or technicians needed.

- **Personnel allocation**, determining the number and types of qualified specialists (mechanics, engineers, diagnostic technicians, electronics experts) involved in each maintenance activity. Additional staff may be required for safety assurance, inventory control, or documentation review.
- **Specialized equipment**, including diagnostic tools, measuring devices, repair equipment, and part removal tools (e.g., for engine removal). This may also include electronic system testing technology or specialized tools for hydraulic and mechanical systems.
- **Spare parts and consumables**, such as mechanical parts, electronic components, fluids (hydraulic, lubricants), filters, and sensors. An effective inventory management system is necessary to ensure timely part availability.
- **Maintenance intervals**, which determine how frequently each system or component needs to be checked, diagnosed, or replaced. For example, flight control systems may require daily inspections, while hydraulic system components might only need servicing every few hundred hours.
- **Infrastructure requirements**, such as hangars with the necessary tools and equipment, diagnostics and repair zones, and storage areas for spare parts. Specialized transport may also be needed to move heavy components or aircraft within the airport.

The aircraft type and model directly affect resource selection. For example, newer aircraft may require different tools and specialized equipment than older models. Manufacturers often provide recommendations on service intervals and required tools for specific models. Operational conditions—such as climate, usage intensity, and flight types (short-haul vs. long-haul)—also influence resource needs. Aircraft operating in hot or humid climates may need more frequent filter cleaning or lubricant replacement due to accelerated wear.

Effective aircraft maintenance requires coordination with other departments, such as logistics (for spare parts supply), management (for workforce and scheduling), and regulatory authorities (for safety compliance). Clear coordination among all stakeholders prevents delays and ensures safe, reliable maintenance operations.

Accurate estimation of all required resources enables efficient maintenance planning, cost and time reduction, and ensures appropriate safety and reliability levels. This process includes considering time, staff, tools, spare parts, infrastructure, and adapting the program to operational conditions for optimal results.

In general, a detailed analysis of operational history and technical specifications is essential for developing an effective maintenance strategy that ensures the reliability and safety of the aircraft throughout its entire service life.

As an example, the Boeing 737 can be selected for the maintenance program development. Below are some technical specifications of this aircraft:

1. **Aircraft type:** Medium-class passenger airplane
2. **Maximum takeoff weight:** 79,000 kg
3. **Engines:** Two CFM56-7B turbofan engines
4. **Maximum speed:** 850 km/h
5. **Range:** 6,000 km (depending on modification)
6. **Maximum passenger capacity:** 189 persons
7. **Main systems:**
   - Power systems: hydraulic, electric
   - Flight control: autopilot, navigation systems
   - Safety systems: emergency exits, oxygen masks, fire suppression
   - Engine control: FADEC system

The Boeing 737 was chosen due to its widespread use in commercial aviation, allowing access to a vast dataset regarding its reliability and technical condition.

This aircraft type features a well-developed maintenance support structure, and although its maintenance program has already undergone numerous improvements, there is still room for optimization and the application of modern maintenance methodologies.

The selection of a specific aircraft, such as the Boeing 737, is a foundational step in maintenance program development, as it defines the maintenance specifics based on technical features, operational history, and system reliability. With this knowledge, an optimized maintenance program can be developed that addresses both safety requirements and economic efficiency. In the following stages of the project, based on this aircraft's characteristics, the necessary inspection tasks will be identified and a detailed maintenance plan will be created.

3.2. Analysis of Functional Systems According to MSG-3

The analysis of an aircraft's functional systems using the MSG-3 method is a key stage in the development of a maintenance program for a specific aircraft. The MSG-3 (Maintenance Steering Group-3) methodology enables an effective assessment of the technical condition of systems and components, as well as the development of maintenance strategies based on the criticality of failures and associated operational risks. This method helps reduce the number of unnecessary inspections and repairs, optimizing maintenance costs without compromising safety.

The analysis of functional systems using MSG-3 involves identifying each aircraft system, its functions, and the corresponding critical elements. According to the MSG-3 methodology, based on failure analysis and its impact on operational safety, the necessary maintenance actions for each system are determined.

The first step in the MSG-3 method is to divide the aircraft into functional systems. For each system, its components that may fail and affect the overall condition of the aircraft are identified. These may include power supply systems (hydraulic, electrical), flight control systems, engine systems, fire protection systems, and so on.

The next step is to assess the functions of each system. The importance of each system for the safety and normal operation of the aircraft must be determined. If a system failure can lead to catastrophic consequences, its criticality is considered high. Such systems require frequent and detailed inspections. In the case of less significant systems, where failure does not lead to major consequences, less frequent inspections or replacements may be planned.

Based on the criticality assessment of failures, risk analysis is conducted. For each functional system, the maintenance approach is selected depending on the identified risk level. If the risk of failure is high, the maintenance may include frequent inspections, component replacements, as well as the use of continuous monitoring techniques. In the case of low risk, the maintenance program may be less intensive, involving scheduled inspections at longer intervals.

After analyzing functional systems and determining the criticality of failures, the maintenance interval for each system is established. These intervals depend on many factors: system type, its importance, reliability, manufacturer recommendations, and operational conditions. All these factors help create a balance between safety and cost-effectiveness of maintenance.

The MSG-3 method is a tool for determining aircraft maintenance intervals and inspection tasks based on functional system analysis and their criticality. Let us consider three systems of a Boeing 737 aircraft analyzed using this method:

The **Flight Control Unit (FCU)** is responsible for controlling the aircraft during flight, ensuring stability, maneuverability, and directional control. Given its criticality for flight safety, failure of this system can lead to loss of control, which is unacceptable in flight. To maintain its efficiency, a functional check must be performed before each flight. As part of regular maintenance, the system is inspected every 200 flight hours or every 6 months, which helps identify any malfunctions or deviations in a timely manner.

The **Hydraulic system** on board is essential, as it powers major mechanisms such as the braking system, landing gear, and rudder. Failure in this system can lead to serious malfunctions in other systems, rendering the aircraft inoperative. To prevent failures, it is necessary to regularly check fluid levels, clean filters, and inspect pipelines for cracks or leaks. The maintenance interval for this system varies depending on the type of inspection: fluid level checks every 100 flight hours and full system inspection every 500 hours.

The **Fire suppression system** plays a vital role in aircraft safety, preventing the spread of fire in engine compartments and other critical areas. Failure of this system can lead to serious emergencies, so regular checks are essential. Sensor inspections are conducted every 500 flight hours, and extinguishing bottles are replaced every 3 years to keep the system in proper working order and ensure reliable protection when needed.

These systems are only examples of how the MSG-3 method enables the assessment of functionality and criticality of various aircraft systems, which in turn defines the maintenance requirements. Proper planning of maintenance intervals is essential for ensuring the aircraft's safety and reliability throughout its operational life.

The analysis of functional systems according to MSG-3 is an effective method for optimizing the maintenance process of aircraft. This approach considers the criticality of system and component failures and allows for the development of a customized maintenance program that minimizes risks and ensures maximum flight safety. The determination of maintenance intervals and methods for each system depends on its importance, characteristics, and operating conditions, providing an optimal balance between maintenance costs and a high level of safety.

3.3. Development of the Maintenance Map and Service Intervals

The development of a maintenance map and the determination of service intervals are key stages in creating a maintenance program for an aircraft. The maintenance map is a tool for organizing all actions required to keep the aircraft in operable condition and for determining the frequency of maintenance for each system or component. Service intervals help plan when specific tasks should be performed to ensure the safety and reliability of the aircraft's operation.

This section discusses the process of creating a maintenance map and the criteria that affect the determination of service intervals. These include the technical condition of systems and components, their criticality for safety, and the recommendations of the manufacturer and regulatory authorities. This allows the creation of an optimal maintenance schedule that meets safety requirements without exceeding economically justified costs.

The first stage in developing the maintenance map is the identification of all systems and components of the aircraft that require maintenance. These may include mechanical, electrical, hydraulic systems, and individual components that need to be inspected or replaced during operation.

Determining the necessary maintenance for each system or component is part of the planning process in accordance with the MSG-3 methodology. This ensures proper aircraft operation, reduces failure and accident risks, and promotes efficient resource use and preservation of the aircraft's technical condition.

For each system, the types of required maintenance are identified. These can include several main aspects:

- **Functionality checks** – these involve testing the operability of the system or component. For the hydraulic system, this may include checking fluid levels, pump performance, or pipeline integrity. For the flight control system, this involves testing the software and electronic components responsible for flight stability and control. These checks are routine and must be performed at set intervals, such as before each flight or after a defined number of hours.
- **Component cleaning** – this includes procedures to remove contaminants, dust, oil, or other residues that may reduce system efficiency. For filters, pipelines, and electronic components, cleaning is critical for maintaining functionality and preventing failures. This may involve cleaning air filters, lubricating bearings, cleaning sensors, or removing dust and moisture from electronics. These procedures are usually scheduled periodically or after a certain number of flight hours.
- **Replacement intervals** – defined based on the service life, wear level, or threshold of operational characteristics. For example, replacing oil, hydraulic fluid, worn bearings, or other mechanical parts. These replacements require precise calculations and adjustments based on operating conditions such as climate, flight style, and more.
- **Overhauls or major component replacements** – performed after inspections or when serious defects are detected. These may involve complex components like engines, suspension elements, fuselage structural parts, or control mechanisms. Such tasks require significant time and resources, as well as specialized equipment and personnel.

According to the analysis of functional systems, service intervals are determined for each system depending on their criticality and safety importance. Systems with high criticality, such as the flight control or hydraulic system, will have shorter intervals, as failures may lead to serious accidents. For less critical systems, like sensors or auxiliary systems, the intervals may be longer.

Manufacturer recommendations and international standards such as those from **EASA**, **FAA**, or **ICAO** must also be taken into account, as they define the minimum intervals for maintenance and inspection. These regulatory requirements may include mandatory intervals for servicing at each stage of aircraft operation.

The final step is compiling the **maintenance map**, which is a clear and convenient tool for maintenance personnel. The maintenance map should contain all necessary information about each system, its components, required maintenance types, intervals, and the procedure for execution. It is a key element for organizing maintenance operations, planning, and control. The map ensures continuous aircraft operation and maintains flight safety.

Table 3.1 – Example of a Maintenance Task Card for Boeing 737

System / Component	**Type of Maintenance**	**Maintenance Interval**	**Notes**
Flight Control System (FCU)	Functionality check	Before each flight	Functionality test after each flight
Hydraulic System	Fluid level check	Every 100 hours	Filter cleaning – every 500 hours; fluid replacement – every 2000 hours
Fire Extinguishing System	Sensor and bottle inspection	Every 500 hours	Replacement of fire extinguisher bottles – every 3 years
Electrical System	Component cleaning	Every 1000 hours	Inspection for corrosion and damage

Engine Compartments	Visual inspection	Every 200 hours	Check for fuel/oil leaks and physical damage

Development of the Maintenance Card and Determination of Service Intervals

The development of a maintenance card and the determination of maintenance intervals are essential steps to ensure the effectiveness of maintenance and the safety of aircraft operations. A properly designed maintenance card enables the optimization of maintenance processes, reducing the likelihood of system failures and lowering maintenance costs, while maintaining a high level of reliability and safety. The determination of service intervals should be based on the analysis of system failure criticality, operating conditions, and regulatory requirements.

3.4. Implementation and Optimization of the Maintenance Program

The implementation of a maintenance program (MP) is a crucial step in ensuring the reliable operation of an aircraft. Once a detailed program is developed, which includes the definition of service intervals, types of tasks, and required resources, the next step is its integration into actual operation. However, the effectiveness of a maintenance program can only be achieved through continuous monitoring, analysis of results, and optimization.

The goal of maintenance program optimization is to improve task planning, reduce maintenance costs, minimize aircraft downtime, and increase safety. This may involve adjusting maintenance intervals, updating maintenance methods, integrating modern diagnostic and repair technologies, and improving resource utilization efficiency.

Implementing a maintenance program requires thorough preparation of the personnel responsible for performing the tasks. This includes training the technical staff in all aspects of the program, such as maintenance intervals, inspection methods, and required tools and equipment. It is essential that the personnel understand not only the technical aspects but also the importance of maintenance for aircraft safety.

The maintenance program should be integrated into the overall management system of the airline or operator. This includes monitoring task completion, ensuring compliance with maintenance deadlines, and providing access to the necessary documentation. Specialized software systems are often used to plan maintenance activities and maintain records of completed tasks.

Following implementation, continuous monitoring of program execution is necessary. This includes verifying whether all planned activities are completed within the established timeframes. It is also necessary to analyze the time and costs associated with each type of task to identify potential problems or inefficiencies.

Evaluating the effectiveness of the maintenance program is a key stage in ensuring aircraft reliability, safety, and cost-efficiency. This evaluation involves collecting data on various aspects of program performance, particularly its impact on safety, reliability, and maintenance costs. Key aspects of evaluation include:

- **Safety Impact**: Evaluation of the safety impact involves analyzing the frequency of system failures and the number of incidents caused by technical issues. Reviewing failure and malfunction data helps determine whether the maintenance program provides an adequate level of safety. Frequent failures or serious technical incidents may indicate the need for program adjustments.
- **Reliability**: Program reliability is assessed based on the frequency of required repairs and component replacements. High frequency of repairs or

replacements may indicate that certain procedures or maintenance intervals are ineffective. These indicators help identify systems or components that require design improvements, better servicing, or revised inspection intervals.

- **Cost Evaluation**: Maintenance cost assessment includes expenses for spare parts, materials, labor, and other resources associated with maintenance. Comparing costs with expected outcomes helps determine whether the program is economically efficient and whether there is room for cost reduction without compromising safety or reliability.

Maintenance personnel, who are directly involved with technical systems, can often identify practical issues or deficiencies in the program. Their feedback provides insight into how effectively certain procedures are executed, whether there are challenges in completing tasks, and whether diagnostic or maintenance methods need to be changed. Personnel may also offer suggestions for optimizing service intervals or modifying equipment.

Feedback from pilots and operators is also necessary for program evaluation, as they can detect system performance changes during real flight conditions. Pilot reports on system malfunctions or irregularities help identify areas of the program that require attention. For example, a pilot may report issues with flight control systems or cockpit interfaces that indicate a need to revise maintenance procedures.

By collecting such data and performing in-depth analysis, weak points in the maintenance program can be identified, and appropriate corrective actions can be taken. This may include changes to service intervals, improvements in diagnostic techniques, or even adjustments to the types of maintenance performed. The program should also be adapted to regulatory updates, technological advances, or changing operating conditions.

Through such adjustments, the maintenance program can become highly effective, ensuring a high level of safety, reliability, and cost-efficiency in the long term. One of the key aspects of optimization is revising the maintenance intervals. If the program includes overly frequent checks that do not significantly impact safety or system performance, their frequency can be reduced. Conversely, if certain components prove to be less reliable than expected, maintenance intervals may need to be shortened to ensure greater safety.

Optimization also includes the use of advanced technologies such as AI-based diagnostics, real-time condition monitoring of components, and automated maintenance planning systems. These technologies allow for precise determination of maintenance needs, reducing costs and minimizing aircraft downtime. Over time, after collecting extensive data on failures, repairs, and expenses, a performance analysis of the program can be conducted. This enables updates to the maintenance plan based on statistical and real-world data. For instance, if a particular system consistently requires maintenance earlier than scheduled, its service interval may need to be shortened.

Maintenance program optimization also involves improving the availability of resources, particularly personnel and materials. Employing highly qualified staff and using modern equipment and tools for maintenance can significantly reduce the time required for task completion and enhance work quality. Another component of optimization is the use of predictive maintenance methods, which allow failures to be anticipated based on sensor data, statistics, and past repairs. This enables maintenance to be carried out only when necessary, reducing the need for preventive checks.

The implementation and optimization of a maintenance program are crucial steps to ensure efficient and cost-effective aircraft maintenance. Proper implementation ensures the required level of aircraft safety and reliability, while also optimizing maintenance expenditures. Continuous monitoring, effectiveness analysis, and integration of modern technologies help improve the maintenance program and adapt it to changing operational conditions, ensuring maximum economic benefit and minimal failure risks.

CHAPTER 4. ECONOMIC AND OPERATIONAL ASSESSMENT OF THE MAINTENANCE PROGRAM

4.1. The Impact of the Maintenance Program on Airline Costs

Maintenance (MRO) is an integral part of aircraft operation and has a direct impact on an airline's expenditures. Since regular maintenance ensures the safety and reliability of aircraft operation, optimizing the maintenance program can significantly reduce operating costs, enhance efficiency, and contribute to long-term economic stability. This section explores various aspects of how the maintenance program influences airline expenses, analyzes the main cost-driving factors, and provides a sample table for detailed analysis.

The maintenance program can affect an airline's costs in several ways:

1. **Direct maintenance costs** include the wages of technical personnel, costs of spare parts, expenses for tools and equipment, as well as maintenance materials (such as oils, fluids, and consumables). The cost of maintenance also depends on service intervals—the more frequent the inspections or replacements, the higher the expenses.
2. **Aircraft downtime** resulting from frequent or prolonged maintenance—such as in-depth inspections or major repairs—can lead to additional costs. These may include flight cancellations, revenue loss from grounded aircraft, and increased expenses for deploying substitute aircraft.
3. **Deferred or insufficient maintenance** can result in serious technical issues requiring emergency repairs. Such repairs are typically far more expensive than preventive maintenance and may incur not only financial costs but also time lost on recovery, further affecting company revenue.
4. **Optimizing the maintenance program** by adjusting service intervals can significantly reduce costs. This might involve reducing service time without compromising aircraft reliability, improving resource planning, and minimizing the need for extra expenses on spare parts or technical work.

5. **Implementing a new maintenance program** may require additional spending on training technical personnel and certifying maintenance specialists. These costs may include both initial training and ongoing qualification upgrades.
6. **Long-term cost implications** of a maintenance program are also significant, particularly in relation to component wear and replacement needs. Regular maintenance helps identify components that need to be replaced before they cause serious failures, potentially reducing replacement costs in the long run.

Table 4.1 – Maintenance Cost Assessment for the Airline

Cost Type	Impact on Expenses	Key Factors	Estimated Impact on Airline
Direct Maintenance Costs	Expenses for spare parts, personnel labor, tools, and materials	Maintenance frequency, type of work, cost of parts and labor	High, depends on scope of work
Aircraft Downtime Costs	Revenue loss due to flight cancellations, need to replace aircraft during repair	Duration of maintenance, type of repair	Medium, depends on frequency and duration of downtime
Emergency Repair Costs	Significantly higher costs for recovery after major failures	Timeliness of maintenance, system failure rate	High, can be a significant source of financial loss
Training and Certification Costs	One-time costs for preparing personnel to work under the new maintenance program	Airline size, number of personnel	Low to medium, depends on company scale

Wear and Replacement Costs	Expenses for replacing failed components	Maintenance intervals, component age	Medium, reduced through effective maintenance

The maintenance program has a significant impact on an airline's costs, particularly in terms of direct maintenance expenses, aircraft downtime, emergency repair costs, and overall operating expenditures. Proper maintenance planning and optimization of service intervals can substantially reduce costs, improve operational efficiency, and minimize unforeseen expenses. At the same time, insufficient maintenance or improper planning can lead to considerable economic losses due to flight cancellations, increased emergency repair costs, and overall wear of aircraft components.

4.2. Comparison of Economic Indicators Before and After MSG-3 Implementation

The implementation of a Maintenance Steering Group-3 (MSG-3)-based maintenance program can substantially change the financial dynamics within an airline, offering cost optimization and increased aircraft operational efficiency. Before adopting MSG-3, airlines often rely on less effective maintenance planning methods, which can lead to excessive expenditures and reduced aircraft reliability. MSG-3 implementation enables precise determination of maintenance intervals, allowing for cost optimization, reduced downtime, and improved economic performance.

This section presents a comparison of economic indicators before and after the implementation of MSG-3, focusing on maintenance costs, aircraft downtime, safety, and operational efficiency.

Traditionally, prior to MSG-3 adoption, airlines frequently used fixed maintenance intervals based on manufacturer recommendations or standard procedures, without considering the actual condition of systems and components. This often led to excessive costs due to frequent inspections, premature replacement of still-serviceable parts, and high expenditures on personnel and tools for maintenance execution.

After implementing MSG-3, thanks to detailed analysis and optimization of maintenance intervals, maintenance costs typically decrease. A thorough assessment of component and system criticality enables more effective planning of inspections and repairs, reducing the need for spare parts, labor, and materials.

Before MSG-3, aircraft downtime could be substantial, as service intervals were often too frequent or not aligned with the actual condition of systems. This resulted in frequent and lengthy checks, leading to revenue loss from grounded aircraft. With optimized maintenance intervals and better planning, aircraft downtime is significantly reduced. MSG-3 allows for condition-based maintenance, minimizing operational interruptions and losses from flight cancellations.

Without detailed system condition analysis and forecasting, airlines may face an increased risk of emergency situations due to component failures not detected in time. This can result in costly emergency repairs, requiring both high financial outlays and extended recovery time. MSG-3 facilitates accurate criticality analysis of components, reducing the likelihood of emergencies. Preventive maintenance based on real data significantly lowers the probability of serious failures and reduces emergency repair costs.

Without MSG-3, resource costs may not be optimized due to overly frequent maintenance, the need to stockpile large quantities of spare parts, or the use of expensive tools for frequent inspections. Implementing MSG-3 significantly reduces costs for spare parts, materials, and human resources by ensuring precise maintenance intervals and minimizing part replacement frequency. This leads to cost savings and improves the overall economic efficiency of the airline.

Table 4.2 – Comparison of Economic Indicators Before and After MSG-3 Implementation

Economic Indicator	Before MSG-3 Implementation	After MSG-3 Implementation	Change
Maintenance Costs	Higher due to excessive maintenance intervals and inefficient resource use	Reduced due to optimized intervals and precise planning	Cost reduction of 15–30%
Aircraft Downtime	Greater due to frequent maintenance and unnecessary inspections	Downtime reduced through optimization	Reduction of 10–20%
Emergency Repair Costs	Higher due to inefficient maintenance and unexpected failures	Reduced thanks to preventive checks and improved monitoring	Reduction of 25–40%
Operational Efficiency	Low due to significant time and resource losses	High due to more efficient use of resources and maintenance time	Increase of 10–15%

Before the implementation of the MSG-3 program, airlines operating the Boeing 737 typically followed standard maintenance intervals based on the manufacturer’s recommendations and general procedures for aircraft of a particular class. Maintenance costs before MSG-3 included regular inspections of all aircraft systems regardless of their actual condition, which often led to excessive expenses. Component replacements and inspections were carried out at uniform intervals for all aircraft, regardless of actual wear levels or system failure risks.

After the implementation of MSG-3, the program allows for optimization of maintenance intervals by conducting a detailed evaluation of the aircraft’s functional systems. This enables inspections and component replacements only when critical wear thresholds or potential issues are identified, significantly reducing unnecessary checks and replacements. As a result, after MSG-3 implementation, the Boeing 737 can operate more efficiently with lower maintenance costs, since maintenance actions are taken only when truly necessary.

Thanks to this optimization, **spare parts costs are significantly reduced**, as components are replaced only based on objective assessments of their condition. In addition, the time required for maintenance also decreases, as the MSG-3 program enables servicing based on the actual needs of the aircraft rather than following standard intervals.

Before MSG-3, maintenance costs for the Boeing 737 included regular checks of all major systems such as engines, hydraulic systems, electrical networks, as well as additional inspections for corrosion, structural components, and other systems. These inspections were performed according to standard requirements, which did not always reflect the aircraft's actual condition.

After the implementation of MSG-3, the program helps to **reduce unnecessary inspections** and **minimize component replacements**, as maintenance is performed based on the actual state of the systems. This leads to **cost savings**, since replacements are done only when necessary rather than at fixed intervals.

Implementing the MSG-3 program for the Boeing 737 allows for **significant reductions in maintenance costs** by thoroughly assessing the functional systems of the aircraft. Instead of performing standard checks at fixed intervals, MSG-3 helps determine the most effective maintenance intervals, leading to substantial savings in both spare parts and time spent on inspections and repairs. This, in turn, improves the economic efficiency of Boeing 737 operations and enables airlines to reduce long-term maintenance costs.

The introduction of MSG-3-based maintenance programs significantly **optimizes airline maintenance expenditures**, reduces aircraft downtime, and decreases the likelihood of emergency situations. This is achieved through precise maintenance planning, criticality analysis of systems and components, and better resource utilization during maintenance operations. As a result, airlines benefit from not only reduced costs but also increased operational efficiency, which is essential for maintaining competitiveness in the air transport market.

4.3. Assessment of Aircraft Efficiency and Durability

The **assessment of aircraft efficiency and durability** is a crucial stage in planning aircraft operation and maintenance, as it determines how economically viable a particular aircraft type is throughout its life cycle. For aircraft like the Boeing 737, the evaluation criteria include maintenance costs, component service life, and operational efficiency under various conditions. In this section, we will examine the key factors that influence the efficiency and durability of the Boeing 737, including engine service life, system reliability and maintenance, as well as the overall economic performance of the aircraft.

The Boeing 737 has multiple variants in airline fleets, but for this evaluation, we will focus on one of the most popular versions — the **Boeing 737 Next Generation (NG)**, specifically the **737-800 model**. This aircraft is known for its fuel efficiency, operational performance, and reliability, making it cost-effective throughout its service life.

The main performance parameters of the Boeing 737 include:

1. One of the key factors determining the efficiency of the Boeing 737 series is **fuel economy**. Thanks to the improved **CFM56-7B engines**, fuel

consumption per passenger per 100 km is reduced compared to previous models, making the aircraft economically viable on medium-haul routes.

2. Due to the **reliability of systems and engines**, maintenance costs for the Boeing 737 are not excessive. The aircraft has dependable systems that perform at a high level with regular servicing. A key aspect is the **optimized intervals for scheduled inspections**, which help reduce the cost of unscheduled repairs.
3. The Boeing 737 is recognized for its **high reliability**, which minimizes expenses for repair and maintenance. Thanks to high-quality manufacturing and materials, most critical aircraft components have a long service life, which positively impacts overall maintenance costs.

The **durability of Boeing 737 aircraft** is ensured by several factors:

1. The engines used on most Boeing 737 models have a service life of **20,000–30,000 hours**, depending on operating conditions. This means that even with intensive use over 15–20 years, the engines can handle a high volume of flights, reducing overall replacement costs.
2. The Boeing 737 is designed for a high number of flight hours and cycles. The projected number of operating cycles for this aircraft is between **50,000 and 75,000** (takeoff/landing), allowing it to remain in service for a long time, provided proper maintenance is carried out.
3. The aircraft is manufactured using **high-strength materials**, ensuring durability and high resistance to wear. The **corrosion protection system and anti-corrosion coatings** allow the aircraft to remain in good technical condition for decades.

The assessment of Boeing 737 efficiency and durability shows that it is a **highly effective and economical aircraft** capable of reliable operation over an extended period. With reliable engines, optimized fuel and lubricant usage, and well-planned maintenance intervals, maintenance costs remain at an acceptable level.

Due to its high durability and ability to endure a large number of flight hours and cycles, the Boeing 737 has **great potential for long-term operation**, making it one of the most attractive options for airlines on medium-haul routes. Overall, the aircraft is an excellent example of **high-performance aviation technology** that combines low operating costs with outstanding reliability and longevity.

The **evaluation of aircraft efficiency and durability** highlights the significant benefits of implementing an MSG-3-based maintenance program. Through optimized maintenance intervals, enhanced accuracy in servicing, and a preventative approach, airlines can achieve **greater operational availability**, **reduced aircraft downtime**, and **extended aircraft lifespan**. This not only reduces maintenance costs but also ensures the **reliability and safety** of aircraft, which is essential for successful fleet operation and maintaining **high competitiveness** in the aviation market.

4.4. Long-Term Maintenance Cost Forecasting

Long-term forecasting of maintenance (MRO) costs for aircraft is a crucial planning element for airlines. It enables the estimation of overall fleet maintenance expenses, ensures financial stability, and supports strategic decision-making aimed at optimizing resources and expenditures. Considering the high cost and intensive use of aircraft, accurate MRO cost forecasting is a key factor in maintaining efficiency and uninterrupted airline operations.

Cost forecasting is based on data analysis regarding the current technical condition of aircraft, maintenance progress, and predictions related to wear and the need for component replacement. The implementation of modern maintenance management methods such as MSG-3 significantly enhances forecast accuracy.

Determining optimal maintenance intervals is a primary factor affecting costs. MSG-3-based programs can accurately predict when scheduled maintenance is required, helping reduce unnecessary inspections and minimizing material and labor expenses. Evaluating the wear of key aircraft components—such as engines, control systems, and structural parts—enables estimation of their lifespan and replacement needs. Regular maintenance based on component condition analysis helps optimize replacement costs.

The incorporation of new aviation maintenance technologies is also important. For example, advanced materials or improved diagnostic methods can reduce MRO expenses, enhance forecast accuracy, and decrease the need for repairs. Aircraft utilization intensity has a direct impact on maintenance costs. Higher utilization leads to faster wear, increasing the need for frequent inspections and component replacements. Forecasting these factors helps accurately plan maintenance budgets.

Spare parts costs can vary significantly depending on the aircraft type and component. Forecasting expenditures on spare parts and analyzing their usage efficiency help optimize inventory and reduce costs.

Maintenance cost forecasting is a critical aspect of effective asset and resource management. It enables budgeting, process optimization, and system reliability assurance. Let’s examine the main forecasting methods in detail.

Mathematical models form the foundation of accurate MRO cost forecasting, as they account for various factors affecting technical condition and expenditures. Key models include:

- **Regression models** – Statistical methods used to establish relationships between MRO costs and different variables, such as operating hours, maintenance intervals, parts and repair costs. For example, a model could link component replacement costs to the number of flight hours. This allows for precise cost predictions based on historical trends.

- **Probability-based models** – These account for the likelihood of failure in different systems and components. For example, if the failure of a component like an engine or hydraulic system results in high repair costs, such models help determine when and which parts are most likely to require replacement or repair. This enables planning under uncertainty.

Mathematical models provide accuracy and reliability in cost planning by using historical data to compute probable future expenses.

Statistical analysis methods help identify patterns in MRO expense data, allowing for forecasts that consider various factors and changes. These are particularly valuable when large datasets are available over extended periods.

- **Time series analysis** allows tracking MRO cost trends over time. For instance, analyzing expenses from recent years can help detect seasonal variations or trends related to specific maintenance types. This method supports future cost forecasts based on historical changes.
- **Correlation analysis** reveals relationships between MRO costs and other factors, such as equipment usage intensity, operational conditions, or the number of failures. For example, analyzing how changes in operational conditions or increased loads affect maintenance costs helps predict future expenditures.

With the development of technologies for collecting and processing large datasets, it has become possible to use vast amounts of real-time information from various sources—such as onboard sensors, monitoring systems, and maintenance and operation reports. These technologies support precise maintenance cost forecasting:

- **Data on aircraft condition**, performance parameters, and past maintenance can be automatically collected using sensors or monitoring systems, providing a real-time picture of the aircraft's condition. This helps detect potential issues that could lead to additional repair costs.

- **Machine learning algorithms** can uncover hidden relationships between factors affecting MRO costs. For example, algorithms may identify which specific operating conditions or parameters contribute to high service expenses and detect patterns not immediately obvious.

Big Data technologies enable highly accurate cost forecasting by considering a vast number of parameters and dynamically adapting to changes in equipment condition.

Integrated software solutions for maintenance management combine all necessary data and tools for cost planning and forecasting. These systems store information about all stages of maintenance—from planning to execution—and perform automatic MRO cost forecasting:

- Integrated systems automatically gather data from various sources, such as sensors, maintenance reports, and records of repair and spare part costs. This ensures accurate and timely expense forecasting.
- These systems can autonomously schedule maintenance based on acquired data and forecast future costs, considering past indicators and operating conditions. They also adapt forecasts based on changing conditions or unexpected issues.

Integrated systems help reduce MRO costs by enabling efficient resource management, expense control, and optimized maintenance schedules.

All these methods provide accurate MRO cost forecasts, allowing for effective budget planning, cost reduction, and maintaining a high level of aircraft reliability.

Table 4.3 – Comparison of Maintenance Cost Forecasting Methods

Method	Description	Advantages	Disadvantages

Mathematical Forecasting	Use of models to predict costs based on operational parameters and technical condition.	Accuracy, ability to consider multiple factors.	Requires large amounts of data and complex calculations.
Statistical Analysis	Use of statistical methods to study historical maintenance data and costs, allowing future cost forecasting.	Easy implementation, effective for large datasets.	May be inaccurate under unstable operating conditions.
Big Data Analysis	Collection and processing of large volumes of data on aircraft technical condition and maintenance using Big Data technologies.	Can reveal hidden patterns.	Requires significant resources for data processing and storage.
Integrated Management Systems	Use of specialized software products to monitor equipment condition and forecast maintenance costs in real time.	Convenience, reduced forecasting errors, process automation.	High implementation and maintenance costs.

For an airline, forecasting maintenance (MRO) costs several years ahead is a strategic planning aspect that allows for cost optimization and ensures the

uninterrupted operation of the fleet. This task can be accomplished through a comprehensive approach that takes into account several key factors.

First of all, it is necessary to analyze current MRO costs, which include routine inspections, part replacements, and repairs. This analysis helps establish a baseline of expenses and identify key areas for optimization. Current costs also allow for estimating the average expenditure across various types of maintenance, such as minor or major repairs, component replacements, and both scheduled and unscheduled inspections. Determining these expenses serves as the foundation for forecasting future requirements.

Another crucial aspect is assessing the technical condition of the fleet. Accurate forecasting requires evaluating the state of major aircraft components such as engines, control systems, avionics, and fuel systems. If certain components are nearing the end of their service life, replacement or repair costs must be incorporated into the forecast. Considering this data helps develop accurate MRO cost projections, as older or worn-out components may require more frequent servicing, thereby increasing expenses.

The fleet's operational intensity also significantly affects cost forecasting. Evaluating the number and frequency of flights over the coming years helps understand how often maintenance will be required. If an increase in the number of flights or fleet utilization is anticipated, more frequent maintenance may be necessary, which will raise overall MRO costs. Conversely, if aircraft usage decreases, maintenance costs are expected to decline.

Equally important is the assessment of innovations in maintenance practices. Continuous advancements in diagnostic technologies, materials, and maintenance methods can significantly impact MRO costs. For example, new diagnostic techniques can reduce the number of unscheduled repairs, while new materials used in spare parts manufacturing may be more durable and reduce replacement costs. Implementing such innovations enables airlines to lower long-term maintenance costs and improve fleet efficiency.

By considering these factors, an airline can create more accurate maintenance cost forecasts for several years ahead, allowing for better budget planning and increased reliability of fleet operations.

Maintenance cost forecasting is a component of efficient aircraft operation planning. For airlines operating the Boeing 737, this task is particularly relevant due to the aircraft’s high flight intensity and the constant need to keep the aircraft in airworthy condition. Such a program helps accurately assess long-term maintenance costs, including repairs, part replacements, and routine inspections necessary to ensure aircraft safety and reliability. In this section, we will examine how MRO cost forecasts for the Boeing 737 can be developed based on its technical characteristics, operational usage, and the specific features of its systems and components.

The Boeing 737 is one of the most widely used aircraft globally due to its efficiency and reliability. Since the aircraft has a long service life and a high utilization rate, planning MRO costs becomes critical to ensuring long-term and safe operation. In this context, it is essential to consider not only standard maintenance costs but also potential expenses related to unexpected repairs and part replacements that may arise during operation.

To forecast MRO costs for the Boeing 737, several core factors must be considered, including the aircraft's technical specifications, flight intensity, aircraft age, and types of maintenance performed within the MRO program. One key element of forecasting is determining maintenance intervals—such as periodic checks every 100, 500, or 1000 flight hours—and major overhauls based on time in service.

Another important factor is the wear and tear of the aircraft's systems and components. For instance, depending on the operational intensity of the CFM56-7B engines, they require regular inspections and servicing, which may include component replacement or major overhauls. Forecasting such expenses also involves analyzing spare part costs, which will be required for replacing worn-out components.

Additionally, the use of hydraulic and electrical systems in the Boeing 737 requires special attention during maintenance. MRO costs for these systems depend on their condition and operational duration.

Forecasting Boeing 737 MRO costs includes analyzing historical maintenance data for similar aircraft, as well as using statistical methods to estimate costs based on operational information. Mathematical models can help predict average expenses for component replacements and regular inspections, taking into account usage intensity and the aircraft’s age.

More precise forecasting can be achieved using statistical analysis methods, which help identify patterns between MRO costs and influencing factors. Using such data allows the airline to estimate the average annual maintenance cost per aircraft and understand how these costs may change over the aircraft's lifecycle.

Forecasting also considers the cost of components, spare parts, and labor. These figures can be derived from historical maintenance data of similar aircraft and information provided by manufacturers and parts suppliers.

Forecasting MRO costs for the Boeing 737 is a vital tool for airlines operating this type of aircraft. Through careful analysis of aircraft characteristics, maintenance intervals, component wear, and operating conditions, airlines can effectively plan long-term MRO expenditures. Considering a broad range of factors—such as engine usage, hydraulic and electrical systems, and standard maintenance costs—enables an airline to obtain accurate forecasts, optimize resources, and ensure the aircraft's reliability throughout its entire operational lifespan.

CONCLUSIONS AND RECOMMENDATIONS

The assessment of the condition of electrical substation equipment is a crucial stage in the development of a maintenance (MRO) program, as it allows for the identification of critical components and devices that require attention. This process involves not only inspecting the physical condition of the elements but also evaluating their functional capabilities, level of wear, and potential failure risks.

Key parameters to consider during equipment condition assessment include the technical state of transformers, circuit breakers, switchgear, cable networks, generators, and backup power sources. The assessment is carried out by analyzing wear, material degradation, and inspecting for signs of corrosion or mechanical damage. Special attention should be given to components under high load, such as transformers and switchgear, as their failure could lead to severe incidents.

Additionally, it is necessary to monitor parameters such as temperature, humidity, load, and vibration, as these factors impact equipment lifespan and the likelihood of failure. Assessing these parameters helps determine inspection and replacement intervals, forming the basis for a tailored MRO program for each type of equipment.

The algorithm for forming an MRO program based on the MSG-3 methodology is a key part of maintaining efficient and safe operation of technical equipment. This algorithm includes several stages, each aimed at identifying components and determining optimal maintenance intervals.

The first stage involves the analysis of functional equipment systems. This requires a thorough study of the technical descriptions of substation elements and identification of all functional blocks. Their criticality and interdependencies between different systems must be evaluated. This helps understand how each component interacts with others and what the consequences of specific component failures might be for overall substation operation.

The second stage is assessing the probability of failure for each component during operation. This takes into account not only historical failure data but also the likelihood of critical situations arising due to certain malfunctions. Evaluating failure probability helps identify vulnerable elements and determine how much time can elapse before the next necessary inspection.

The third stage involves defining the frequency of inspections and replacements. Through analyzing wear and load on components, the optimal time for maintenance activities is established. This not only conserves resources but also ensures the safety and efficiency of all systems.

The next stage is modeling scenarios based on mathematical models, which help predict the need for maintenance considering various factors such as operational load, wear, and failure probability. Modeling enables accurate forecasting of when maintenance is required to prevent unexpected breakdowns and reduce costs.

The final stage is evaluating MRO costs. For each component, costs for maintenance, part replacement, and labor are determined. This helps develop a cost-effective MRO program that minimizes expenses while ensuring the necessary reliability and safety.

To maximize the effectiveness of the MRO program, it is important to precisely determine the intervals for performing maintenance. The most effective intervals are based on statistical data analysis, which helps forecast failure rates and component wear. Collected data on equipment condition and operational loads aid in defining optimal maintenance schedules.

In cases of variable operating conditions, such as increased load or adverse weather, maintenance intervals may need adjustment. This approach allows for flexible adaptation of the work schedule and ensures proper servicing even if equipment usage conditions change.

A risk-based approach underpins the determination of maintenance frequency. Components critical to substation safety and stability should be inspected more frequently. For certain elements, longer maintenance intervals may be appropriate, reducing costs without compromising system reliability.

The implementation of an MSG-3-based MRO program provides significant economic benefits. Maintenance costs are reduced through accurate determination of inspection and replacement intervals, avoiding unnecessary part usage and redundant work. Defining optimal service intervals also helps lower labor costs by reducing the need for frequent checks.

Reducing downtime is another advantage. Minimizing periods when equipment is offline due to repairs or inspections increases substation efficiency and reduces financial losses from non-operational systems.

By lowering the number of emergency situations, the company also saves on emergency maintenance and recovery costs. As a result, the implementation of the MSG-3 methodology yields tangible economic effects through reduced overall maintenance expenses and improved operational profitability.

Implementing an MRO program based on MSG-3 significantly reduces maintenance costs while ensuring the required reliability and safety of the equipment. Assessing the technical condition and analyzing functional systems enable more accurate forecasting of servicing and replacement needs, thereby lowering the likelihood of unexpected failures.

Developing a maintenance algorithm based on MSG-3 enables the creation of individualized service programs, allowing the strategy to be adapted to the real condition of each equipment component. Defining effective timeframes for maintenance helps optimize costs, improve operational efficiency, and reduce equipment downtime.

In the long term, this methodology will deliver economic advantages and enhance operational performance, making technical maintenance cost-effective, reliable, and safe.

LIST OF REFERENCES

1. Laarhoven P.J.M. Simulated Annealing: Theory and Applications / P.J.M. Laarhoven, E.H.L. Aarts. – Boston: Kluwer Academic Publishers, 1987. – P. 55-70.
2. Bischoff E.E. A Comparative Evaluation of Heuristics for Container Loading / E.E. Bischoff, M.D. Marriott // European Journal of Operational Research. – 1990. – No. 44. – P. 267-276.
1. Bischoff E. Three - dimensional packing of items with limited load bearing strength / E.E. Bischoff // Journal of Operational Research. – 2006. – No. 168. – P. 952-966.
3. Bortfeldt A. A hybrid genetic algorithm for the container loading problem / A. Bortfeldt, H. Gehring // European Journal of Operational Research. – 2001. – No. 131. – P. 143-161.
2. Chen C. An analytical model for the container loading problem / C.S. Chen, S.M. Lee, Q.S. Shen // Journal of Operational Research. – 1995. – No. 80(1). – P. 68-76.
4. Dyckho H. A typology of cutting and packing problems / H. Dyckho // European Journal of Operational Research. – 1990. – No. 44. – P. 145-159.
3. George J.A. A heuristic for packing boxes into a container / J.A. George, D.F. Robinson // Computers & Operations Research. – 1980. – No. 7(3). – P. 147-156.
5. Sahun Ye. Current status of aircraft load optimization problem / Ye. Sahun // Proceedings of the National Aviation University. – 2019. – No. 1(78). – P. 35-39.
6. Suhl Uwe H. Solving Airlinefleet Scheduling Problems with Mixed-integer Programming / Uwe H. Suhl, M. Leena Suhl // Operational Research in Industry, 1999. − P. 135-156.

7. Trivella A. Bin-packing problems with load balancing and stability constraints / A. Trivella, D. Pisinger // Informs Transportation and Logistics Society. – Chicago, United States, 2017. – P. 5-8.
8. A comparative review of 3D container loading algorithms / X. Zhaoa, B. Bennella, A.T. Julia, K. Dowsland // International Transactions in Operational Research. – 2016. – No. 23. – P. 287-320.
9. Методичні вказівки до виконання курсової роботи з дисципліни «Реконструкція автомобільних доріг і аеродромів» для студентів ступеня бакалавра спеціальності 192 «Будівництво та цивільна інженерія» ОПП «Автомобільні дороги і аеродроми» денної та заочної форм навчання / Укладачі: Юлія БАЛАШОВА, Віктор ДЕМ'ЯНЕНКО, Олександр ТРЕГУБ – Дніпро: ДВНЗ ПДАБА. – 2022. – 33 с.
10. Тимочко О.І., Дмітрієв О.М., Олізаренко С.А., Задкова О.В., Падалка І.О. Курс лекцій з навчальної дисципліни Льотна експлуатація повітряних суден / Кропивницький: ЛА НАУ, 2023 - 180с.
11. Проектування аеропортів: підруч. для студ. вищ. навч. закл. / М.Ф. Дмитриченко, М.М. Дмитрієв, О.М. Папченко та ін. – К.: НТУ, 2010. – 248с.