MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS
DEPARTMENT OF AVIONICS

APPROVED
Head of department
________Yu.V.Hryshchenko
'___'___________2023

GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF MASTER

SPECIALITY 173 'AVIONICS'

Theme: "Modernization of power supply systems of a modern medium-haul aircraft to increase its autonomy"

Done by: ___________AV-254Ma, Karen Rukhkian__________________
(student, group, surname, name, patronymic)

Supervisor: ______PhD, As. Prof., O.V. Kozhokhina__________________
(scientific degree, academic rank, surname, name, patronymic)

Consultant on 'Labor protection': ___________ ____________
(signature)(surname, name, patronymic)

Consultant on 'Environmental protection': ___________ ____________
(signature) (surname, name, patronymic)

Standard controller: ___________ V.V. Levkivskyi
(signature) (surname, name, patronymic)

Kyiv 2023

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation, Electronics and Telecommunications

Department of avionics

Specialty 173 ‘Avionics’

APPROVED

Head of department
_________ Yu.V.Hryshchenko
‘___’___________2022

TASK

for executiongraduation work

Karen Rukhkian

1. Theme: “Modernization of power supply systems of a modern medium-haul aircraft to increase its autonomy” ,approved by order 1413/ст of the Rector of the National Aviation University of 13 September 2022.

2. Duration of which is from 05September 2022 to 30November 2022.

3. Input data of graduation work: Modernization of power supply systems of modern aircraft in order to increase its autonomy is a complex and multifaceted task that involves various technical and economic considerations. Functional cost analysis is a valuable tool for evaluating the relevance of such modernization efforts.

4. Content of explanatory notes: List of conditional terms and abbreviations, Introduction, Chapter 1, Chapter 2, Chapter 3, Chapter 4, References, Conclusions.

5. The list of mandatory graphic material: figures, charts, graphs.

6. Planned schedule

№	Task	Duration	Signature of supervisor
1.	Validate the rationale of graduate work theme	05.09.2022	
2.	Carry out a literature review	06.09.2022 – 20.09.2022	
3.	Develop the first chapter of diploma	21.09.2022 – 05.10.2022	
4.	Develop the second chapter of diploma	06.10.2022 – 20.10.2022	
5.	Develop the third chapter of diploma	21.10.2022 – 03.11.2022	
6.	Develop the fifth and fourth chapter of diploma	03.11.2022 – 10.11.2022	
7.	Tested for anti-plagiarism and obtaining a review of the diploma	15.11.2022	

7. Consultants individual chapters

Chapter	Consultant (Position, surname, name, patronymic)	Date, signature	
		Task issued	Task accepted
Labor protection			
Environmental protection			

8. Date of assignment: ‘___ ‘ ____________ 2023

Supervisor _______________ O.V. Kozhokhina

The task took to perform _______________ Karen Rukhkian

(signature) (surname, name, patronymic)

ABSTRACT

Explanatory notes to graduation work “Modernization of power supply systems of a modern medium-haul aircraft to increase its autonomy” contained 69 pages, 14 figures, 2 graph, 22 references.

Keywords:AIRCRAFT, BATTERY, FUNCTIONAL-COST ANALYSIS, NICKEL-CADMIUM, COST

Theobject of the research - process of finding waste in aircraft battery components.

The subject of the research - Nickel-Cadmium Aircraft Battery.

Purpose of graduation work – investigation of the problem of high cost of Nickel-Cadmium aircraft batteries.

Research Method – Methods of analysis, Morphological method, statistics theory, information theory, and expert judgment method were used to solve this goal.

Scientific novelty – proposed recommendations and methods of decreasing violation rates in maintenance and their effects on flight safety.

CONTENTS

LIST OF ABBREVIATIONS

FCA	Functional – Cost Analysis
FM	Functional Model
Ni-Cd	Nickel-Cadmium
EMI	Electromagnetic Interference
EMR	Electromagnetic Radiation
CF	Contributing Factor
CS	Cognitive science
FAA	Federal Aviation Administration
HF	Human Factor
HFACS	Human Factors Analysis and Classification System
MEDA	Maintenance Error Decision Aid
MRM	Maintenance Resource Manual
NASA	National Aeronautics And Space Administration

INTRODUCTION

Actuality. Upgrading the power supply systems could potentially increase the range and endurance of the aircraft. This is especially true for military drones, electric or hybrid-electric aircraft, and long-haul commercial flights.

Analysis of costs and benefits. A functional cost analysis helps to evaluate the costs associated with modernization against the benefits it provides in the form of increased autonomy. This includes not only the initial investment but also the ongoing operation and maintenance costs. Functional cost analysis can also help assess the risks associated with the upgrade, such as potential technical problems, delays or cost overruns.

Environmental Concerns: The aviation industry is under pressure to reduce greenhouse gas emissions. Modernizing power systems to make aircraft more efficient and environmentally friendly is highly relevant given the growing focus on sustainability.

Airlines and manufacturers that can offer aircraft with greater autonomy may have a competitive advantage in terms of route flexibility and operational efficiency.

Advances in battery technology, electric powertrains and power management make retrofitting more relevant and feasible than ever before. As environmental regulations become more stringent, upgrades may be required to meet standards and avoid fines.

Longer flight times without the need for refueling can improve operational efficiency, reduce downtime and increase profit opportunities.

In summary, upgrading the power systems of today's aircraft to increase autonomy is urgent and can have several benefits, including extended range, environmental compliance, and operational efficiency. However, a thorough functional cost analysis is essential to determine the feasibility and cost-effectiveness of such modernization efforts. This analysis must take into account a number of factors, including costs, benefits, risks and long-term consequences, in order to make informed decisions about whether and how to proceed with modernization.

Purpose of the workis to investigate the problem of human factors and violations in aircraft maintenance.

Following tasks should be done to achieve this purpose, the:

1. Analyze the existing studies in the field of human factor and violation in maintenance of aircraft.
2. Identify common problems of human factor in aircraft maintenance, as well as reasons of human violation occurrence.
3. To analyze existing effects of violation on aircraft maintenance and their investigation technique.
4. Develop recommendations to reduce the impact of violations during aircraft maintenance.

Theobject of the research - process of functioning of the aircraft maintenance technician.

The subject of the research–Nickel-Cadmium Aircraft Battery.

Research Method – Methods of analysis, Morphological method, ,statistics theory, information theory,

Scientific novelty – proposed recommendations and methods of decreasing violation rates in maintenance and their effects on flight safety.

Validation of obtain resultswas during the following conferences:

Kozhokhina O., Benko V., Violations and Their Elimination During Aircraft Maintenance. Scientific and Technical Conference "Проблемирозвиткуглобальноїсистемизв’язку, навігації, спостереженнятаорганізаціїповітряногоруху CMS/ATM": abstracts of reports of the scientific and technical conference 21-23 November 2018, Kyiv, Ukraine, National aviation university / editors: Kredentsar S., Herasimenko T. and others. – K.: NAU, 2019 – 84p.

CHAPTER 1
SUBSTANTIVE PROVISIONS AND DEFINITIONS

Be relative to new requirements process as a whole should be subordinated to requirements of an intensification of a social production and acceleration of scientific and technical progress, increase of efficiency and quality of work, it should promote manufacture of new style of thinking. preparation of the expert which office-work and business differs.

Working tool of the decision of these new tasks is FCA, directed on optimization of a ratio between quality and expenses - minimization of expenses for unit of useful effect. Expressing in such a way tasks of intensification and defining a way of their decision, FCA becomes means of formation of new technical and economic style of thinking.

Application FCA allows to lower the cost price of manufacturing of production due to economic material and labor expenses, a fixed capital of the enterprises are more effectively used, to improve technical and economic parameters of their industrial - economic activities

English economist V.L.Gejdzhem has given such definition FCA that shows is more convex one of the sides of a method.

« Functionally - worth the analysis is the concentrated attack to superfluous cost, first of all on that its part that is connected from an imperfect design ». FCA it is possible to consider and as one of moder methods of an intensification of rationalization and inventive work because with help FWA it is possible to increase a stream of rationalization and inventive decisions particularly on that site where they are especially necessary.

1.1 A history of an origin functionally - worth the analysis

FCA has more than a 70-years history. It has arisen simultaneously at the end of 40th years in the USSR and the USA.

Birth FCA and its development is closely connected to occurrence and improvement of methods of search of new technical decisions. FCA was bom as the response to needs of the industry in new technical decisions.

During the second world war because of lack of materials many products began to release from more accessible "substitutes". So our air builders have applied to manufacturing some detailspig-iron instead of bronze. In some cases on replacement to metal details came even wooden.

Similar work was conducted and abroad. In the USA in firm « General the electrician » after war have analyzed work of "substitutes" in different designs. The analysis has shown, that in everyone even well fulfilled design there are significant reserves. Transition to more accessible and cheap "substitutes" in the majority of designs has not worsened characteristics of machines and units. Details worked normally, and in some cases their reliability even has increased.

The analysis of quality of releasing products has been lead during war when the engineering specification was broken.

The analysis has shown, that from 100% of products:

- 60% conceded on quality;
- 25% appeared at the same level, as those products which engineering specifications was not broken;
- 15% have exceeded quality of those products which engineering specification was not broken.

So 40% of products appeared at a necessary level and is higher.

At 1947 the group of experts has been created led by L.D.Majlzam that was engaged in systematic reduction of expenses, being based on disclosing of reserves of a design. The method hasbeen thought up, which L.Majlz has named " Velus Analys and Engineering" (engineering - worth the analysis).

On L.Majizu, “ the analysis of cost ... is an organizational creative approach which purpose will consist in effective expression of unproductive expenses or expenses which do not provide neither qualities, nor benefit, neither durability, nor appearance, other requirements of the customer “

In 1949-1952 in the USSR J.M.Sobolev, the engineer of the Perm telephone factory; has published a number the robot in which has stated a method which has received the name" theEconomic analysis and on element processing a design "

Basis of a method have made an individual approach to each element of a design, division of these elements behind a principle of their functional applicability on two groups - the basic and auxiliary, a finding as a result of the analysis of new, more favorable constructive - technological decisions.

Application of a method on unit of fastening of microphone has allowed to reduce transfer of the applied details of a product to 70 %, charges of materials - to 42 %, labor input - on 69%. The cost price of unit of fastening of a microphone has decreased in 1,7 times.

1.2 Efficiency of application the functional - cost analysis

But to at us in the country, and in the USA and in the countries of the Western Europe all over again method FCA has not received support. As English economist A.Harris " At the majority of heads has noted at acquaintance with bases FCA the wrong impression is formed, that they use this method in the practice "

However, for the first 17 years of use FCA (with 1947 for 1964), behind the application of the head « General the electrician », the method has saved the companies of 200 million dollars. During the period with 1965 on 1968r. for each dollar spent on FCA « General the electrician » has received 25 dollars of economy. At this period of manufacturing the robot were reduced to 25 %.

Economic efficiency FCA has involved to it attention of suppliers « General the electrician » and its competitors. First they, and then and began to use other companies of different spheres FCA.

In 1959 the Community of the American engineers - experts on FCA has been organized. L.Majlz was the first president of this community. Till 1964 over 10 % of all firms of the American processed industry used this method. Now all industrially advanced countries apply FCA: in Europe, in Asia, but Japan nevertheless is in the lead. They began to use in 1953 right after the USA. Now 100% of export of products of Japan has passed FCA. It is hard to compete to them, because in their products high reliability and high quality.

Distribution of a method was promoted by its high efficiency. It is counted up, that each dollar spent for carrying out of the analysis, provides up to 10 dollars economy. In 1970 about 25% of industrial firms the USA used method FCA. The economy, is received due to a method, only the ministry of protection the USA in 1968 has exceeded 1 million dollars.

FCA read in 84 higher educational institutions in Germany. Average downturn of expenses of manufacturing of production with help FCA makes in independent firms - 35 %, at the enterprises of exact mechanics - 40 %, in machine-building firms - 30 %. On occasion's downturn of expenses reached 80-90 %.

In USSR FCA has received the greatest distribution to the electro technical industry. The general economic benefit from FCA for 1978-1983 80 million rubles.

However for a parameter of efficiency of works with FCA accept a parity of expenses for carrying out FCA and economy, it is provided due to use of this method. To expenses for carrying out FCA except for the expenses connected to the maintenance of research working group,designing, manufacturing and check of tools and technological equipment, recustomizing (including replacement) the equipment ietc carry as well expenses for introduction of recommendations FCA of object that includes expenses for development and registration of the design and technological documentation.

The parity of expenses and effect at carrying out FCA changes from 1:5 till 1:30 depending on qualification of experts which spend FCA, and also from a level of novelty and improvement of object of the analysis. Average value of efficiency answers usually 1:10. It is necessary to recognize that FCA "powerful" methods of increase of a production efficiency concern to number enough. On the published data, time spent on carrying out FCA, makes 1/4 or 1/5 times for the decision of problems in the traditional way or otherwise 100 hours FCA save 400-500 hours of usual work.

1.3 Objects of functional-cost analysis

The role of prudent manage grows presently, careful attitude toward all types of present resources, new technical-economic thought. Next to the study of new methods of manage, exactly in new terms of work to a full degree will be able to show up high efficiency of FCA - method of system research of object, directed on optimization of correlation between consumer properties of object and charges for it's development, production and use with the purpose of the combined cost cutting on unit of useful effect. In this determination FCA is the used notion of «object analysis». It is necessary to specify, what can be the object of analysis. Three basic groups of objects are given: wares, processes, structures.

In the group of objects of analysis «wares» usually include details, assembling units, machines and equipments, their complete sets and complexes, commodities of folk consumption, facilities of mechanization and automations and etc

To the group of objects of analysis «processes» usually include technological processes and after this sign as objects of analysis consider the technological equipment, rigging, instrument, actually technology as a sequence of executable operations and etc, and also processes of organization of management, production, labour and etc

To the group of objects of analysis «structure» can be delivered organizational structures of management of different levels (from a team to the ministry) see scheme (Pic.1). On this scheme the systematization of objects of FCA is given.

By means FCA it is possible: to complexly decide the task of construction technology; to conduct the analysis of functions of technological process with clarification of sequence and intercommunication of detailed operations; to expose the low indexes of the use of materials related to the unsuccessful structural-technological decisions; to explore a structure and technical state of general funds, to set the level of prosperity of quantity of workers and salary fund and etc Thus, orienting on the variety of objects of

FCA it is possible to speak about the high degree of universality of FCA. If to make an attempt shortly to define notion of object of analysis, it is possible to offer the following determination:

Any sphere of still human activity, that is accompanied by charges the size of which can be numerically estimated, can be an object of FCA.

Marking universality of FCA, in future we will concentrate only on one group of objects – wares.

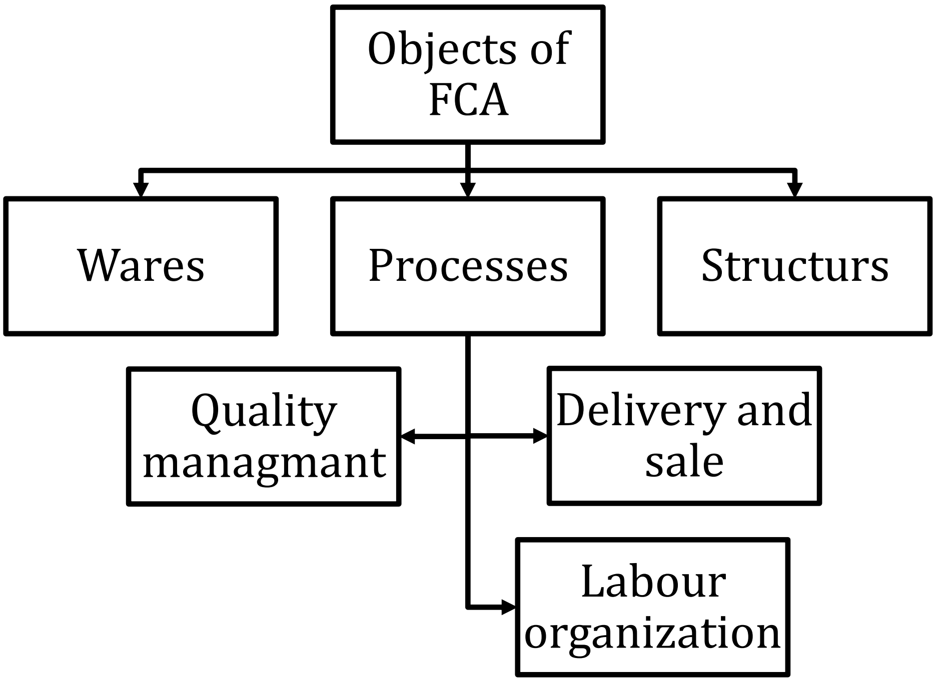


Fig. 1. Systematization of objects of FCA

Experience of conducting of FCA shows that practically in any mastered good there are spare charges because of imperfection of construction, conditioned by different reasons. FCA can be conducted on any good even repeatedly and give positive results on the cost cutting on it's production.

Two forms of FCA are distinguished:

-wares already producing with the purpose of modernization of their construction on the base of the use of alternative, more economic methods of realization of the set functions;

-on the stage of constructing of wares with the purpose of finding optimal variant of construction, that provides implementation by good of the set functions at minimum charges.

1.4. Principles of functional-cost analysis

FCA sometimes equate with the traditional technical-economic analysis, oriented on that both methods of analysis lean against technical-economic computations. However there are principle differences, that allow to consider FCA as a method, that has the independent scientific and practical value. We will consider the most important principles, that distinguish FCA from other methods of production efficiency:

I. National economy approach

II. System approach

III. Functional approach

IV. Cost approach - principle of accordance of meaningfulness (utility) of functions to the charges on their realization

V. Principle of collective creation.

National economy approach turns out in raising and decision of tasks important from national positions, unlike raising of tasks in the decision of which only separate collectives are interested (developers, manufacturers, users).

We may say, that National economy approach is folded in the necessity of determination of charges and results on to all stages of life cycle of good, that are definite by the spheres of public production and consumption, presented on a fig. 2.

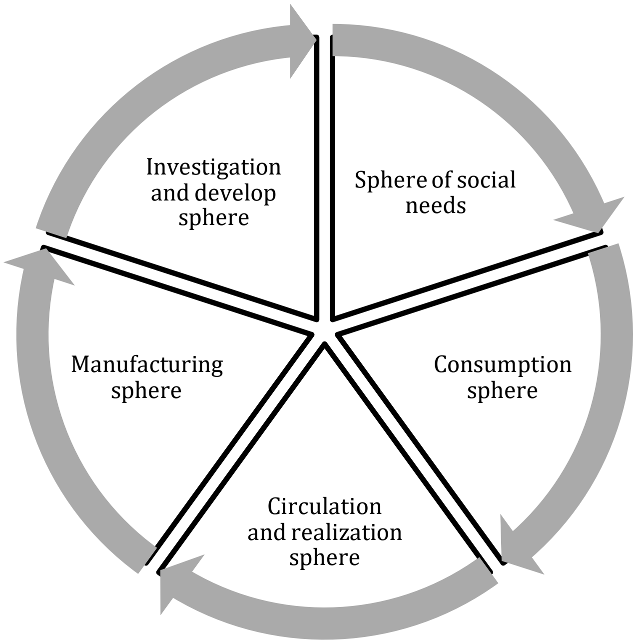


Fig. 2. Spheres of public production

The stages of life cycle of good are presented on Fig. 3.

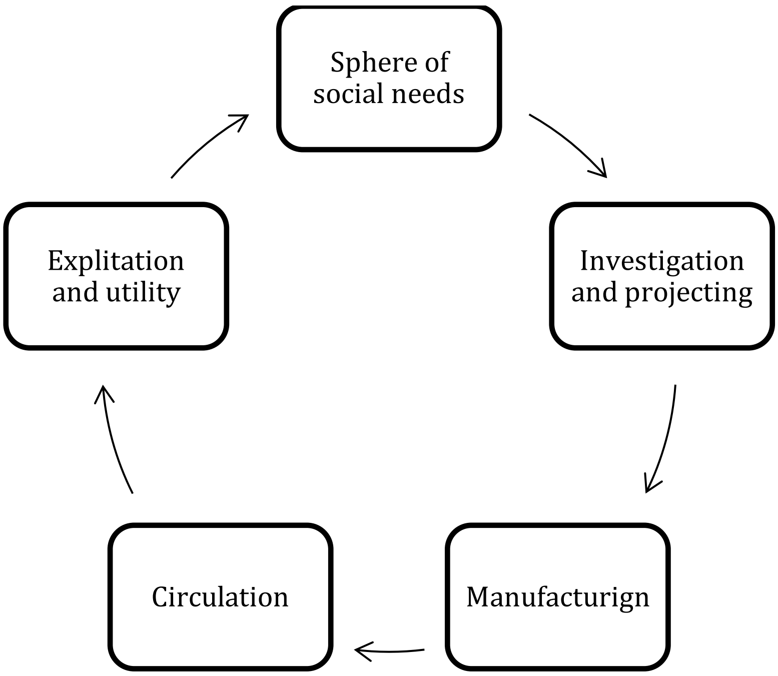


Fig. 3. Stages of life cycle of good

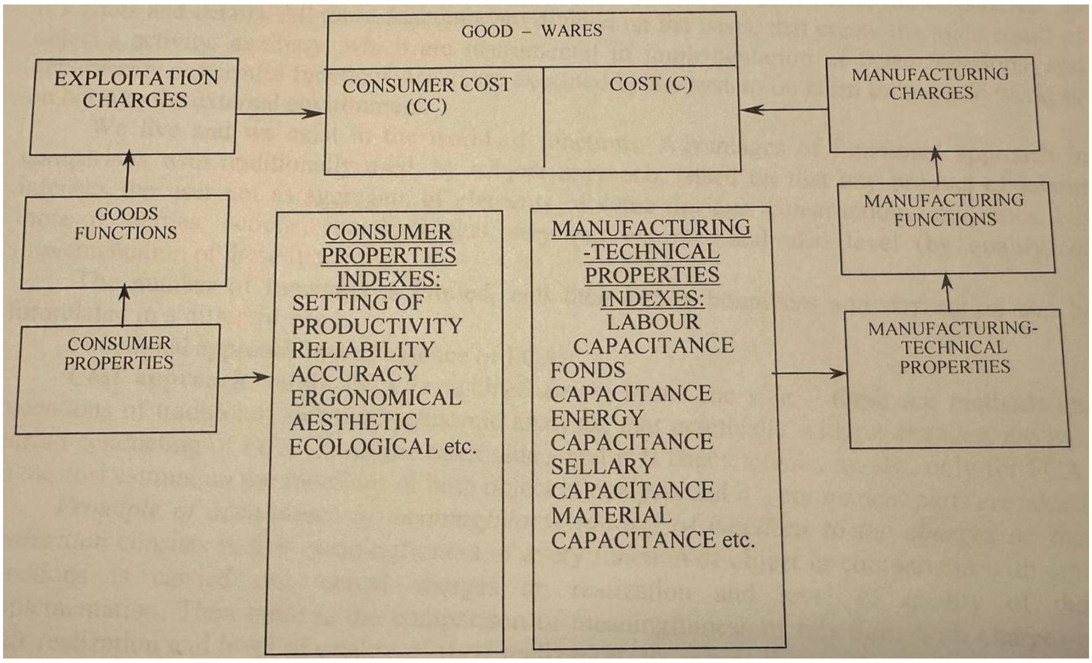
The most important characteristics, which machine-building products should have on to the stages of life cycle presented in table. 1.

Table.1

Stages	The most important characteristics of machine-building products
1 stage	- It must answer social needs; - Outstripping accordance or exceeding of the best world standards
2 stage	- It must exactly correspond 1 stage documentation; - Level of charges which appear at producing this good; - The level of charges must be socially needed level
3 stage	- Saving ability of wares – is the property, which allows to carry that level which was created on the 1 stage; - Competitiveness – is the ability to be sold at the concrete market in concrete terms
4 stage	- Functions, which a good from the point of user view has

Commodity, including also machine-building products, is the unity of consumer cost and cost (Fig.4).

The use of the given approach in practice means the following of principle: activity of every separate performer or collective useful in that degree, in which it is useful to all society, state; the technical or organizational decision confesses to advantageous, if the increase as a result of it's realization charges on one of stages of life cycle will decrease the sum of the combined charges.



(Пока так, схему потом сделаюномрально)

Fig. 4. Unity of consumer cost and cost

System approach assumes consideration of object analysis from one side, as a system, i.e. one whole, that is found from the aggregate of interdependent component parts, that are found in co-operation, and from other side - as an element (component part) of the system of higher order (over-system), at which the analyzed object is found in co-operation and in the mutual relations with other component parts of over-system.

The use of system approach during conducting of the FCA objects is related to that optimization of correlation of quality-expends of separate element of the system can not be produced isolated from other components of the analyzed system. Such kind of optimization necessarily must take into account that influence, which it makes on the state of other components of the given system, and as a result also on the state of the system of higher level (over-system). We may say, that system approach -is an organizing mean in realization of all basic directions of rise of efficiency of production. It connects a technique and economy, optimizing correlation between consumer properties of good and charges on their display; all articles of life cycle of good - research, development of construction, preparation and organization of manufacturing, exploitation; co-ordination of developers, performers and users of a new technique. In addition, by means of FCA, it is possible to co-ordinate the work of separate people inside one subsection, and also groups of people in workshops inside an enterprise, union.

Thus, the result of conducting of FCA must be more effective technical-economic equilibrium of the considered object as the system.

Functional approach assumes consideration of object of analysis as aggregates of executed functions. Functional approach at all importance and necessity of other principles (approaches) is determining in the method of FCA, because practically, all analysis of object isconducted in relation to it's functions, considered from different positions of their meaningfulness, place and form of display and etc

It's essence consists in that functions executed by an object as a whole are considered, by it's knots and details. All these functions are divided on the basis, that create the main result of object's activity, auxiliary, which are instrumental in implementation of basic functions, and unnecessary or harmful functions which are executed by the system on harm to its basic work, or on harm to the external environment.

We live and we exist in the world of functions. Advantages of functional approach in comparison with traditionally used, by subject approach, based on that any product of labor interests the user not as aggregate of elements of some devices, constructions, machines, but those properties, actions, functions, that they can execute, and also level (by quality) of implementation of these functions.

The number of functions is limited, and their use is boundless and any action can be formulated in a different way.

Functional approach makes essence of FCA.

Cost approach within FCA is realized twice. From one side - these are methods and receptions of traditional technical-economic analysis, that practically without changes, are used during conducting of FCA. From the other side - and it is characteristic, maybe, only for FCA - to the cost estimation the functions of both object of analysis and it's component parts are added.

Principle of accordance of meaningfulness (utility) of functions to the charges on their realization consists in that meaningfulness of every function of object in comparison with other functions is carried out, actual charges on realization and level of quality of their implementation. Then there is the comparison of meaningfulness of functions with charges on their realization and level of quality of their realization. By means this methodical reception the original economic diagnosis of that or other technical decision is carried out, expedience of present or offered structure of object is analyzed.

Principle of collective creation, used during conducting of FCA, turns out in two interdependent forms.

The display of the first form is conditioned to those, that at FCA knowledge of many scientific disciplines is needed, including techniques, economies, management etc. Therefore it is conducted by the group of specialists of different professions, that allows to execute research from different positions thanks to the synthesis of knowledge and experience of employees, well acquainted with constructing, technology, economy,management,organization ofmanufacturing, setting of norms, knowing the material, delivery, sale, exploitation and other processes related to creation, production and the functioning of analyzed object.

The second form of the considered principle is used for the search of new and more progressive) variants of realization of functions of the analyzed object. Practical realization of this form is connected to the use of methods and receptions of technical creation (concerning to the objects-wares), the aggregate of which can be considered as modern technology of planning of original technical ideas and decisions. Within the framework of this technology such effective methods as morphological analysis, algorithm of decision of engineering tasks, functional-physical method of constructing, brainstorming and others find application.

The search of alternative variants of implementation of functions is the necessary member of FCA method, it's feature.

The quite universal character of the method is another distinguishing feature of FCA. The most important notions of the method equally can be used for estimation of various objects, that creates favorable terms for the wide use of FCA practically in all environments of national economy, for the decision of any technical, organizational and economic tasks.

1.5 Stages of functional cost analysis

To carry out a functional-cost analysis, a special methodology or work plan is developed by the research working group. which implements the most important principles of FCA and includes a number of steels.

In the regulatory documents of different countries, a different number of steps of the work plan is indicated. These are the stages:

- preparatory;
- informative;
- analytical;
- creative;
- research;
- recommendation;
- implemented.

1.5.1 Preparatory stage

At the preparatory stage, specialists are trained, a research working group is formed, an object of analysis is selected, research goals and analysis tasks are determined.

Analysis methodology can be studied in two directions:

- the analysis of product design research options is carried out within the framework of the existing principle scheme of the product, i.e. when upgrading products that are in production;
- when designing and manufacturing a new product.

Practice shows that FVA is most effective in cases where it is used at all stages of designing and manufacturing products, starting from the stage of sketch design and ending with the stage of serial production of products. The greatest costs arise in the production of the product due to the imperfection of its design.

The enterprise usually produces several products and there is a question about the priority implementation of FCA. In such cases, it is recommended to choose products according to the specific weight of its own value in the cost price of all products, taking into account the perspective of the production of the product in the coming years.

The subject of analysis can be individual nodes and sub-nodes of the product, especially if this product has a complex design. Cost is also a criterion for selection in these cases.

ABC analysis method is often used to identify primary objects of analysis. According to it, the elements of the product (assemblies, subassemblies and parts) are grouped into three groups: group A - expensive; group B - medium cost; group C - cheap. Usually, first of all, the elements of group A are subject to FCA.

At the preparatory stage, a group of specialists is formed to conduct the FCA. The most effective are the groups consisting of specialists from the FCA and other services - designers, technologists, specialists in the supply and sale of products and some others. An order is drawn up to carry out the FCA of the selected object, the sources of costs are determined, and the goal that needs to be achieved in the process of the FCA is established.

After the formation of goals, the tasks of the analysis are specified

Table 1

Costs	**Quality**
∨	Unchanged
Unchanged	∧
∧	∧∧
∨	∧
∨∨	∨

In the table 1 arrows show directions of changes in indicators; double arrows indicate a significant change in the indicator.

Thus, a far from complete list of problems solved with the help ofFCA can be presented in the following way:

- achieving the best ratio between the consumption value of the object and the costs of its unloading;
- reducing the cost of manufactured products and improving quality;

- reduction of operating and transport costs;
- reduction of material intensity, labor intensity, energy intensity and capital intensity ofthe object;
- increasing labor productivity;
- replacement of scarce, expensive and imported materials;
- reduction or elimination of shortage;
- elimination of bottlenecks and disparities.

At the preparatory stage, formal and informal relations are also linked under the conditions of the existing organizational structure.

One of the main tasks of the leader of the research working group at the preparatory stage is the psychological mobilization of the group's team, concentration and adjustment of the group to overcome the problems that arise in the research process.

The preparatory step is considered completed if:

- an order on the creation of a research working group was approved (signed);
- the object of analysis is selected;
- issued requests to accomplices;
- the regulations of the work of the research working group were agreed and adopted;
- the minimum limit has been reached in the training of members of the research group.

1.5.2 Information stage

The main tasks of the information stage are the collection, systematization and comprehensive study of the information of the FCA object. This stage is often called the foundation of FVA, because the success of the following stages of the functional-cost analysis largely depends on the completeness and reliability of the information collected, the correctness of its processing and study.

The collection of information begins with technical documentation: drawings, specifications, technological conditions, descriptions, technological 1 rationing maps, instructions, special requirements, etc. Information about the operation of the product is also collected from consumers and according to laboratory studies and examinations. Appropriate standards are being prepared, information on the latest materials, technological processes and progressive design solutions in the field of research on similar products is being collected.

Valuable information necessary for analysis is selected, costs are calculated not only for the product, but also for its individual components and parts.

At the information stage, a structural model of the object is built, in which the interrelationships of its elements are revealed; an element-by-element economic analysis of the design and technology is performed; conditions of use of the object are investigated, patent information is studied. At this stage, the primary detection and formation of functions, construction of a functional model is carried out.

The stage is considered completed if the following results are obtained as a result of the work performed:

- structural and cost models;
- functional models;
- proposals of members of the research working group;
- abstract.

1.5.3 Analytical stage

The analytical stage involves a deeper study of the object and establishment of connections between elements, as well as between the object and the environment, taking into account the specific conditions of its application.

The analytical stage involves identifying the functions of the object of analysis as a system, as well as the functions of its elements (component parts), analysis and classification of the identified functions, construction of functional and functional-structural models of the object, assessment and comparative analysis of the significance of

functions and costs for their implementation, assessment of the level using the functions of the object and its elements.
From the point of view of difficulties and execution time, this standard takes more time in the FCA cycle. The main thing is to correctly formulate questions and tasks. The success of the analysis often depends on their clarity. It is believed that the effectiveness of the FCA is directly proportional to the quality of conducting the analytical table.
Any design has hidden reserves, but it is not easy to find and formulate them. Usually, a number of options are developed for the improvement or creation of this or that node or part. Unfortunately, there are currently almost no objective criteria for assessing the generalized level of products. The designer most often works intuitively.
Application of the FCA method significantly changes the case. The method seems to prepare the product, allows you to reveal the unknown and find out how optimal the relationship between technical requirements and technical level, costs and consumer qualities of the product and its constituent parts is; shows how fully the structure fulfills its functional purpose.
And this is very important for the developer. Having received such information, the designer can immediately outline the correct direction of work. In other words, the method allows you to move from intuitive actions to controlled actions.
At the analytical stage, areas of concentration of excess functional costs in relation to material media (for example, nodes, parts) and identification of tasks for the search for technical and organizational solutions for the implementation of functions are revealed.
At the analytical stage, a quantitative relationship between the costs of implementing the functions performed by the product and their satisfaction with consumer properties determined by the customer is revealed.
The work at the analytical stage can be considered completed after the selection of functional areas and elements of the object subject to improvement. A list of adjusted requirements for the object is also drawn up, tasks for the creative stage are formed.

1.5.4 Creative stage

At this stage, FVAs identify as many ideas as possible for the implementation of the established functions, discuss and select the most salient of these ideas. The main content of the creative stage is a creative search for alternative options for the implementation of the function.

Often, specialists reject many useful ideas and options for solving problems, guided by the tactics of ignoring innovations.

The reasons for this relationship may be:

- reluctance to deviate from generally accepted, usual approaches to problem solving;
- fear of risk;
- reluctance to criticize;
- excessive confidence in the infallibility of past experience;
- fear of rejecting decisions that were previously considered the only correct ones,
- the desire to protect oneself from the possible consequences of wrong decisions, etc.

In order to eliminate or reduce the influence of subjective factors on the creative process, it is necessary that work on creative steel is carried out in the form of meetings. Meetings should be held according to a complex plan in advance, regulated in time, and have a creative, business character. Participants of the meetings, members of the research working group and specialists involved in its work have the right to express any ideas and suggestions regarding the improvement of the design, manufacturing technology, and organization of production.

One of the mandatory principles underlying the work of the research working group is respect for any idea, opinion and proposal expressed by the participants of the work. Their service should be of a business nature.

At creative steel, as a result of collective creative discussion, the main function of the product is defined and formed. After that, it is possible to move to putting forward as many ideas as possible for the technical solution of the problems formulated at the analytical stage, and developing, based on them, alternative options for the implementation of the main function, proposals for the modernization of the product.

Work at the creative stage is considered complete if several options for technical solutions are selected from the point of view of economic feasibility, preliminary design and technological development and selection of the most likely option from the point of view of its implementation. Ideas in the form of a list, options for solutions in the form of sketches with short explanations and calculations can be provided to specialists for a more thorough study of the implementation of layouts and working drawings.

1.5.5 Stages: exploratory, recommended, implemented

The research stage is an organic continuation of the creative stage. Its main goal is to find the most effective options for solutions, which after appropriate consideration can be presented as proposals - recommendations of the FCA.

When evaluating this or that idea, it is necessary to take into account its economic efficiency, the availability of resources necessary for its implementation, design, technological capabilities, and production capabilities.

The work at this stage is considered completed after all options for solving this problem have been considered and those that meet technical capabilities and are economically feasible have been selected.

As a result of the research stage, the number of alternative solutions to the problems identified in the FCA process is significantly reduced.

The purpose of the recommendation stage is the final selection of one of the alternative options for each of the problems to be solved.

The choice of the best option must be approved by the management of the enterprise; at the same time, the conclusions of the interested services and divisions are taken into account. The result of the work of this stage is the development of a plan-schedule for the implementation of the FCA recommendations.

The implementation of the recommendations of the FCA is practically no different from the existing system of implementing measures to improve the technical level of production products.

The work of the FCA working group on this product is considered complete after the transfer of the approved recommendations to the relevant services, which, according to the schedule, must ensure their implementation.

The described scheme of carrying out FCA, by stages, allows you to comprehensively and consistently consider the problem of reducing the production costs of any specific product in all aspects - design, technology, production, supply.

1.6 Causes of excessive costs

Experience shows that in the manufacture of almost any product, excess costs occur due to design imperfections due to various reasons. What are the causes of excess costs? At the stage of research and development works, it is a choice of non-economic ideas and solutions, which, although they ensure the implementation of the specified requirements, do not take into account the real amount of costs. At the stage of design and technological preparation of production - this is the wrong choice of materials, technical processes, equipment, excessive requirements for tolerances, dimensions, for the processing of details, as well as the wrong choice of the form of production organization. In the production process itself, costs arise due to inconsistencies in the work of various production units, undersupply of necessary materials and components, violations of production, technological and labor discipline. Even at the stage of delivery of products to the consumer, losses occur due to improper transportation of goods, improper packaging, violation of installation conditions, lack of completeness of product deliveries, etc. All the mentioned disadvantages lead to excessive costs. Each type of expenditure has objective and subjective reasons. FSA allows you to identify the sources of these unnecessary costs, reduce them to a minimum or completely eliminate them.

CHAPTER 2
NICKEL-CADMIUM AIRCRAFT BATTAREY

To consider not only the initial cost, but also the maintenance, replacement and disposal costs of a lead acid battery compared to a nickel-cadmium battery, there are several key aspects to consider:

Battery Life: Nickel-cadmium batteries generally have a longer life than acid batteries. This means that lead acid batteries may require more frequent replacement.

Maintenance Costs: Lead acid batteries require regular maintenance, including checking electrolyte levels and cleaning contacts, which can increase operating costs.

Disposal: Nickel-cadmium batteries require special disposal due to the heavy metals they contain, which can be more costly than acid-acid batteries.

Reliability and performance: Nickel-cadmium batteries provide more stable power and perform better under extreme conditions, which can reduce the cost of unexpected repairs or equipment replacement.

In my work we will consider Nickel-Cadmium batteries.

Fig 5 Examples of NiCad Batteries

2.1 The Nickel-Cadmium Cell

Aircraft engines, particularly turbines, require extremely high current for starting. High rate discharges of lead-acid batteries causes their output voltage to fall, due to the increased internal resistance caused by the build-up of sulphate deposits. This drawback led to the development of the alkaline cell for aircraft use.

The nickel-cadmium, or ni-cad, battery has a very distinct advantage in that its internal resistance is very low. Its output voltage, therefore, remains almost constant until it is nearly totally discharged. The low resistance also allows high charging rates without damage.

The ni-cad cell has positive plates made from powdered nickel which is fused, or sintered, to a porous nickel mesh. The mesh is then impregnated with nickel hydroxide.

The negative plates are of the same construction but are impregnated with cadmium hydroxide.

Separators of nylon and cellophane, in the form of a continuous strip wound between the plates, keeps the plates from touching each other. Cellophane is used because it has low electrical resistivity and also acts as a gas barrier preventing oxygen, given off at the positive plates during overcharge, from passing to the negative plates. If the oxygen were allowed to reach the negative plates it would combine with active cadmium, reduce cell voltage and produce heat as a result of chemical reaction.

The cell construction is shown in Figure 5, where the complete plate group is mounted in a sealed plastic container.

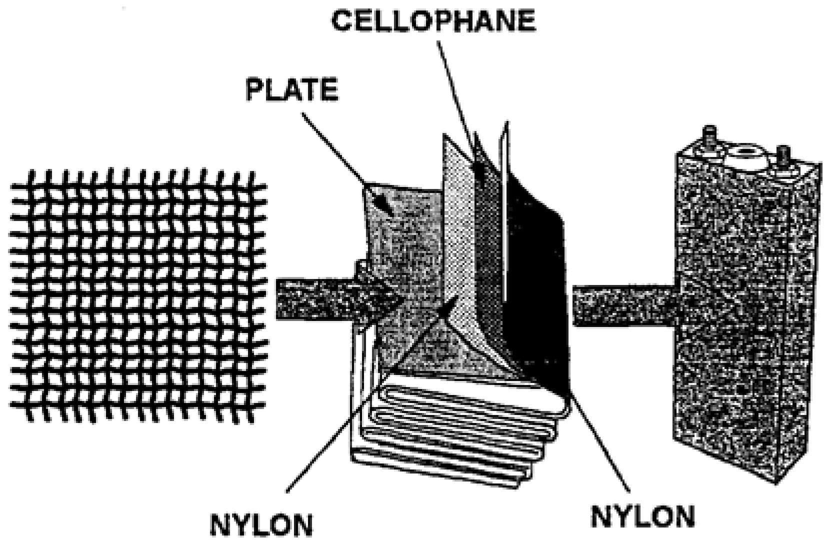


Fig. 5 Nickel-Cadmium Cell Construction

The electrolyte is an alkaline solution of potassium hydroxide and distilled or de-ionized water with a specific gravity of 1.24 to 1.30.

The specific gravity of the electrolyte does not change during charge or discharge so it cannot be used to indicate the state of charge.

The electrolyte does not play an active part in the chemical reaction and is used only to provide a path for current flow.

During charging of the cell an exchange of ions takes place. Oxygen is removed from the negative plates and added to the positive plates, the electrolyte acting as an ionized conductor. The positive plates are, therefore, brought to a higher state of oxidation.

When the cell is fully charged all the oxygen is driven out of the negative plates, leaving only metallic cadmium, and the positive plates are highly oxidized nickel hydroxide.

The electrolyte is forced out of both sets of plates during charging so that the electrolyte level in the cell rises. The electrolyte level is, therefore, only checked and any water added when the cell is fully charged.

Towards the end of the charging process and during overcharging, gassing occurs as a result of electrolysis. This only reduces the water content of the electrolyte.

During discharge the chemical action is reversed. The positive plates gradually lose oxygen to become less oxidized and the negative plates regain lost oxygen and change to cadmium hydroxide.

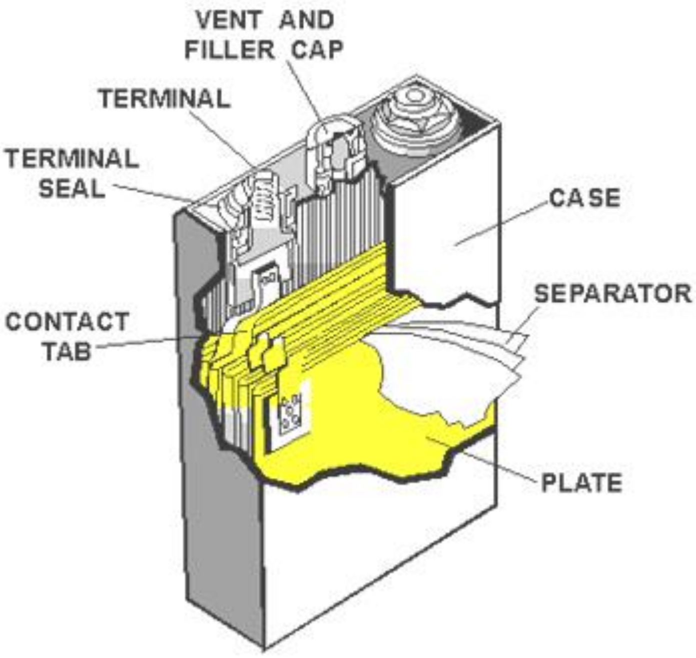


Fig 6 Nickel-cadmium cell

The plates absorb electrolyte so that the level in the cell falls but it should always cover the top of the plates. The charge and discharge levels are shown in Figure 7.

The discharge and charging cycle of a ni-cad cell produces high temperatures which, if not correctly monitored, can break down the cellophane gas barrier. This creates a short circuit allowing current flow to increase. More heat is produced, causing further break down. The condition is aggravated by the internal resistance of the cell falling as the temperature rises.

Fig. 7 Nickel-Cadmium cell electrolyte levels

These factors all contribute to a process known as “thermal runaway”, which ultimately results in the destruction of the cell.

The ni-cad electrolyte would be contaminated, and its specific gravity reduced if it were to be exposed to the carbon dioxide in the air. The atmosphere must, therefore, be kept out of a ni-cad cell. Three basic types of ni-cad cell are, therefore, produced:

a)The sealed type where the cell is completely sealed, as used in small capacity batteries.

b)The semi-sealed type where the cell is almost fully sealed but has a safety pressure valve.

c)The semi-open type which has a non-return valve, allowing the cell to gas yet preventing the electrolyte from being contaminated by the air. This type is used in the main aircraft battery.

The individual ni-cad cell produces an open circuit voltage of between 1.55 and 1.80 volts, depending on the manufacturer.

Although the nickel-cadmium battery has become the preferred type in today’s aircraft, there are also the nickel-iron and silver-zinc types of alkaline cell. Silver-zinc rechargeable

batteries have been used in the space programme, where size and weight factors greatly outweigh initial cost.
The capacity of each cell is added together to obtain the total capacity. In effect the area of the plates has been increased. The voltage, on the other hand, does not increase.

2.2 Saft Batteries

Each Saft nickel-cadmium battery consists of a metallic box, usually stainless steel, plastic-coated steel, painted steel or titanium, containing a number of individual cells. These cells are connected in series to obtain a specified voltage, usually 12 or 24 volts nominal. Individual cells are enclosed in a polyamide container that provides insulation, allowing them to be fitted side-by-side in the battery box. Interconnection of cells is via rigid, highly conductive, nickel-plated copper links. Each link is held in place by nickel-plated copper nuts on the cells terminals (or nickel-plated steel screws for internally threaded termi-nals). Inside the battery box, individual cells are held in place by partitions, liners and spacers, and acover assembly. Each battery is designed with appropriateventilation to allow the escape of gases produced during an overcharge condition and to provide cooling during normal operation.

Fig. 8 SAFT Nickel-Cadmium Aircraft Battery

The 24V battery is made up of 20 cells connected in series, which are assembled in a battery case. The battery container and the lid are typically made of stainless steel. Some battery types have a container of stainless steel and a lid of polymer material. The interior container walls are lined with heat resistant plastic plates. The lid is lined with a ribbing, which acts as a pressure pad for the cells. The electrical connector typically is mounted on the front of the battery container; but on some battery types the electrical connector is mounted at the side. It enables electrical connection of the battery to the power supply system. All batteries can be additionally fitted with heater and temperature sensors or temperature sensors only.

Each Saft battery is connected to the aircraft by either a standard main power connector, such as an MS3509 type, or a special connector as specified by the aircraft manufacturer.

Fig. 9 Connectors of SAFT Aircraft Battery

The recommended temperature range is + 20 °C +15 °C (68 °F +27 °F). However, occasional excursion into the range of -60 °C to +60 °C (-76 °F to +140 °F) is permitted.

long term storage

The storage life is 10 years, if using the following conditions:

Sealed packaging.

Temperature: + 20 °C ‡ 15 °C (68 °F + 27 °F).

Humidity: < 70 %.

Normal vertical position.

Isolated from detrimental agents: dirt, dust, humidity, vibration, corrosive atmosphere.

Lead batteries must not be stored in the same room.

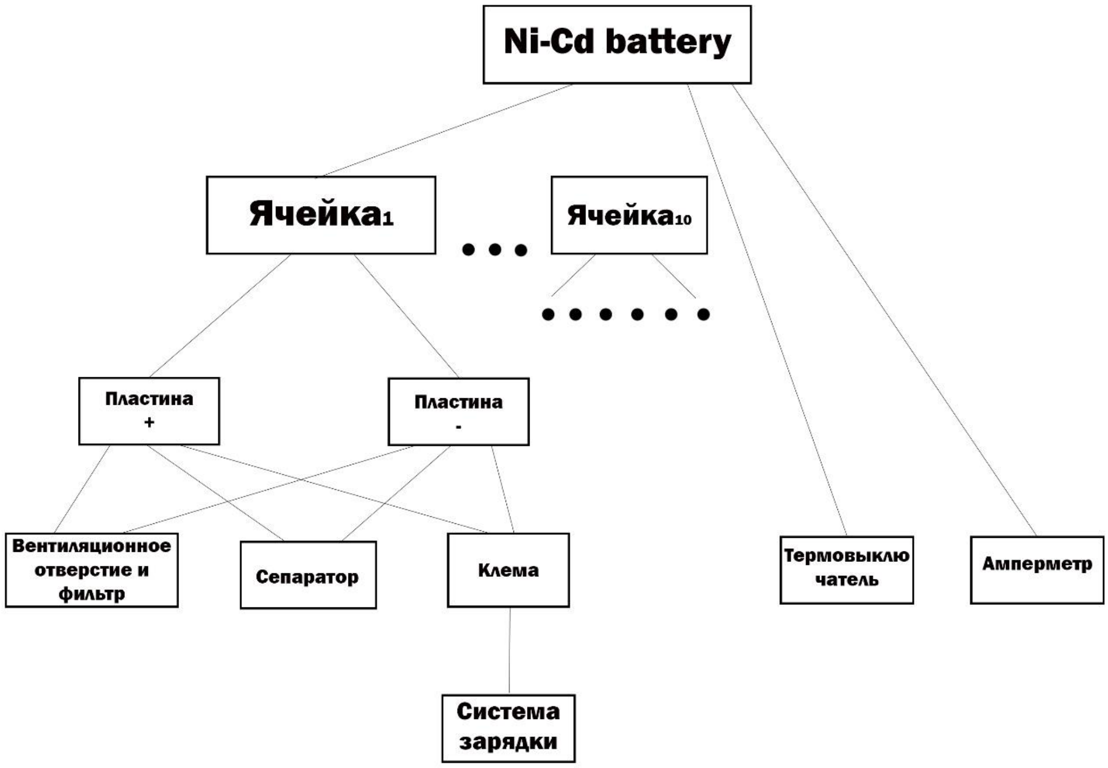
Saft Ni-Cd batteries may be stored in temperatures ranging from -55 °C (-67 *F) to +60 °C (+140 °F) for short periods of time without harming the battery.

The standard cardboard packaging is considered unsealed and allows 2 years of storage under the above conditions.

So the battery is charged after being serviced then stored fully charged in a dedicated room in such a way that it can be installed in the A/C without further check. Charge retention depends on the ambient temperature in which the battery is stored and the duration of the storage .

CHAPTER 3
APPLICATION OF FCA ON BATTERIE

The totality of all material carriers of functions in the product (parts, assembly units, sets, etc.) is the material structure of the object. Its reflection is the structural model of the product (CM), which can be graphically depicted as a graph (strictly hierarchical), where the nodes of the graph are details, component units, and the connections between the nodes give an idea of how the material elements of the product fit into each other.



Structure model

The totality of all functions of an object and their interrelation represent its functional structure. A representation of the functional structure of an object is a functional model (FM), which is usually depicted as a hierarchical graph, where its nodes are functions, and the connections between them are connections between functions. On the first level of FM, external (general object) functions are located: main F1 and secondary F2. Internal (intra-object) functions are located at the second level and further - the main ones (F1.1, F1.2, F1.3, F1.4), which ensure the implementation of the main function.

The secondary function F2 is not directly related to the functional purpose of the object, so it has no functions at the basic level.

Starting from the third level of FM, auxiliary functions are located (F1.1.1, F1.1.2 .., F1.4.3, ..., F2.1.2)... The number of FM levels of an object depends on its complexity and can be large.

After the construction of FM, the analysis of functions begins. Exact mathematical methods of function analysis have not been developed to date, so expert evaluations are used.

For each FM level separately, a group of ekeperts determines the significance of functions r, (sequentially by FM levels, starting from the first).

The starting point in determining the importance of the main and secondary functions (F1, F2) is the distribution of consumer requirements (quality, parameters, properties) from the point of view of their necessity.

Those functions that satisfy the most important requirements of the consumer are of great importance. When determining the significance of the functions for each level of the normalizing FM, there is a requirement

(formula) =1

where: K is the number of functions located on the same level of FM included in the general node above the standing level; r, - the significance of the j-th function belonging to the i-th FM level.

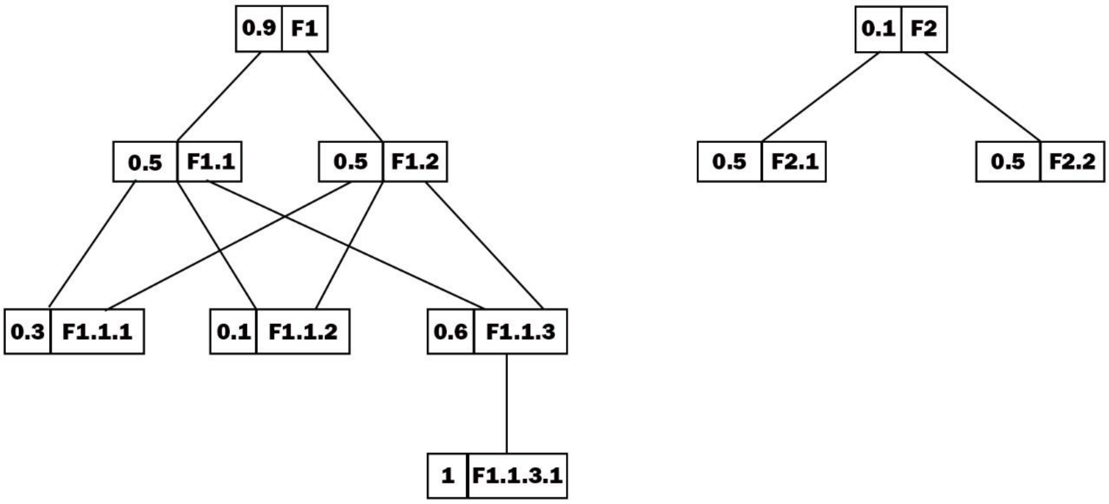
For the functions of the next level of FM, the determination of significance is made based on their role in providing functions of a higher level.

Along with the assessment of the importance of the functions in relation to the nearest higher one, the indicator of the relative importance of the functions of any i-th (R) level in relation to the product as a whole is determined.

(formula) R=P*r

where G is the number of functional model levels

In the event that one function simultaneously participates in the implementation of several functions of the upper level of the model, its significance is determined for each of the higher functions separately, and the relative importance for the product as a whole is the sum of the values for each branch (from the i-th level to the I- tho)



Functional model

F 1.1.1 – Plate separation
F 1.1.2 – Filtration and release of gases
F 1.1.3 – Supplying current to the plate +
F 1.1.3.1 – Supply current to terminal
F 1.2.1 – Plate separation
F 1.2.2 - Filtration and release of gases
F 1.2.3 - Supplying current to the plate –
F 1.1.3.1 – Supply current to terminal
F 2.1 – Temperature control
F 2.2 – Current measurement

F1.1.2 = 0.1 * 0.5 * 0.9 + 0.1 * 0.5 * 0.9 = 0.09
F1.1.1 = 0.3 * 0.5 * 0.9 + 0.3 * 0.5 * 0.9 = 0.27
F1.1.3 = 0.6 * 0.5 * 0.9 + 0.3 * 0.5 * 0.9 = 0.54

F1.1 = 0.5 * 0.9 = 0.45
F1.2 = 0.5 * 0.9 = 0.45
F2.1 = 0.5 * 0.1 = 0.05
F2.2 = 0.5 * 0.1 = 0.05
F1.1.3.4 = 1 * 0.6 * 0.5 * 0.9 + 1 * 0.6 * 0.5 * 0.9 = 0.54
F1=0.9
F2=0.1

Then, knowing the costs of manufacturing each node, part, it is possible to present the structure of costs for the product as a whole.
The combination of SM and FM makes it possible to build another model - the functional-structural model (FSM). This model reflects the relationship between the functions of the object and the material carriers of these functions in the product, and also allows you to estimate the costs incurred by each function (S). FSM is depicted in matrix form (Table 1)

Table 1

	F 1								F 2	
	F 1.1				F 1.2				F 2.1	F 2.1
	F 1.1.1	F 1.1.2	F 1.1.3		F 1.2.1	F 1.2.2	F 1.2.3			
				F 1.1.3.1				F 1.2.3.2		
Separator	+				+					
Filter and vent		+				+				
Terminal			+				+			
Charging system				+				+		
Temperature Sensors									+	
Ammeter										+

$8,621.44 – batterycostSAFT 410946 Model 2758 Nickel-Cadmium Aircraft Battery

Table 2

	Properties	**Cost**	**Weight**

Cells	The basic building blocks of the battery, Ni-Cad cells consist of nickel (Ni) and cadmium (Cd) electrodes submerged in an alkaline electrolyte, usually potassium hydroxide (KOH). Each cell generates a certain voltage, and multiple cells are connected in series to achieve the desired battery voltage	The majority of the battery's cost, possibly ranging from $50 to $200+ per cell depending on capacity and quality. https://www.made-in-china.com/products-search/hot-china-products/Nickel_Cadmium_Battery_Price.html	Each cell might weigh between 0.5 to 2 kg, depending on capacity.
Electrolyte	This is a potassium hydroxide solution in water. It facilitates the movement of ions between the nickel and cadmium electrodes during charging and discharging	Relatively low, possibly a few dollars per liter	Might range from 0.5 to 2 kg for the entire battery, depending on the number of cells
Separator	This is a non-conductive material placed between the positive and negative electrodes (nickel and cadmium, respectively) to prevent short circuits while allowing ionic transfer	Low, possibly a few cents to a dollar per separator	Very light, negligible in terms of overall weight
Case and Cover	The cells and electrolyte are enclosed in a durable case, typically made of steel or plastic, which is designed to withstand the rigors of aviation use	Can vary, possibly $20 to $100, depending on material and size	Could be 1 to 5 kg, depending on construction and size
Terminals	These provide the connection points for the battery to the aircraft's electrical system	Relatively low, possibly $5 to $20	Light, perhaps a few hundred grams
Venting System	Ni-Cad batteries can produce gases during charging and discharging. A venting system is essential to safely release these gases and prevent pressure build-up	Low, possibly under $10	Negligible, a few grams to a hundred grams
Temperature Sensors (if present)	In some advanced designs, temperature sensors are included to monitor the battery's temperature, providing essential data for safe operation	Moderate, possibly $10 to $50	Very light, negligible in overall weight
Safety Valves	These are designed to release excess pressure if it builds up inside the battery, thereby preventing potential damage or hazards	Moderate, possibly $5 to $30	Light, a few grams to a hundred grams

Inter-Cell Connectors	These connect the individual cells in series or parallel configurations to achieve the desired voltage and capacity	Low to moderate, possibly $1 to $5 per connector	Moderate, a few hundred grams to a kilogram in total
Charge Control Circuitry (if present)	In more sophisticated battery systems, there may be integrated circuitry to control and monitor the charging process to optimize battery life and performance	Can be significant, possibly $50 to $200	Light, usually under a kilogram
Positive Nickel electrodeplate		From 4 to 15 $	
Negative Cadmium electrode plate		From 4 to 15 $	

Batterycase– 2000 $
Caseofeachcell – 50 $
Electrolyte - 200 $

8200-2000-(50*20)-200=4400 $

Cell (ячейка) – 125 $
125*20=2500$
2500/4400=x/100
X=2500*100/4400=56%

Separator (сепаратор) – 1 $
1*20=20 $
0.23 %

Terminals(клема) – 20 $
20*20=400 $
9.1 %

Venting System (вент система) – 25 $
25*20=500 $
11.3 %

Temperature Sensors (термовыключатель) – 50 $
1.1 %

Safety Valves (амперметр) – 30 $
0.68 %

Charge Control Circuitry(система зарядки)– 200$
4.5 %

Positive Nickel electrode plate(пластина+) – 10 $
10*20=200 $
2.3 %
Negative Cadmium electrode plate(пластина-) – 10 $
10*20=200$
2.3 %

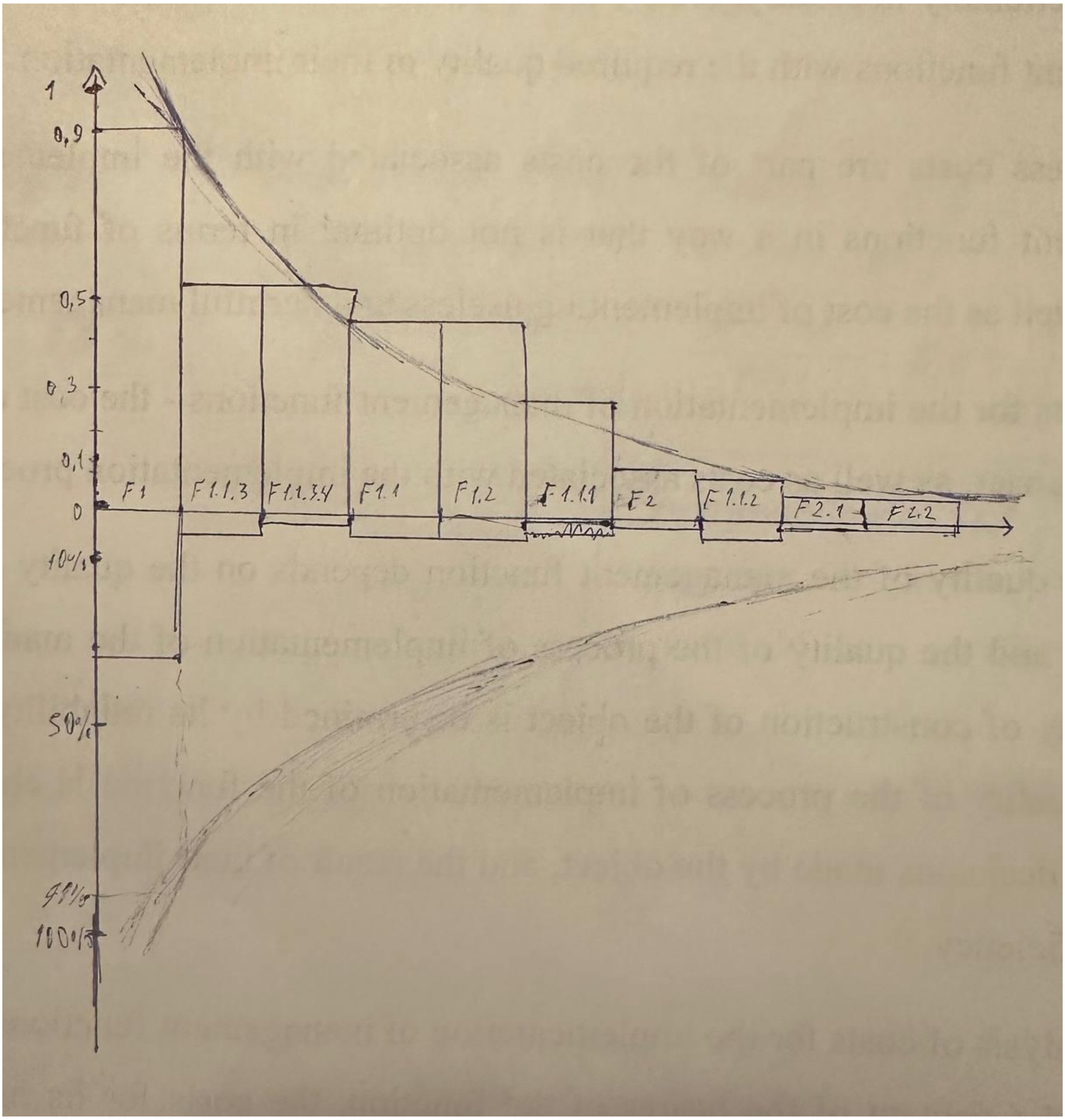
Now it is possible to determine the degree of conformity of costs by function and its relative importance for the product as a whole (R). This is done with the help of a function-cost diagram (FVD), where the distribution of functions by importance is shown in the upper part, and in the lower part - by costs for each of them (in relative shares, for example, from the total costs of the product)

According to FCA, it is possible to determine the zones of imbalance in the product, that is, those nodes (parts) where there is a discrepancy between the importance of the performed functions and the costs of their implementation. Fig. follows

(formula)

Thus, "bottlenecks" in the product are established and the task is to find such an alternative implementation of the same function (F) in order to bring the cost of the function into line with its significance, i.e.

(formula)



Functional cost diagram

CONCLUSION

LIST OF REFERENCES

1. Functional cost analysis: lecture notes. - K.: NAU, 2001. - 44 p.
2. Safety behaviors: human factors for engineers [Electronic resource]. – 2013. – Access mode: https://www.casa.gov.au/sites/default/files/_assets/main/lib100215/hf-engineers-res.pdf/(lastaccess:31.05.20). – Title from the screen.
3. Industrial–Organizational Psychology: Science and Practice [Electronic resource]. – 2015. – Access mode: https://www.sciencedirect.com/science/article/pii/B9780080970868220072/(lastaccess:30.05.20). – Title from the screen.

4. What Is Industrial Engineering? [Electronic resource]. – 2014. – Access mode: https://www.livescience.com/48250-industrial-engineering.html/(lastaccess:30.05.20). – Title from the screen.
5. Clinical psychology [Electronic resource]. – 2011. – Access mode: https://www.britannica.com/science/clinical-psychology/(lastaccess:30.05.20). – Title from the screen.
6. What is Experimental Psychology? [Electronic resource]. – 2020. – Access mode: https://www.bestmastersinpsychology.com/faq/what-is-experimental-psychology/(lastaccess:22.05.20). – Title from the screen.
7. Jordi Goldstein-Fuchs National Kidney Foundation Primer on Kidney Diseases / D. JordiGoldstein-FuchsAmyFrancesLaPierre ; National Kidney Foundation. – Philadelphia : Published by National Kidney Foundation, 2014. – 664 p.– Bibliogr.: p. 467-475.
8. J. Clarkson Product Experience / J. Clarkson ; University of Cambridge. – UK : Published by University of Cambridge, 2008. – 668 p.– Bibliogr.: p. 165-198.
9. A Quick Guide on Safety Engineering [Electronic resource]. – 2018. – Access mode: https://www.ehsinsight.com/blog/a-quick-guide-on-safety-engineering
10.