MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL UNIVERSITY «ZAPORIZHZHIA POLYTECHNIC»

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BASIC ERGONOMICS IN AUTOMOTIVE ENGINEERING

Study guide

Zaporizhzhia • NATIONAL UNIVERSITY
«ZAPORIZHZHIA POLYTECHNIC»• 2023

UDC 629.3.022(075.8)
B-29

Recommended for publication by the Academic Council of the National University «Zaporizhzhia Polytechnic» (Signed. No. 3 from 6.11.2023)

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B-29 Basic ergonomics in automotive engineering : Study guide / O.M. Artyukh, K.A. Lut, M.O. Kuzmina et al. Zaporizhzhia : National University «Zaporizhzhia Polytechnic», 2023. – 160 pp.
ISBN 978-617-529-428-4

The study guide aims to help students majoring in 133 Industrial Engineering gain theoretical knowledge that provides a systematic approach to vehicle design. It covers essential aspects, including ergonomic, aesthetic, and social factors. Additionally, the handbook aims to familiarize students with the fundamentals of technical aesthetics and the challenges associated with incorporating artistic design methods into industrial production. Furthermore, it prepares future engineers to collaborate effectively with automotive designers.

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ISBN 978-617-529-428-4

CONTENTS

INTRODUCTION

The course ‘Fundamentals of Ergonomics’ introduces students majoring in engineering and technology to the basic ergonomic standards concerning rational consideration of the «human factor» in the design and construction of transport vehicles.

Its purpose is to create the most effective and reliable control systems and working conditions, which correspond to people's abilities and help maintain their constant productivity and health.

Specific points and common issues of the course are covered in one lecture, allowing the combination of two or even three topics on the same subject matter. Such an arrangement of lecture topics demonstrates the opportunities for the practical application of ergonomics and design to solve production tasks in various process schemes.

The lecture course ‘Fundamentals of Ergonomics’ is created to help students gain theoretical knowledge; it ensures a systematic approach in vehicle design, taking into account ergonomic, aesthetic, and social factors. It is also intended to introduce students to the basics of technical aesthetics, problems related to the application of artistic design methods in industrial production, and to prepare future engineers for cooperative work with automobile designers.

The authors of the course consider these issues especially significant because, in modern conditions, a future engineer must be ready to work in any field, even if it is not within the scope of their diploma qualification.

Upon completion of the course ‘Fundamentals of Ergonomics’, students should **know**:

- The meaning of the design of automobiles and the role the shape plays in the actual process of designing a car or a tractor.
- The basic principles of ergonomics, the system «human-machine-environment», and the fundamental principles of designing the driver's workplace and passenger areas.
- Basics of vehicle aerodynamics.
- General principles of passive safety.
- Methods of fixation of the car body and cabin surfaces.

Students must be **able** to:

- Critically analyze the design of an automobile.

- Design the driver's workplace and passenger compartment of the vehicles.
- Find design solutions that ensure comfort and passive safety of a car and a tractor.
- Carry out basic measurements of the car body surface.

Students must acquire **skills** in:

- Analyzing the ergonomics of structural and component solutions of cars and tractors.
- Evaluate the safety and comfort of component solutions.

The material in this handbook provides students with the necessary information for each section of the curriculum of the course ‘Fundamentals of Ergonomics’, allowing students to reach the required level of knowledge, practical skills, and abilities.

The book is based on the published manual «Fundamentals of Ergonomics: a textbook / O. M. Artyukh, O. V. Dudarenko, V. V. Kuzmin and others. Zaporizhzhia: National University of Zaporizhzhia Polytechnic, 2021. - 168 p.»

All chapters of this study guide were authored by the university teachers of NU «Zaporizhzhia Polytechnic» Artyukh O.M., Kuzmin V.V., Dudarenko O.V., Shcherbina A.V., Kuzmina M.O., while primary responsibilities for translating its text material and editing was done by Kateryna A. Lut, Associate Professor at the Department of Foreign Philology and Translation of NU «Zaporizhzhia Polytechnic».

1 INTRODUCTION TO THE COURSE «FUNDAMENTALS OF ERGONOMICS»

1.1 Emergence of Ergonomics

Automobiles and tractors are created for people. This simple phrase actually defines the objectives of ergonomics and design in relation to these machines.

Ergonomics (comes from Greek words *ergon* – work and *nomos* - law) is a science about fitting equipment and working conditions to people. It studies the peculiarities of people and their functional capabilities in the process of work with the aim to create optimal conditions for high productivity and safety.

Ergonomics as science emerged relatively recently, only a few decades ago, but the foundations of ergonomic knowledge were laid in that period of human history when the first pieces of equipment produced by people appeared. At that time people began to evaluate these tools by the simplest criterion - «comfortable - uncomfortable».

The main task of ergonomics is to increase the reliability of the functioning of human-machine systems. The statistics of technogenic accidents show that the most reliable element of such systems is people (so-called «human factor»). One of the most urgent problems is the problem of matching the design of the machine in that part, which is associated with people, with the psychological and physiological characteristics of people.

Ergonomics is a complex science; it is based on physiology, biology, medicine, psychology, biomechanics, industrial hygiene, neurophysiology, anthropometry, and other human sciences. In this book, taking into account the addition of ergonomics to certain industrial products, we will be interested, first of all, in anthropometry, engineering psychology, and haptics.

1.2 Branches of Ergonomics

Anthropometry studies the size and shape of the human body and its components, examines the range of motion of body parts and muscular strength. It is a part of the general science of humanity, i.e., anthropology. Without knowledge of basic anthropometric characteristics, it is impossible to correctly position automobile or tractor control parts.

Engineering psychology examines the general and specific patterns of information interaction processes between people and technology. It is the basis, in particular, for the construction of the control panel and ways of presenting information on it.

Haptics studies the interaction of people's hands with various handles, buttons, switches, and other elements of machines, devices, and, other industrial products.

1.3 Design and its Relation to Ergonomics

The other important term is *design*. **Design** (comes from English meaning *plan, project, drawing*) – is a term that denotes various kinds of constructive activities, intending to form the aesthetic and functional qualities of the object environment. In a narrow sense, design is the purpose of artistic construction (a type of artistic activity, design of industrial products, which have aesthetic properties).

A designer is a specialist who not only develops an artistic image of a product but also conducts the artistic design. The activities of various specialists who take part in the development of the product design can be divided into two categories – technical design and heuristic activity.

Technical design is usually understood as work (calculating, layout, graphical, drawing, etc.) based on an algorithm, a programmed scheme, standards, norms, and rules. The result of such work manifest itself in the ergonomic properties of a car and a tractor.

Heuristic activity is mainly based on technical erudition, on a system of logical methods and methodological rules. The activity of an inventor can be considered heuristic. Designer's work occupies an intermediate position between these two types of creative activity. Technical aesthetics makes the ideological basis of design.

If the artist is engaged only in the creation of the artistic image of the product, he or she is more of a design artist or a graphic artist, and in most cases the product having external attractiveness does not possess the necessary ergonomic qualities. The design departments of industrial enterprises and firms involved in the production of motor vehicles and tractors most frequently belong to the Chief Designer's office.

1.4 Ergonomics and Design as Professional Activities

Both ergonomics and design as a kind of professional activity can be considered in different aspects: social, technical, economical, and aesthetic.

The social aspect takes into account the society's actual demand for transport vehicles (cars and vans, buses) and various working machines (agricultural, forestry, industrial, and many other tractors).

The technical aspect deals with comfortable seating, easy entry-exit, accessibility of controls and optimum forces on them, good visibility, and many other things. An indispensable condition of the high level of structural and design engineering of the machine is its maintainability with possibly longer intervals between these maintenance operations.

The economic aspect is twofold. Firstly, it is manifested in its cost-effectiveness (and price) in the sphere of car manufacturing. Secondly, the economy can be observed in the sphere of operation. Operating costs consist of the cost of operating materials, primarily fuel, and the cost of maintenance. It is obvious that when you improve the air shape (aerodynamics) of a car or a road train, fuel consumption will fall. A designer can influence this process by creating an appropriate body shape.

Efficient municipal bus interior design reduces the time of entry-exit of passengers, i.e. its dwell time, increases the average speed of the bus, and reduces the cost of transportation per one passenger. The same effect can be achieved by a reasonable increase in bus capacity.

The aesthetic aspect makes a car or a tractor competitive and attractive for a potential buyer. However, aesthetic properties are not limited to these features.

Automobiles in many ways shape the look of modern cities, greatly influence the rural landscape (high-speed roads, pipelines, bridges). The impact of tractors is less evident, as they are used in areas devoid of crowds, and their impact on the development of society is measured by the results of their work: tilled fields, built roads, etc.

It is not an exaggeration to say that an automobile is a trendsetter. However, fashion also has an influence on automobiles. This interdependence between fashion and automobiles belongs to social factors.

This lecture course is devoted to the basics of car and tractor ergonomics. But it is necessary to understand that car ergonomics is intricately connected with car design; as a result, these two directions of technology creators' activity require profound study.

The main task of the course «Fundamentals of Ergonomics» is to give a construction engineer and a designer an understanding of the general ideology of the interior space of the car body and cabin, taking into account anthropometric characteristics, comfortable, safe interaction of people and machine, and minimization of the influence of negative factors.

This lecture course also covers the basics of the aerodynamics of an automobile and a tractor, general principles of ensuring structural safety, methods of designing the external forms of bodies and cabins, and their interior; the system «driver - vehicle - road - environment» is also presented..

The material of this course is explained gradually, in compliance with the curriculum, but any section, in the case of interest to a particular topic, can also be studied independently, when deemed necessary.

Test yourself

1. What is Ergonomics?
2. Why did Ergonomics emerge?
3. What is the focus of Ergonomics?
4. Which tasks does Ergonomics solve?
5. What is the scientific and technical significance of the «Fundamentals of Ergonomics» course of lectures for students of technical universities?
6. How do ergonomics and design affect the automotive engineering?
7. What are the main aspects of Ergonomics as a type of professional activity?

2 ORIGINS AND DEVELOPMENT OF ERGONOMICS

2.1 Engineering Psychology and Haptics – Their Origins, Subjects, and Content

The term ‘ergonomics’ (from Greek: ergon - work, nomos - law) means ‘the law of work’. Wojciech Jastrzębowski, who first proposed it in 1857, intended it to be the science of work based on the laws of natural science.

V.N. Myasishchev used the same meaning in the concept of «ergology» and V.M. Bekhterev incorporated it into the science of ‘ergonomics’. The authors of the projects of these new (even for the 1920s) scientific disciplines emphasized that labor activity was not studied comprehensively by any of the existing sciences and did not fit into the framework of any existing subject, despite its extreme importance.

The term 'ergonomics' was finally defined in England in 1949 and has since become widespread throughout the world. A similar field of knowledge in the United States is referred to as 'human factors'.

Ergonomics is a comprehensive science that emerged at the intersection of engineering, psychology, physiology, hygiene, anatomy, biomechanics, anthropology, and biophysics. It encompasses engineering psychology and anthropometry and is concerned with addressing physiological and hygienic requirements for tools, workplaces, and production facilities.

Over many centuries, tools have evolved and improved, altering the dynamics of interaction between humans and technology. However, until the beginning of the 21st century, human functions in relation to technology remained fundamentally unchanged, relying primarily on muscular strength to control technology.

Such work demanded complex motor skills, considerable physical strength, high coordination, coherence, and dexterity.

Matching man and machine was largely limited to considering the anatomical and physiological characteristics of individuals and the corresponding requirements for the machinery being used or serviced. The following factors were taken into account, for example: the external shape of the tools, the impact of work on the body, etc.

In the early twentieth century, new types of labor activities such as driving a car, locomotive, airplane, etc., emerged, necessitating the consideration of not only anthropometric and physiological qualities of individuals, but also, and primarily, their psychological qualities (e.g., reaction speed, memory and attention peculiarities, emotional attitude, etc.).

The changing nature of the interaction between humans and technology led to the development of a new scientific discipline - occupational psychology. It studies the psychological characteristics of human labor activity and the development of professionally significant qualities to enhance labor productivity. Human labor activity began to be studied both in the field of physiology and labor psychology.

The continued advancement of technology led to serious contradictions in the mid-20th century between the requirements of rapidly evolving production and its material and technical foundation, which, at a certain point, impeded further progress in manufacturing.

This served as a driving force behind the modern scientific and technological revolution. At the heart of this revolution lies the widespread implementation of automated control systems (ACS), as well as the extensive mechanization and automation of production processes. Consequently, modern machine operation entails more mental rather than physical stress.

They are associated with the need to process larger volumes of information and make complex decisions. As technology advances, human capabilities expand, but technology also becomes increasingly intricate, making it challenging to manage effectively.

The task of harmonizing machine designs with human psychological and physiological characteristics becomes crucial. Regardless of how perfect a machine is, its efficient use ultimately relies on the actions of the people operating it. Therefore, it becomes necessary to study both machine operation and the activities of operators within a single human-machine system (HMS).

The problem of interaction between humans and modern technology (the human-machine problem) has become one of the main problems of modern science. This issues encompasses various aspects, with one of the most significant being the study of information interaction processes between humans and technical devices.

Engineering psychology is the scientific discipline that investigates the objective patterns of these information interaction processes between humans and technology, aiming to apply them in the practice of designing, creating, and operating an HMS.

Engineering psychology considers human activity and machine functioning as interconnected entities, emphasizing the leading role of humans. It is impossible to understand the human-machine relationship correctly without considering a person as a subject and a machine as a tool. Any machine and technical device are created solely for facilitating the labor process and are meant to be used by humans.

As an independent science, engineering psychology started to take shape in the 1940s. Its development as a science has gone through a number of stages – from collecting and analyzing data on the human factor to optimizing individual technical control and management methods, to adopting a systematic approach to the design and operation of complex human-machine systems.

Changes in the nature of labor activities have posed new challenges in human-technology interaction. While technology has expanded human capabilities, it has also become so complex that humans find it difficult to fully control.

2.2 Main Tasks of Engineering Psychology

The main tasks of engineering psychology can be broadly defined into two interconnected groups:

As a **psychological science**, engineering psychology studies mental processes and human characteristics. It aims to determine the specific requirements for technical devices that arise from the characteristics of the human body. In this capacity, it solves the problem of adapting equipment and working conditions to suit human needs.

As a **technical science**, engineering psychology investigates the design of control posts and panels, car cabs, processes and algorithms of their functioning to find out what requirements they impose on the psychophysiological characteristics of the driver, i.e. design principles considering psychological and physiological characteristics of the driver. As a result, the task of adapting a person to technology and working conditions is accomplished.

2.3 Goals and Objectives of Haptics

Haptics, an applied discipline of ergonomics, focuses on the problem of ensuring the shape of elements and tools (associated with human hand movements) complies with convenience requirements.

Systems and controls are selected based on a thorough analysis of technical and economic requirements, taking into account the type of operations they perform. There are three main control systems: manual, mixed, and automatic.

Controls are further subdivided as follows:

- On/Off Controls: buttons, pedals, handles, levers, etc.
- Switching Controls: These involves handles for various step shifts, rotary handwheels for smooth shifts, twin and compound handwheels, and handwheels for multi-step shifts from 180 to 360°.
- Controls: This category comprises handwheels and steering wheels for mechanical control, mnemonic handles, buttons, verniers for electrical, hydraulic, and pneumatic control. In some cases, they are also referred to as on/off controls.
- Emergency Action Controls mainly coincide in the form with the On/Off Controls, but they are quickly triggered as a result of pushing away or down, pressing with the palm, etc.

2.4 Haptic Requirements for Vehicle Controls

Controls must meet the following haptic requirements:

- They should be easy to manipulate.
- The movement of the control must align with the driver's orientation concerning the control.
- The placement should prevent any mutual interference with the control.
- Controls should facilitate the optimization of the applied force.
- They should ensure the highest reliability, even in unexpected directions of movement.
- Controls should be designed to prevent any impact that could cause injury to the driver's hands and feet.
- If there are multiple identical controls, they should be easily distinguishable to avoid errors in their operation.

To facilitate operation, reduce errors, and minimize the time needed to locate the appropriate controls, it is recommended to code controls using various attributes such as shape, size, method of operation, color, and labeling.

Color coding can be highly effective in combination with other methods. Recommend colors for coding are red, orange, yellow, green, and blue. **Green** is used for On controls, while **red** is used for Off controls.

Various types of controls are found on the dashboard, including buttons, keys, toggle switches, knobs, levers, and selector switches. The shape of the control knobs depends on the nature and mode of operation, the driver's psychophysiological and anthropometric characteristics, and the total number of controls.

For buttons located next to each other, an optimal width is 12.5-18 mm is recommended. The distance between the edges of adjacent buttons should not exceed 5 mm (with the optimal distance being ¾ of the button width).

Groups of buttons should be spaced at a distance of 200 mm. Frequently used buttons require a pressing force of 140-600 g, while rarely used ones may need a force of 600 to 1200 g.

The depth of the recess for buttons should vary. For frequently used buttons, a depth of 3-5 mm is suitable, while for rarely used ones, a depth of 6 to 12 mm is recommended.

Toggle switches must meet the following requirements:

- The diameter of the toggle switch handle should range from 3 to 12 mm, and the length of the lever arm (handle) should be between 12 to 25 mm.
- The distance between the toggle switches in a horizontal position should be at least 18 mm.
- For a two-position toggle switch, when moving from one position to another, the center line of the lever should move by at least 60°, and for a three-position switch it should move by at least 40°;
- When toggle switches are located horizontally, a turn to the right should always indicate 'On' or 'More', and a turn to the left should indicate 'Off' or 'Less'.

Leverages, handles, and pedals must withstand a resistance of 1-2 kg, or 25% of the maximum force. The distance between the near edges of adjacent selector switch handles, if they are used simultaneously, must be at least 75 mm. When using only one hand, the distance should be at least 25 mm.

The positions of the switches are secured with clamps, and the maximum spacing of the clamps is 45°. The layout and design of controls involve the proper relative positioning of all types of equipment and its external design.

It requires taking into account psychophysiological, hygienic and aesthetic requirements. With the introduction of automation, the rational placement of a large number of monitoring and remote control devices becomes crucial.

Fig. 2.1 illustrates correct and incorrect layouts of control systems and the constructive use of buttons and toggle switches. Fig. 2.2 shows examples of handle shapes in accordance with haptic requirements. The design of display equipment is carried out taking into account visual, auditory and other indicators, the number of which increases with technology development.

Fig. 2.3 provides two variants of handles for a hand-held mechanized tool that requires the operator to apply additional forces «forward» and «down» during operation. It is evident that the handle shown in Fig. 2.3a, is much better than the one in Fig. 2.3b.

The former is more comfortable to grip, there is no unnecessary local pressure on the hand on the edges of the handle, and it is easier to apply a downward force. Thus, this handle is preferable..

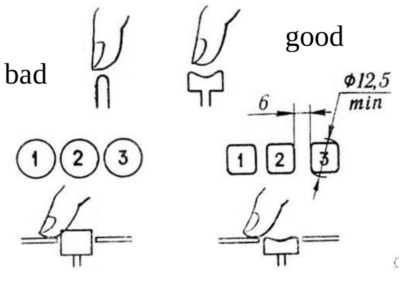


Fig. 2.1. Examples of button design

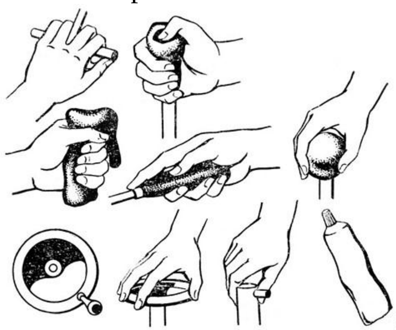


Fig. 2.2. Handle design according to haptic requirements

2.5 Ways to Grip Control Arms

Hand parameters are essential anthropometric characteristics. Let us consider some of the key features of the human hand that are crucial in the design of controls and operating tools.

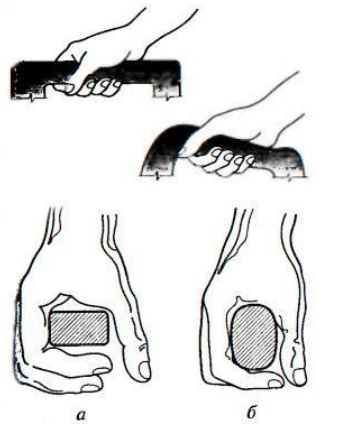
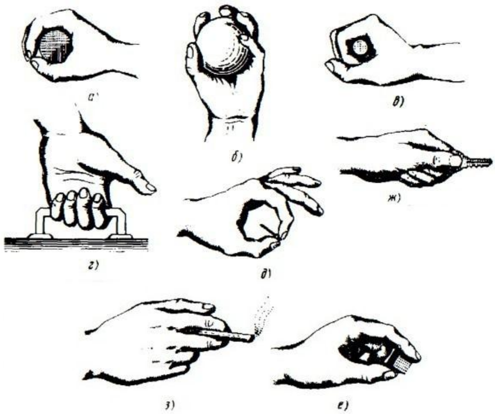


Fig. 2.3. Examples of handles for hand tools



a - cylindrical, b - spherical,
c - fist grip, d - hook grip,
e – pinch grip, f - palmar, g - key, h - between-the-fingers grip

Fig. 2.4. Types of grasps

Many work movements are performed by manipulating the hand and require a certain spatial position of the hand relative to the body. It should be noted that the mobility of the hand and fingers differs slightly between men and women: the range of motion in hand joints is on average 4-6° greater in women than in men.

Hand movements can be classified into grasping and non-grasping movements. In grasping movements, the handle, object, or part of it is held in a certain position by fingers or palm.

In non-gripping movements, the fingers or palm come into contact with the object, and force is applied in the direction of the object. Such movements are common when working on a typewriter or computer keyboard, playing volleyball, or controlling an object by pressing buttons or keys.

There are many ways of gripping, and the choice is often made involuntarily and depends on the shape of the specific object the person is dealing with at the moment.

Types of gripping can be divided into power and precision. The former can transmit considerable force, while the latter should ensure that the position of the object is as accurate as possible. In addition, grips can be classified based on the predominant area of the palm that interacts with the object.

Some ways to grip objects (handles) are shown in Fig. 2.4.

2.6 Grasps

Cylindrical grip (Fig. 2.4, a) is formed by the entire surface of the palm and fingers, with the thumb opposing the others. Depending on the diameter of the object to be gripped, the thumb may or may not touch the middle or index finger. It is used when gripping large handles, such as a shovel handle, ax, or baseball bat.

Spherical grip (Fig. 2.4, b) is used when interacting with objects like the gear lever of a car or tractor. Depending on the diameter of the sphere, the hand can touch it with the inside of the fingers or with the palmar side.

Fist grip (Fig. 2.4, c) is similar to the cylindrical grip, but is used when the diameter of the object is relatively small. The thumb is on the back of the other fingers.

Hook grip (Fig. 2.4, d) is used when applying a pulling force to a handle, such as a parking brake lever or a tractor's onboard friction. It is formed by the inside of the fingers. The thumb may not be involved in the grip or may be «backed up» by the others.

A similar grip is used when driving a car or tractor using the steering wheel with the hands at the top of the wheel. The grip can be passive, for example, when carrying a heavy object with a handle.

2.7 Pinch grips

Pinch grip (Fig. 2.4, e) is formed by the tips of the thumbs and index or middle fingers when grasping a small object, such as a needle. It is sometimes called a pincer grip.

Palmar grip (from the Latin palmaris - palm, Fig. 2.4, f) is used to hold a pencil, a small rotary control knob. The thumb is opposed to the other two fingers, usually the index and middle fingers, touching them with the inner side of the terminal phalanx. With a slightly changed position of the middle finger, this grip can also be used to pick up a pinch of salt, for example.

Lateral grips:

Key grip (Fig. 2.4, g) is used for objects with flat surfaces and small thickness, which are grasped between the lateral surface of the index finger and the thumb. It is a typical grip for holding a key when turning it in a lock, hence the name.

Between-the-fingers grip is well known to smokers, for example, when holding a cigarette.

The maximum forces that can be applied to an object or handle vary significantly with different grips. For example, the average values of the compression force of a hand dynamometer in men are 386...455 N, in women - 230-280 N..

Some manual car and tractor controls are characterized by combined handles, which, in addition to the handle, have an element that allows you to block its movement or, conversely, unblock it. This is, for example, the handle of a car parking brake lever. When pressed, its lever is released, and the car is «off the brakes».

Handles of this kind, found on motorcycles for clutch and brake control, are also typical of tools such as sharp-toothed pliers, regular pliers, and many others.

In these cases, the parts of the handle are not parallel to each other, but positioned at a certain angle, and the distance between them can vary. The maximum squeezing force of the handles also changes: as the grip width increases, it first increases and then decreases.

It is very important to choose the right shape for a tool or control handle. It should allow for the closest possible contact with the hand, enabling greater accuracy of movement for the associated tool or control. Local overloads, i.e., unnecessarily high pressures between the elements of the hand and the handle, must be avoided.

In addition to the abovementioned, **specific requirements for the handles** of car and tractor controls, as well as for the handles of tools used in their maintenance, need to be formulated:

- The handle must have a rough texture to increase friction and prevent the hand from slipping, even if the hand is dirty, for example, with grease.
- The surface of the handle should not be shiny to avoid glare from reflected light.
- The handle should feel «warm» to the touch and have low thermal conductivity.
- The surface of the handle should not stain hands, it should be resistant to the action of operating fluids used in cars and tractors. It should be easy to clean from dirt.

- The material of the handles should not cause allergic reactions.

Test yourself

1. Who first coined the term «ergonomics»?
2. What was the reason for the emergence of Engineering Psychology?
3. When was engineering psychology formed as an independent science and what are the main tasks it solves?
4. What is haptics?
5. What are the haptic requirements for the controls?
6. Name the main types of grips.
7. What are the haptic requirements of toggle switches and buttons of devices?
8. What are the haptic requirements to the handles of car and tractor controls?

3 ANTHROPOMETRY AND VEHICLES

3.1 Basics of Anthropometry

Every person knows from personal experience that all people differ in height, bodily constitution, posture, or size of body parts. Each person is unique; it is almost impossible to find two identical individuals. Therefore, a designer who creates cars or tractors faces a difficult task.

The designer must create comfortable seats for the driver and passengers to suit people of any height and body proportions, or at least for an average person. To that end, numerous factors concerning body dimensions must be considered. It affects the reliability of functioning of the whole system «human-machine-environment», i.e., safety on the streets and roads.

Anthropometry (from Greek *anthropos* – human and *metreo* – measure), is the science that studies physical measures of a human body and its parts. Since all people are different, anthropometry uses statistical methods to analyze data. The size of a human body and its parts are defined by anthropometric characteristics (AC).

Anthropometry is a system of examining methods (special measurements) of human body structure, including body measurements, range of motion of different body parts, and muscle strength. Anthropometric data are taken into account while designing various products to increase the comfort of their use.

Anthropometric characteristics are values measured in linear, angular, or weight units, which correspond to the size and weight characteristics of human body parts and their mutual positioning. Anthropometric characteristics include, among others, the height of a person, head circumference, calf size, body weight, range of motion around joints, etc.

Anthropometric characteristics are random variables that can be represented by the normal distribution law (Fig. 3.1-3.2).

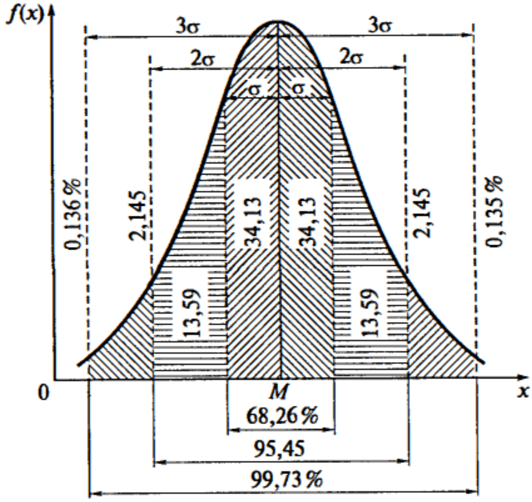


Fig. 3.1 – Normal probability plot of a random variable

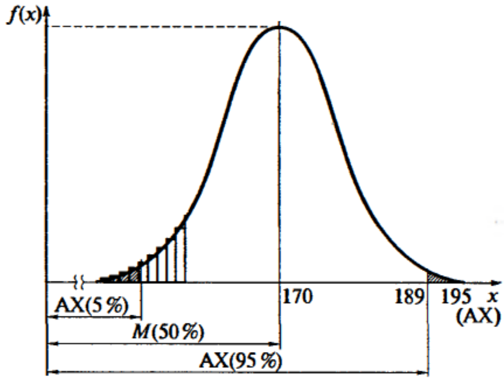


Fig. 3.2 – Plotting a distribution curve for anthropometric measurements

In the graph of the normal probability law of a random variable, the value of random variable x is plotted on the X-axis (in our case - the numerical value of anthropometric characteristics), and on the Y-axis, f(x) represents the probability of occurence of one or another value of the random variable (as a percentage or a decimal).

The average, which is the most probable value of the random variable, is the expected value M, corresponding to the peak of the distribution curve, also known as the «hump». The width of the distribution curve, its horizontal extension, illustrates the variability of the random variable, which is characterized by the mean-square deviation from the expected value M.

The areas under the distribution curve represent the number of random variables falling within those regions. 68.25% of all random variables fall within the range of ±σ from the expected value M, 95.45% fall within ±2σ, and 99.73% fall within ±3σ.

3.2 Concept of Percentile

In anthropometry, the concept of percentiles is used to estimate the probability of placing a specific anthropometric characteristic into different areas of the distribution curve.

Percentiles divide the obtained data (the total number of people subjected to anthropometric measurements) into hundredths. If we divide the area under the normal curve into 100 equal parts (percent), we will get the same number of percentiles. Each of them has an ordinal number.

The 1st percentile represents the lowest value (1%) of the anthropometric characteristic, the 2^{nd} percentile represents a slightly higher value (2%), and so on. Under the normal probability law, the 50th percentile corresponds to the arithmetic mean value (the expected value, mode, median).

In anthropometry, the most characteristic are 1^{st}, 5^{th}, 50^{th}, 95^{th} and 99^{th} percentile. The proportion between the 1^{st} and the 99^{th} percentile is 98% of the total data, while the proportion between the 5^{t}h and the 95^{th} percentile is 90%.

Percentiles allow for a more realistic notion of the range of human body sizes for designers to consider compared to simply looking at the range of variation from minimum to maximum values in the normal distribution.

Boundary values are an occasional phenomenon, which for practical purposes should be avoided. If we remove 1% on both sides of the normal distribution curve, then these random variables will disappear and the boundaries will remain, which will cover 98% of the population.

The level of representativeness is a value expressed as a percentage and corresponds to the part of the population with an average number of individuals where the numerical value of anthropometric characteristics is less than or equal to a given value.

Anthropometric data of people are based on anthropology, a branch of anatomy and physiology that investigates biological nature and size of human beings.

Anthropology means «science about people», it looks at people from a biological and social point of view. Physical anthropology examines the characteristics of the body of individual people or groups of people. Some of these characteristics, such as weight and height, are quantitative, while others are qualitative, such as skin color, hair type, and blood type.

3.3 Factors Affecting the Measurement of Human Body

In the design of « human-machine» systems, the human body, its structure and mechanical functions hold a central position. Sometimes a slight lack of space, just a few centimeters, can have critical implications for the driver, potentially compromising their work and health, as well as that of passengers.

Fortunately, adjustments can often be made to accommodate these critical centimeters without adversely affecting the machine's overall design. Reliable anthropometric data and evaluation methods are essential tools that enable the optimization of dimensions for various mass-produced items, ranging from oxygen masks to airplane cabins and lorries.

Depending on the working position for which the equipment is designed, the dimensions of the object must be carefully considered by the designer.

Certain dimensions of the human body and equipment can easily be specified within the interval from the 1^{st} to 99^{th} percentile. For other dimensions, it is necessary to specify a range from the 5^{th} to 95^{th} percentile or for 90% of people (Fig. 3.3).

While it is essential for designers to aim for vehicles that are suitable for at least 90% of the population, they should make every effort to ensure that the 95^{th} percentile of human body dimensions can meet the requirements of 98% or more of users, if feasible (Fig. 3.4).

Fig. 3.3. Effects of Clothing on Body Size

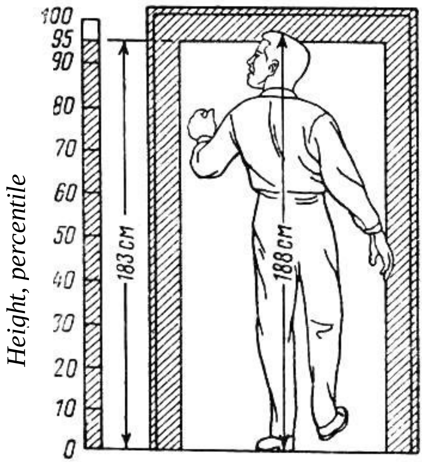


Fig. 3.4. Limitations of Anthropometric Data

The use of the concept of an average person is misleading. The only correct solution is to take into account the size of the 5th and 95th percentiles or 2.5th and 97.5th percentiles. Furthermore, it is necessary to envisage a constant improvement of car body - person dependence, as ergonomics is expected to evolve.

Designing a car for the ‘average’ person is a serious mistake. If the car is designed based on these values, corresponding to 50% of any group of people, only 50% of people in this group will be able to steer it properly.

For instance, 50% of smaller drivers will not be able to reach the steering controls, which are designed for the «average» 50th percentile driver.

Designers often encounter the problem of interdependence of human body dimensions. For example, they may need to consider arm span for individuals in the 90% range, both in standing and sitting positions or with limited knee room, or sitting eye height for people with short legs who drive the car themselves.

In case where specific size information (e.g., the size of the lumbar region) is unavailable, designers will have to approximate these dimensions from the available height and weight data.

Fortunately, there exists a close interdependence between height and length, weight and width of the body, as well as waist and hip circumference. This allows for an approximate characterization of groups of people (though not of individual variations).

3.4 Correlation Tables

Correlation tables display the number or proportion of people corresponding to each value of size A in relation to size B. In other words, they show where and to what extent size B changes depending on size A.

For instance, consider the correlation between body weight and the width of thighs (in a sitting position). Designers can use these tables to find the correlation between various dimensions of the human body for any group of people for which these tables were created.

Anthropometric characteristics can be theoretically divided into static and dynamic ones. ‘Theoretically’ because all anthropometric characteristics are determined in a static state when the examined person is in a fixed position.

Static anthropometric characteristics refer to linear or angular values that characterize dimensions of different human body parts, while dynamic anthropometric characteristics encompass linear and angular dimensions that characterize rotations in the joints, reach zones in different positions, etc.

Static anthropometric characteristics are used to determine general dimensions of the operator's workplace, seat positioning and dimensions, control elements, and other parameters.

Dynamic anthropometric characteristics are used to determine the amplitude of the working stroke of levers, pedals, and other controlling elements, as well as to identify reach zones for various positions of the human body, among other applications. The basic anthropometric characteristics are shown in Fig. 3.5.

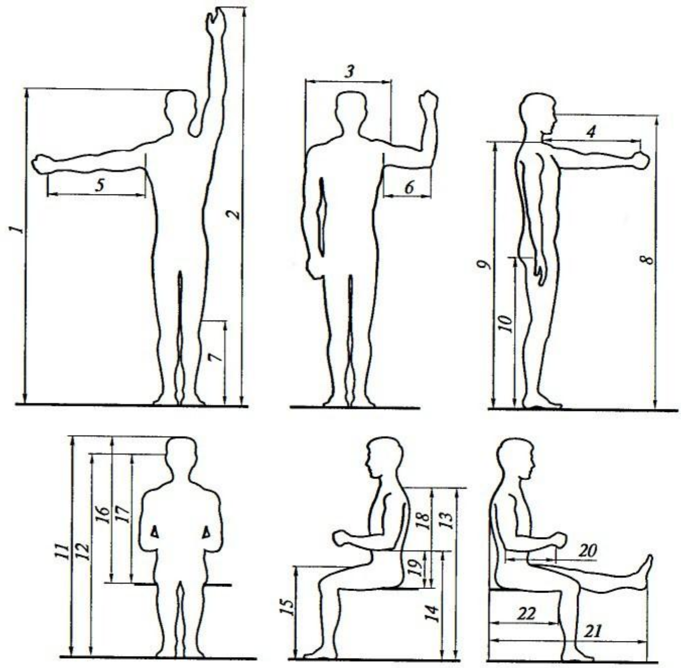


Fig. 3.5. Basic Anthropometric Characteristics

Some dynamic anthropometric characteristics, concerning the angles of rotations in joints (amplitudes of working movements), are shown in Fig. 3.6.

In addition to kinematic characteristics of an individual's movements, time characteristics are of great importance. These characteristics refer to the time that elapses from the receipt of a signal by a human operator (e.g., the deflection of an instrument arrow on the panel) to the actuation of the corresponding control. This time can be determined during subsequent tests.

The test person is required to perform a specific work movement (e.g., press a button, move a lever, turn a steering wheel, etc.) with the maximum possible speed in response to a known but sudden signal (e.g., flash of a warning lamp or a sharp sound). The reaction time consists of two components: the latency period and the motor response time.

The latency period is the time from the moment a stimulus occurs until the body responds.

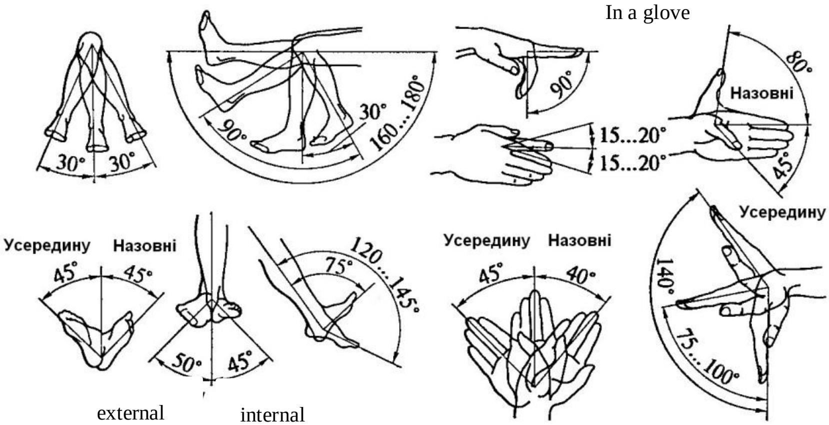


Fig. 3.6. Amplitudes of movement of certain body parts

The total reaction time is the period between the moment the signal occurs (e.g., change of traffic lights, start of a sound signal) and the end of the control action on this signal (e.g., pedal depression, switching of a toggle switch, turning of a handle). It is determined by the sum of three components

- Latency period of the reaction.
- Time of movement of the arm or leg to the control (motor component).
- Time to overcome the free travel of the control.

The motor component of the reaction time depends on the type of movements required to exert a controlling influence. It can be assumed that the movement of the hand to the control occurs at a speed of 0.35 m/s, and the bending or extension of the hand at a speed of 0.7...1.7 m/s. The time for a simple movement with a leg or foot is 0.36s, and with significant effort, it takes twice as long.

The time to overcome the free stroke of the control is evaluated for each specific case, but in most cases, the designer tries to minimize it.

Faster movements include:

- Movements in the direction of the body.

- Movements in the vertical plane.
- Movements from top to bottom.
- Movements from right to left.
- Rotational movements with a large amplitude.

Slower movements include:

- Movements away from the body;
- Movements in a horizontal plane or at an angle to it;
- Movements from the bottom up;
- Movements from left to right;
- Translational movements with a small amplitude.

The shortest time is required to move the fingers. If you take it as a unit, it will take twice as much time to move the hand, three times as much to move the hand and fingers, and four times as much to move the arm at the shoulder joint. Tilting the body and lifting it from this position requires seventeen units of time.

Dynamic anthropometric characteristics also include visibility zones, and these zones can be determined with the head position unchanged (visibility is determined only by eye movement) or with head rotation and tilt.

Figure 3.7 shows the visibility zones achievable with the head turned toward the gaze. The optimal (normal) line of sight corresponds to the minimum activity of the muscles of the back of the head, and therefore to the least fatigue in this working posture.

The visibility zones in Figure 3.7 are constructed taking into account the decrease in eye sensitivity from the center of the visual field to the periphery.

The center of the visual field is the point where the focused gaze is directed. If the light signal is located on the periphery of the visual field, the latency period of the motor response increases. However, peripheral vision is more sensitive to weak and light moving signals.

When such a signal is received, a person turns his or her gaze to it for detailed analysis. Within the field of view, micro movements of the eyes are constantly occurring, and these movements are made in jumps. The time of each such jump is a hundredth of a second. The time it takes to move the gaze from one point in space to another depends on the angular distance between these points and the route of the gaze.

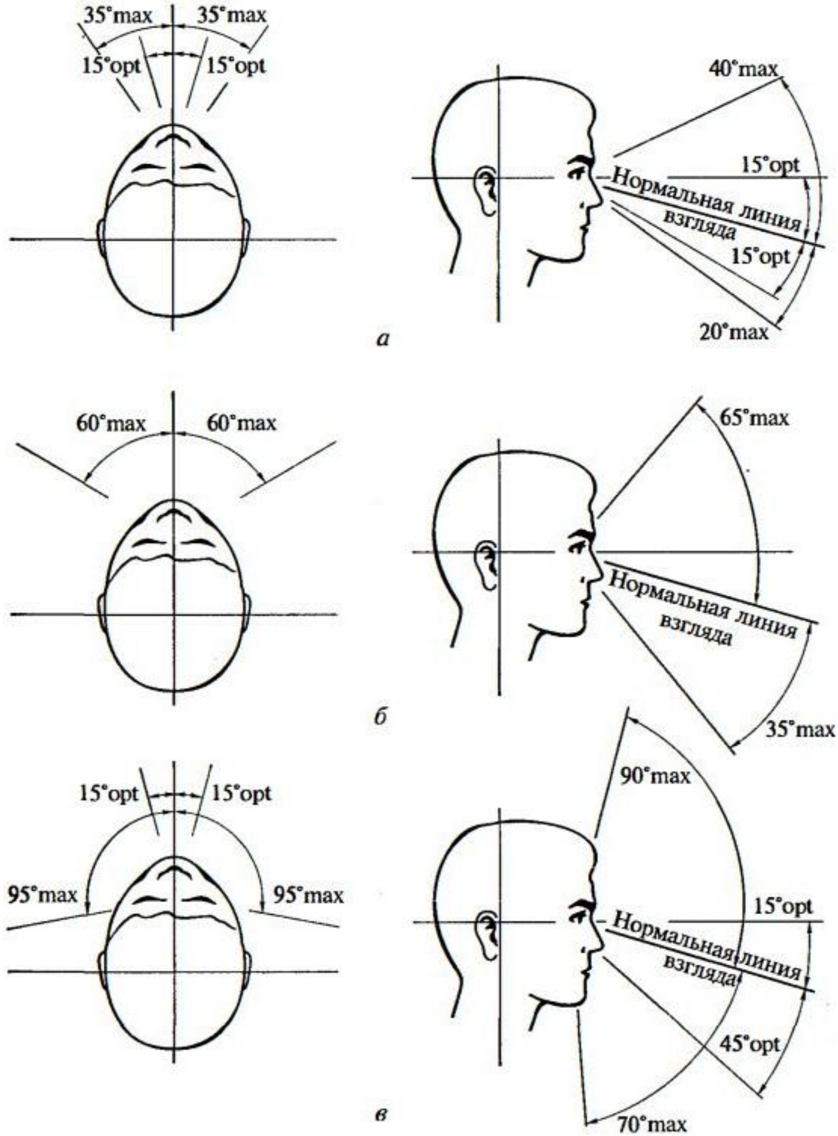


Fig. 3.7. Vertical and horizontal visibility zones when turning
(a – eyes only, b – head only, в – both head and eyes)

Micromovements of the eyes are used to search for an object, read device readings, and recognize an object. To perform these functions, an area bounded by an angle of approximately 15° downward and to the right and left of the normal line of sight is optimal.

Dynamic anthropometric characteristics, including reach zones, are often determined not only by the size of human body parts, but also by the speed and accuracy of hand movements in these zones.

This is correct from the point of view of practice, and formal reach zones should be understood as zones of rational location of controls. When working in a standing position, the limits of the reach zones increase by 100...200 mm, because the operator can move the body more widely.

Test yourself

1. What does anthropology study?
2. What is anthropometry?
3. What role do anthropometric and physiological indicators play in artistic design?
4. What is percentile?
5. What is the level of representativeness?
6. What is the fallacy of the concept of the «average person»?
7. Why are correlation tables needed?
8. List the factors that affect the size of the human body.
9. How are anthropometric characteristics distributed?
10. What is the latency period?.

4 BASICS OF AUTOMOTIVE STYLING

4.1 Theory of Industrial Design

Design is an artistic and creative activity in the industry that encompasses the work of a designer, the methods and outcomes of their efforts, and the conditions for implementing them in production. The purpose of design is to create new types of industrial products with a high technical level, whose content and form meet the requirements of public benefit, ease of use, and aesthetic appeal.

The essence of industrial design is closely related to the inherent nature of the relationship between the developed object and human beings, functional processes, and the reciprocal influence of structure and form. The primary focus of a design artist's work is the form of the industrial product, aiming for practicality, beauty, and its connection with both the user and the surrounding environment. When conceiving a new form, designers consider three key aspects: functional, constructive, and aesthetic elements.

At the theoretical core of industrial design lies technical aesthetics, with one of its essential components being the theory of composition. Composition involves the art of organizing elements and properties within a designed product to achieve a cohesive and expressive form. This aspect is vital in achieving visually appealing and harmonious designs.

The coherence of the form of an industrial product reflects the logical and organic relationship between the design solution and its compositional embodiment. A well-composed form significantly influences a person during the utilitarian consumption of the product or in the process of work. Industrial products created solely by a design artist focusing of the external form without considering the constructive basis often fail to find practical application.

Studying the mechanism of form perception by a designer is quite useful in creative terms as it helps to reveal the essence of professional intuition. Typically, emotional analysis follows this pattern: an initial impression of the product shape -> forming judgment about it -> analyzing the composition based on the theory of shape structure -> drawing conclusions and the final decision about the shape.

To achieve the compositional integrity of the form, design artists must align and harmonize the main formative elements of the product. Compositional balance is a state in which all the elements of the product are balanced with each other.

4.2 Collaboration between Automotive Designers and Design artists

The development of a styling design project should be carried out, as a rule, by a styling design bureau or a styling design group.

An exemplary composition of the group may be as follows: industrial design director (designer), who must be a deputy chief engineer or designer; one, two or more design artists (process engineer, economist, ergonomics consultant, etc.). When designing a number of products, a designer can be a project manager and take full responsibility for it.

A designer is extremely rarely the sole author of a product design; they usually work as part of a large creative team. This is quite natural because the process of shaping a product is in continuous connection with the search for its structure.

When designing objects for people's use, a designer is guided by holistic and socially specific images of life, which they model with the help of artistic imagination. At the same time, they must be capable of thinking in terms of technology and communicating in the same professional language as an engineer.

The designer must work in a creative team in cooperation with design engineers, scientists, technologists, economists, doctors, and find appropriate solutions for products that are progressive not only in appearance but also in structure.

Designers must be capable of conducting current and prospective design work, engaging in creative exploration based on scientific, technical, and artistic ideas. They should not only conceptualize general solutions in sketches and technical designs but also develop them into working drawings and templates. It is essential to select the most economical solution while ensuring the high artistic quality of the car.

A designer must possess not only sufficient knowledge in specialized fields such as engineering, economics, and aesthetics but also have a professional command of composition, a deep understanding of the principles of three-dimensional structures, architectonics, tectonics, combinatorics of form, and the skill to proportionally and skillfully use rhythm, scale, contrast, and nuance ratios. Additionally, designers should correctly apply color and tonal ratios to achieve desired visual effects. While a designer should be well-versed in these matters, the responsibilities of design engineers, technologists, and ergonomists differ and should not fall under the domain of the designer.

The role of a design engineer is quite responsible, especially at the first stage of design. He is the first to start developing a product, he is the first to engage in a creative designer-designer dialog.

The role of a design engineer is of significant importance, particularly in the initial stage of design. They are the first to initiate product development and engage in a creative dialogue with the designer. The engineer's responsibility is to ensure that the machine they design meets specified speeds of the mechanisms and fulfills the required technical qualities. However, it is not their task to ensure that the machine's structure aligns with the customer's aesthetic tastes – this is the responsibility of the designer.

However, it must be borne in mind that the practical presence of two design professionals - a designer and an engineer - does not imply a strict limitation on their areas of creative activity. A «design dialogue» is a specific aspect of the creative activity shared by both engineers and designers.

The key distinction lies in which specialist is more qualified to address a particular task. In each specific case, the effectiveness of their work and the formation of a creative team of designers depend on the harmonious unity of their realized areas of competence, which ultimately determines the leading role of a particular specialist.

4.3 Technical Aesthetics and its Requirements

Technical Aesthetics emerged in the era of industrial culture as a response to the growing demands of modern society. As human societies progress into higher spheres of activity, life becomes increasing complex, leading to greater specialization.

In contemporary times, numerous branches of science and industry have emerged that did not exist a few decades ago. Initially, during the early stages of industrial production, artistic design was not deemed necessary. The primary focus was on the increased productivity of new machines compared to manual labor.

However, as industrial products evolved, new requirements were imposed, leading to higher production standards. Initially, this focused on clear improvements in performance, but gradually, as products continued to advance, the elevation of production standards extended to factors influencing the appearance of products.

Aesthetic requirements became particularly pronounced as production volumes increased, and competition intensified among numerous manufacturers producing similar products, including cars. According to these requirements, every product of mechanical engineering, especially a car, should possess a good appearance that harmoniously aligns with the product's purpose. This emphasis on aesthetics arises from the recognition of its importance in attracting consumers and differentiating products in a competitive market.

Aesthetics requires each product of mechanical engineering, and in particular an automobile, to be attractive. These requirements have become increasingly stringent due to the rise in production and heightened competition among numerous manufacturers producing similar goods.

Experience and observation demonstrate that a well-designed machine or tool that combines an attractive appearance with uncompromised performance not only facilitates product sales but also ensures better usability.

The reliability and efficiency of a vehicle driver's work depend significantly on how well engineers consider and implement specific requirements related to information reception, assessment of regulated objects' conditions, and processing information based on the psychophysiological nature of human work.

The ultimate goal is to create cars that are more user-friendly, comfortable, and that minimize the negative impact of working conditions on the driver's nervous system and performance.

In the design process, special attention should be given to ensuring that the machine does not generate excessive noise or vibrations (beyond permissible limits) during operation. Additionally, the concentration of harmful gases emitted during operation should remain within permissible limits to safeguard both the driver and the environment.

These aesthetic, psychological, and physiological factors are closely interrelated, intertwined, and complement each other. Only a car design solution that takes into account all these factors and requirements simultaneously ensures the correctness of the design.

The emergence of these new requirements in the creation of industrial products necessitated the establishment of institutes, specialized schools, and artistic design bureaus for artistic design. They could no longer be adequately addressed by engineers without professional education in design.

Thus, **technical aesthetics** is a theory of artistic creativity in industry that focuses on the nature, patterns of development, and problems of the creative method in artistic design. It also examines a wide range of problems concerning the practical needs of human consumers, such as the variety and types of products, ease of use, and consideration of ergonomic requirements.

As a scientific discipline, technical aesthetics delves into a set of issues that arise when analyzing the connections and relations within the human-machine system. The goal of their research is to understand the essence of designing functionally appropriate, technically sound, economically justified, and aesthetically expressive vehicle structures. Additionally, studying the properties of a car that manifest during its operation is especially crucial in this context.

The properties incorporated into the design and manufacture of a car depend on a variety of factors and conditions, including technological, socio-cultural, and others. The collection of these properties represents the ultimate goal of creating a car and serves as the primary criterion for consumers to assess its quality.

The most important consumer properties of automobiles include social expediency, suitability for the intended purpose, ease of operation and repair, and aesthetic value. These key factors significantly influence consumers' perception and satisfaction with the product.

The set of requirements for technical aesthetics and the consumer properties of products can be divided into four groups: **social, utilitarian and functional, ergonomic,** and **aesthetic.**

The final criterion for assessing the compliance of vehicles with the requirements of technical aesthetics is the result of comparing the value of the useful effect of consuming an item and the total material costs.

Social requirements. Cars, as public objects, must align with the laws of social reality, meaning they should be useful, convenient, and beautiful. This group of properties should primarily capture the attention of designers and engineers as creating beautiful cars is their primary task.

Artistic design is not a goal in itself but a means that establishes a link between consumption and production. The intermediate points in this system are distribution and trade. Consequently, the general model of the subject activity includes four interdependent spheres: design, production, distribution, and consumption.

The functions of cars in social processes are diverse. Each car can play at least four roles:

- A project-idea
- A product of manufacturing
- A commodity
- A consumer item.

A car is born as a project created by a designer, takes on a material form, becomes an industrial product as a result of the work of a designer, engineer, and worker, and then, after becoming a commodity and passing through the hands of a seller, it reaches the consumer and transforms into a consumer item.

As a result of labor, a product ceases to be a simple natural body processed by a labor tool and transforms into a consumer item with a set of useful properties.

Consumer demand plays a decisive role in the sphere of commodity circulation, which is directly influenced by the range and quality of goods. Therefore, designers and engineers focusing on solving economic problems is a crucial condition for their successful activity.

The practice of styling, design, and engineering endeavors impacts the country's economy in various ways, ranging from improving the quality of industrial products to enhancing the turnover of goods in the domestic market, increasing the competitiveness of domestic products in the foreign market, and ultimately strengthening the country's economic potential.

Taking this into account is one of the most significant requirements of technical aesthetics. In this sense, styling, design, and engineering practice can be viewed as a sphere of industrial product quality production. The integration of aesthetics, design, and engineering ensures products that not only meet functional needs but also cater to consumer demand, contributing to economic growth and development.

Utilitarian and functional requirements. Utilitarian and functional requirements encompass several aspects, including the necessity for a product to have a structure and shape that aligns with human anatomy and physiology. Additionally, the product should possess properties and qualities that make it genuinely essential for users.

For instance, when considering vehicles, there are two perspectives to examine: from the viewpoint of passengers on a bus, the focus is on the convenience of boarding, the comfort of the trip, and the end results of the journey. From the perspective of the driver, the emphasis is on the ease of driving, a clear view of the road, and the interior of the bus. Consequently, the set of social and functional requirements for technical aesthetics is determined by the functions that a vehicle should fulfill.

Ergonomic requirements play a crucial role in modern design, with ergonomics being a comprehensive science with its subject and research methods. Based on ergonomic research, requirements are developed to consider the «human factor» in the design of various vehicles. Achieving unity between ergonomic and styling and design solutions is vital for a design that fully meets the requirements of the human factor. Ergonomics can effectively address many practical issues that may arise during styling.

Aesthetic requirements. Both the design artist and the engineer should be guided by principles that lead to the development of visually appealing and pleasing products.

4.4 The Main Directions of Automotive Styling Design

A designer attempting to identify aesthetic features when analyzing specific car models encounters certain difficulties. The attempt to isolate «beauty» in its purest form without «mechanical impurities» often ends in failure. Beauty remains elusive, either blending with concepts of rationality, convenience, and technical perfection, or being canonized as a stylistic template. The secret of the relationship between usefulness and beauty can only be unraveled by studying the laws of creativity, production, consumption, and the emergence of aesthetic ideals.

For an artist, engineer, or architect, meeting socio-economic, functional, constructive, technical, ergonomic, and other requirements takes precedence. They must possess a developed sense of beauty and professional skills in form construction, while also considering the demands of style, fashion, and aesthetic ideals.

There exists a beauty that is not created by the artist's hand - it is the beauty of nature, arising from the objective laws of form and reflecting the inner harmony of the world. Occasionally, we witness a peculiar transformation of utilitarian products into aesthetically expressive properties. In such instances, the primary creator of utilitarian beauty is the engineer, who designs a product reflecting the laws of nature based on scientific and technical principles.

Thus, **artistic design** is an integral part of the process of designing industrial products intended for direct human use. Artistic design ensures the ease of use of the object, maximum compliance with the operating conditions, creation of a harmoniously integral form and high aesthetic qualities.

Artistic design and engineering design are interacting parties of a single process of designing industrial products. A **design artist** is a specialist who leads the artistic design of industrial products in a team of designers.

Unlike a decorative artist, who only decorates the product externally, and a design engineer, who develops its structural and technical foundations, a design artist is responsible for the ease of use, rationality of layout, integrity of form and beauty of the product.

The more talented and experienced a designer is, the more professional their sketches are and the more complex the car layout problems they can solve, relying on the ability to think not just in terms of a «picture» but in terms of a meaningful form that carries a solution to a complex set of technical and utilitarian tasks.

A designer or engineer should never compromise when designing, they should look for and find the optimal form - comfortable and beautiful. Technique and function, matter and technology become creative accomplices in the aesthetic activity of a designer and engineer.

4.5 The Concept of Styling

The word styling is of English origin, it means stylization, stamp, imitation, manipulation of ready-made elements of form found in design practice.

The main thing that guides a design artist in his search for a solution is the visibility of the form, its special extravagance and constant novelty. Styling became widespread in the 20s and 30s in capitalist countries, during the crisis, when it was necessary to win over the consumer by any means necessary. Artists involved in the industry helped to sell products.

Styling has long been considered one of the main means of open commercial design. As design gets older and modern technology accumulates all sorts of formal solutions, the connection between form and function of a thing seems to become more complicated.

It can be assumed that at a time when there were still few true works of design and they were programmatically opposed to the elements of chance and forms and patterns taken from the past, conscious non-imagery was perceived as the essence of the design profession, aimed at creating basic, non-associative object forms.

This approach, by the way, left no room for stylization or styling. Therefore, traditionally, the concept of «styling» reflects a negative attitude towards any deviation from true or good design.

Test yourself

1. What is the connection between design, technical aesthetics and the process of designing a car or tractor?
2. What are the responsibilities of a designer?
3. What is the joint work of a designer and a design engineer?
4. What is the process of artistic design of a product?
5. What should be the main composition of an artistic design bureau or an exemplary composition of a group?
6. Specify the main responsibilities of the design engineer in the process of their joint work with the designer.
7. What is styling?
8. What are the historical causes of styling?
9. What is the difference between design and styling?
10. What is the functional and compositional analysis of products?

5 DEVELOPMENT OF EXTERNAL FORMS OF VEHICLES

5.1 Means of Composition, Types and Features of Vehicle Forms

Means of composition. The main means of composition are proportions, symmetry and asymmetry, statics and dynamics, tectonics, volumetric and spatial structure, scale, rhythm, accent, nuance, color, and contrast.

Proportions. In technical aesthetics, proportions are understood as the balanced relationship between elements, a system of harmonious connections between the parts of an object's shape and the whole, which imparts it with a sense of integrity and artistic completeness.

The form is often visually divided into parts that exhibit a certain similarity, contributing to the overall harmony of the design. However, in technical domains like automotive and tractor design, the form's proportionality is heavily influenced by the underlying structure. The proportionality of a car or tractor is intricately linked to its type, wheel formula, kinematics, and drive scheme, making it essential to determine these engineering aspects before refining the design's shape.

During the engineering development of the structure, which precedes the final form design, the dimensional relationships of the main elements in the three-dimensional structure are specified based on calculations and overall dimensions of assembly units and parts. The resulting proportional order and harmony of parts and the whole serve as a significant indicator of the technical perfection of the design. It is worth acknowledging that proportions are, to a large extent, objective - they are deeply rooted in the underlying structure.

The stages of engineering design development precede the refinement of the form, resulting in the proportions of the car and tractor being derived from their engineering layout. The proportional order and harmony of parts and the whole serve as an essential evaluation of the technical perfection of the design. Proportions are largely objective as they are closely related to the underlying structure.

In artistic design, modular proportions, also known as proportions of multiple relations, are frequently employed. These proportions are based on a conventional unit called a module. When designing structures, arithmetic or geometric progressions are often used to achieve harmonious dimensions of elements. Dimensional ratios are determined through mathematical calculations or geometric constructions.

5.2 Symmetry and Asymmetry

Symmetry is understood as an order in the construction of a form that observes proportionality and the arrangement of parts and the whole relative to the centerline or center. There are three types of symmetry - axial, mirror, and central - all of which find applications in automobile and tractor construction.

In the design of cars and tractors, the law of symmetry is used to organize their appearance from the front, above, and behind. While absolute symmetry rarely exists in nature, deviations from symmetry are commonly employed in technology due to the operational and functional requirements of machines.

Achieving perfect symmetry in a machine-tractor unit (MTU) can be challenging. However, deviations from symmetry do not necessarily disorganize the overall shape. The tractor, as part of the MTU system, need not possess complete symmetry.

Asymmetrical elements can emerge through rational layouts, provided they are organically connected to other components, maintaining compositional balance within the whole design. In technical aesthetics, asymmetry is understood as an order in a form where the balance of masses relative to the main element of the composition is strictly observed. For tractors, these elements often include the chassis and the hitch system.

To maintain balance in a tractor, the masses must be distributed accordingly, relative to the longitudinal base determined by the position of the propulsion system. Violation of mass balance when dealing with asymmetry can lead to disruptions in the laws of tectonics and rhythm.

5.3 Statics and Dynamics

Static is understood as a state of calm, stillness, and stability of the form in its entirety. On the other hand, dynamics is characterized by an emphasis on one direction, creating a sense of movement and invasion of space. Dynamic compositions often exhibit clear asymmetry, leading to a certain tension in the geometric structure of the form.

In static objects, the axis or plane of symmetry also serves as the main axis of the composition. However, in moving vehicles such as cars, airplanes, and ships, the external shape is typically asymmetrical, with the main axis subordinate to the direction of movement.

Dynamism is particularly important in compositions related to wheeled vehicles. A dynamic form is characterized by a strong unilateral direction, giving the impression of actively invading space. When dynamism is prominent, it becomes the defining quality that shapes the composition. The equality of the body's dimensions in three spatial coordinates indicates a more relative static nature of the form. Introducing contrast in these ratios creates the effect of dynamism, often emphasizing the predominant dimension, such as length.

Dynamic shapes are commonly found in high-speed vehicles like passenger cars, especially sports and racing cars, intercity buses, and mainline trains. The construction of their dynamic shapes is heavily influenced by the laws and requirements of aerodynamics.

5.4 Tectonics

Tectonics is the visible expression of the structural basis, bearing capacity, and stability of an object, as well as its individual parts. The structural basis encompasses the functionality of the load-bearing components, the distribution of forces, the arrangement of masses, and the organization of structural materials. The form of an object should clearly reflect all these features related to the structural basis.

In practice, we often come across machines whose shape only partially or incorrectly reflects these structural features. For instance, a large element of a tractor might appear tense even when it is not under heavy loads. Similarly, enclosing covers may resemble elements that are actually not subjected to significant stress. The regularity of tectonics cannot be utilized by a designer without considering the material used for structural elements and the manufacturing techniques involved.

The artistic and figurative arrangement of an object, formed by compositionally connected structural elements, constitutes a tectonic system. The law governing the tectonic system is stylistic unity, meaning that all the elements should harmoniously come together to create a coherent and aesthetically pleasing whole.

5.5 'The Golden Ratio'

The eye can easily perceive a form if its segments, surfaces, and volumes differ slightly in size.

Therefore, a certain proportionality is necessary in the composition of any structure. It was proved by practice that one of the most favorable proportions for perception is the proportion of the so-called «golden ratio».

'The Golden Ratio' involves dividing a segment into two parts in the extreme and middle ratio, which are in the following relationship:

$$\frac{b}{a} = \frac{a - b}{b} = 0{,}618, \quad (5.1)$$

where a – the length of the entire segment;

b – its longer part.

This proportion, known as the «golden ratio,» can be found in classical architecture, certain plants, the structure of shell spirals, and more. It is believed to be aesthetically pleasing and easy for the eye to compare elements with sizes related in this specific way. The eye easily compares segments, shapes, and bodies whose sizes are related as 0.618:1, while with a smaller or larger difference in size, comparison becomes difficult.

When designing, it is essential to arrange the segments, lines, volumes, and other elements in a sequence that allows for smooth and continuous eye movement during observation. For instance, having sharply different constructions of cutouts in the sidewall for the front and rear wheels and the main contour line of the body might be perceived as unattractive, whereas using the same design principle creates harmony. However, repetitive lines of the same character should be used carefully to avoid creating monotony in the overall form.

5.6 Scale

Scale in technical aesthetics refers to the comparison of an object's characteristics with fixed sizes of the human body. It plays a significant role in harmonizing the design of products, including cars and tractors. Scalability involves checking the dimensions of an object against a human figure to ensure appropriate proportions (Figure 5.1).

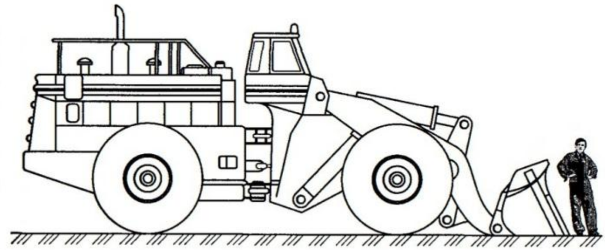


Fig. 5.1. The ratio of human and tractor scales

In the context of cars and tractors, scale characteristics are found in design elements directly related to a person, such as bodies, cabs, seats, doors, windows, and headlights, which are referred to as scale carriers.

Maintaining an appropriate scale in technology is essential. Excessive fragmentation of the form can hinder the grouping of elements into a coherent whole, distracting human attention. When there are too many elements within the field of view, the perception of individual figures diminishes. To create a visually pleasing composition, designers need to identify the main elements of the car and tractor design that will take the center stage.

The chassis and the tractor's hitch system can serve as focal points, symbolizing traction and carrying capacity, respectively. The phenomenon of perspective comes into play when a person visually perceives the shape and composition of a car or tractor. Creating drawings and mockups in different positions helps avoid mistakes and enhances the efficiency of the design process.

Thus, scale is a crucial compositional tool that shapes the design of cars and tractors. During the layout stage, design engineers work on integrating the human form into the design, placing human figures on all orthogonal projections of the general view.

5.7 Volumetric and Spatial Structure

Any form interacts with space in various ways, ranging from simple and clear to highly complex. Regardless of how a form is constructed, it can be seen as comprising two main components: volume and space.

In a well-organized volumetric and spatial structure, the organic relationship between individual elements or parts is of utmost importance. The overall orderliness of the structure is a condition for its integrity and harmony. A structure with random connections between elements makes it difficult for viewers to perceive and understand its organization. On the other hand, when this structure is organized with elementary simplicity, its principles become easy to discern and comprehend.

Complete chaos in a working structure is rare in technology. More commonly, there may be disorder, which is of a hidden nature but still leads to negative perceptions. In other words, an apparent lack of any system in the organization of a structure can be unsettling for observers.

Both cars and tractors can be viewed as typical three-dimensional structures. In the context of artistic design, the main organizing three-dimensional structure is initially created through the compositional grouping of elements, emphasizing certain commonalities. This goes beyond mere technical generalities since any structure consists of individual components and assemblies, but also involves compositionally emphasized condensations and separate groups within the structure as a whole.

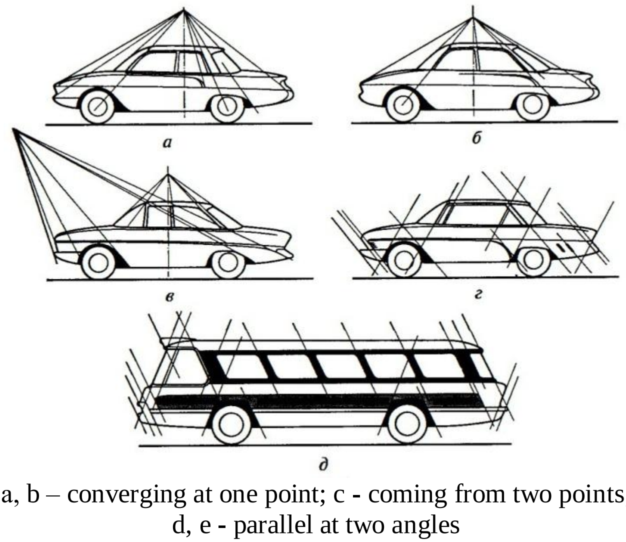
5.8 Structure, Shape, and Composition

The term 'design' encompasses the structure, composition, and the arrangement of elements relative to each other in a product. In the context of design, 'composition' refers to the organization and arrangement of individual parts, assembly units, and components, such as car and tractor units (front axle, clutch, transmission, rear axle, engine, body, cab).

Structures can be different based on their shape and appearance. There are open structures, seen in bicycles and motorcycles, closed structures found in cars and buses, and combined structures, characteristic of tractors, trucks, and road trains.

'Shape' refers to the external outline and appearance of a car or tractor. It comprises elements such as lines, points, flat and curved surfaces, and their various combinations. The shape of an object can have various properties, such as spatiality, length, completeness, discontinuity, infinity, and depth. Shapes can be natural (like the shape of a sheet or a tree) or man-made (all manufactured products). Man-made shapes are further classified as calculated (like the shape of a ship's propeller or an airplane wing) and relatively production shapes, which are created by the designer's imagination while considering the product's functionality. The relatively production shapes can be permanent or variable, depending on the specific product.

In the process of designing an industrial product, the shape is not solely determined by its function; it should also possess spiritual value in addition to utilitarian value. Therefore, the formation of a shape should adhere to the laws of composition to achieve a harmonious and meaningful design.



a, b – converging at one point; c - coming from two points;
d, e - parallel at two angles

Fig. 5.2. Different schemes of car composition with the use of basic formative lines

Form is a structure of interdependent elements in space. It interacts with the space itself. The three-dimensional structure is already a category of composition.

Composition is understood as the structure, the relationship of parts and the whole of the three-dimensional structure of an object. Composition is a factor that connects the design (layout) with the aesthetic form, i.e., using its regularities, the design of the product can be given an aesthetic form. The most important properties of composition include integrity, expressiveness, static, dynamic, etc.

There are three-dimensional, flat, and linear compositions. If the shape in space has approximately the same dimensions and directions of the coordinate axes, the composition is considered to be three-dimensional.

A significant difference in size in the direction of one of the coordinate axes relative to the other two leads to a flat and linear composition. If one of the relative sizes is small, the composition is flat. A flat composition is often called a frontal composition. A three-dimensional composition can be considered to be conditionally composed of frontal compositions. For example, in a car and a tractor, their front, rear, and side views are a set of interrelated frontal compositions.

The front and rear views are based mainly on the law of symmetry, and the side view is based on the law of asymmetry. The composition is based on a plan, an idea, a motive, which lead to the ordering and subordination of the elements of the form.

In the development of car and tractor designs, there is a clear trend towards enhancing the working conditions of the driver (or operator). This is achieved by increasing the volume of the cabs through the creation of protective zones and incorporating reversible control stations.

The artistic design solutions are driven by an ergonomic approach, particularly in the composition and organization of the interior and the driver's (or operator's) workplace. Controls are strategically mounted on separate panels and positioned to maximize the free space for easy passage from the door to the seat. Moreover, to optimize visibility, the glass area is expanded, particularly on the front and rear panels of the cab, and rear-view mirrors are effectively utilized.

Test yourself

1. What is symmetry?
2. List the types of symmetry.
3. What is the statics of shape?
4. How are the statics, unity, and imagery of the shape reflected in the product?
5. What is the dynamism of the shape?
6. What is the idea of composition based on?
7. What means the unity of shape and composition in artistic design?
8. List the basic rules for building a car shape.
9. How does the streamlined shape of the car influence its aerodynamic properties?
10. What is the golden section?
11. What is the relationship between the layout of vehicle controls and ease of operation?

6 GENERAL LAYOUT OF AN AUTOMOBILE

6.1 Specification and draft design

Let us explore the process of developing the general layout of automobiles based on classical construction with the front engine and rear drive wheels (Fig. 6.1). For the sake of clarity, the description of the general layout process is based on the assumption that all major vehicle components are redesigned.

The logical sequence of working stages predetermines the following order of narration. In practice, the overall arrangement of the car is complicated by numerous limitations. It is performed with successive approximations considering different options.

Automotive engineers are constantly forced to return to the work already done in search of the best compromise. The overall arrangement of a car begins with designing the passenger compartment, primarily with the placement of the driver and passengers based on two-dimensional templates using a three-dimensional dummy that reproduces the shape and weight of a human.

The process of designing a car can be divided into the following stages:

- Preparation of the specification.
- Creation of the general layout of the object.
- Construction of necessary mockups that allow you to solve complex technical problems.
- Preparation of rough drawings, specifications, and other documentation transferred to the production facility to develop technological processes and order necessary equipment.
- Construction, finishing, and testing of new samples.
- Adjustment of rough drawings and their transfer to the production facility.

At the last stage, the design engineering department is involved in the creation process of serial or mass production, which is dedicated mainly to the elimination of defects in the object and its modernization. Creating a new car is a complex and multifaceted process; the creative work of a designer should be closely related to production processes and research.

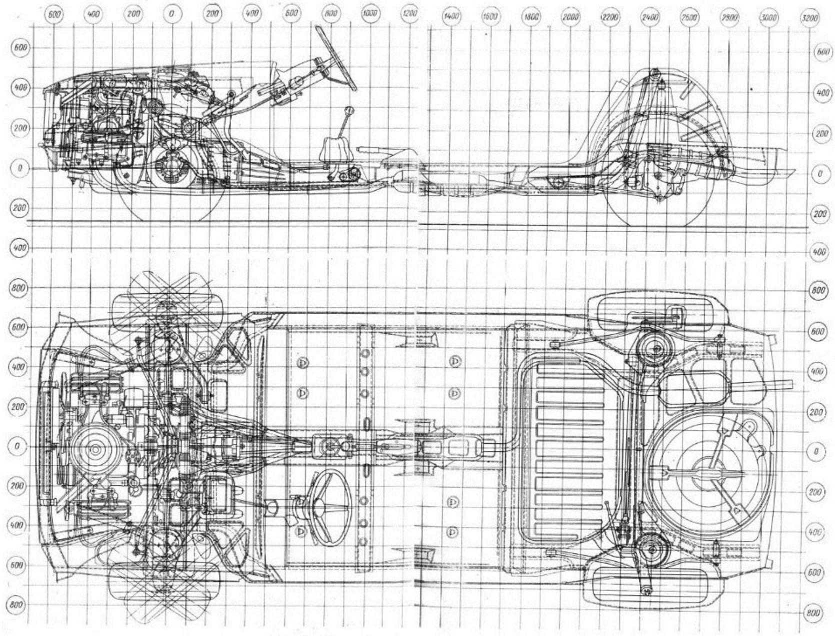


Fig. 6.1. Schematic drawing of motor vehicle chassis

The task of the general layout development is to clarify or find the most favorable interposition of the components, adjust dimensions, and agree on the performance of major vehicle components, according to the initial design data and preliminary characteristics, intended technical specifications, and the draft.

The general vehicle design is used as a basis for ***working tasks for the design of the individual assemblies*** with reference to identified characteristics and required limitations. As long as the overall design is based on solid, theoretically based methods, the task will not hinder or interfere with the designer's creativity while working on a single unit but rather serve as an organizing and directing start, which ensures the implementation of the ideas laid down in the design of a new vehicle.

Whether the general vehicle design complies with the specified performance indicators depends on a detailed general layout. It influences the time and costs needed to prepare technical documentation for test samples production, for finishing works on separate assemblies and a vehicle as a whole. It also determines the quality of the final product.

All specified data on the design can be refined and corrected during the development of the technical project, though vehicle properties must not be deteriorated.

Designers develop an overall vehicle configuration based on the specification, which includes the indicators set for the final goal, the engineering design, and explanatory note. For this purpose they utilize available experience from the design, presentation, and production of previous car models as integration diagrams, general views of the whole vehicle and its separate units, test reports and data on the general assembly and testing of vehicles with parameters close to the intended product.

The general layout is typically developed before the design of most of the assemblies. It determines the specifics of general layout development, which involves a continuous and consistent refinement of the geometric and weight parameters of the main vehicle components.

This process begins with selected components based on preliminary assessment in the initial stage of the design and finishes with refined major vehicle components, after completing the design and calculation of said components, modeling motor vehicle chassis, interior space, and external forms of a body in the following stages of automobile creation.

Considering the relative complexity of the engine, hydraulic transmission, and steering mechanism, as well as their critical influence on the overall layout of the vehicle, and the fact that they are closed 'integral' systems, the layout designer must possess at least preliminary dimensional drawings of these units before commencing the development of the overall vehicle layout.

Practical design almost always incorporates a portion of the units that have been produced, tested, or developed in advance as part of the design process.

On the one hand, this reduces the amount of design work, but on the other hand, it imposes additional limitations on the layout. To ensure completeness, the following description of the overall layout process is based on the assumption that all vehicle components are redesigned.

Such presentation can be considered ‘ideal’ as it is based on the logical sequence of the individual stages. In practice, the overall arrangement of the car is complicated by various limitations and is achieved through the method of successive approximations while considering numerous options.

When designing a passenger car, the layout designer is continually compelled to revisit the work already done in search of the best compromise. Not all units play a role in the overall layout of the car and should not be thoroughly studied at this stage of design.

The following components carry the most significant influence on the performance of the vehicle, the design of adjacent parts and its external shape: engine, power transmission, front and rear suspensions, steering drive, frame, and body.

Units that are relatively compact or partially integrated within other units, such as wheel brakes, do not significantly affect the overall layout of the vehicle and do not require in-depth design consideration. On the other hand, the ‘joints’, such as the powertrain suspension or the steering mechanism, are of great importance for the overall layout.

6.2 Approval of the Technical Specification

The technical specification is a crucial initial document for the development of the vehicle and its design documentation. It is prepared by the developer, which could be the manufacturer or a design organization.

The creation of this specification is based on the approved type, research and development plan, and other directive documents. Additionally, the technical requirements of the customer or main consumer, if provided to the developer, are also considered. Alternatively, the manufacturer can initiate the preparation of the technical specification independently.

The primary objective when preparing the technical specification is to ensure that the newly designed vehicle offers economic advantages over the one it is intended to replace. These advantages may include higher performance, improved dynamic qualities, greater comfort, structural safety, and other desirable features.

The technical specification typically consists of several sections, including:

- Purpose and scope of use.
- Technical requirements.
- Economic indicators and limit price.
- Stages and phases of development.
- Applications.

The technical requirements from the customer or main consumer must encompass essential aspects such as:

- A feasibility study with the maximum price of the vehicle clearly outlined,
- Vehicle operating conditions and mode of operation,
- Technical parameters and characteristics, including the expected service life,
- Volume of production,
- Requirements for design safety and adherence to sanitary and technical standards.
- Requirements for patent purity and compliance with standards, rules and recommendations of international organizations.
- Requirements for architectural and artistic design.
- Additional requirements at the discretion of the customer or the main consumer.

If the technical requirements are not sufficiently complete for the development of the project, the developer has the right to establish the missing requirements himself.

6.3 Preliminary Design

The preliminary design phase encompasses several essential tasks, including the development of the preliminary layout, exploration of architectural solutions for both the exterior and interior, and verification checks to confirm the validity of the chosen approach.

At the outset of **the preliminary layout**, the primary objective is to establish the initial configuration of the vehicle. This involves determining the preliminary dimensions and relative positions of its main components, as well as the arrangement of the driver, passengers, and their luggage within the vehicle.

In cases where the basic layout of the vehicle has not been predetermined, multiple layout options are generated during this stage. The selection of a particular layout is based on various factors, such as overall vehicle dimensions, weight distribution over the axles, seating comfort, ease of entry and exit, accessibility of crucial components (especially the engine) for maintenance and repair, manufacturability, and production costs.

Experience has shown that it is prudent to begin the design process with a stable schematic diagram (Fig. 6.2). Only when it is determined that the existing schematic is unsuitable or inadequate for a particular scenario should alternative options be explored.

Neglecting to study established schematic diagrams may result in the failure to identify the advantages of a new design compared to tried-and-tested solutions.

Therefore, a preliminary drawing of the preliminary layout, along with illustrations providing an overview of the fundamental architectural concepts for the exterior of the vehicle, should be an integral part of the draft technical specification.

This necessitates commencing work on the preliminary layout almost simultaneously with the technical specification, allowing for a certain degree of elaboration by the time it is approved.

Drawings of the preliminary layout are commonly produced at a scale of 1:5 or 1:10. This scale strikes a balance, providing sufficient accuracy for this stage of design while being convenient for interpretation, work, storage, and requiring less time for drafting.

The sketch layout drawing typically includes side and top views, front and rear perspectives, as well as necessary cross-sections. The vehicle is depicted in height, moving to the left, and in the design position relative to the road surface.

Preliminary drawings, which outline the overall dimensions of the main vehicle components, serve as the foundation for the development of the preliminary layout.

In practical design, it is common to leverage units that have already been successfully produced or developed during the creation of a design concept, as comprehensive information about them is readily available.

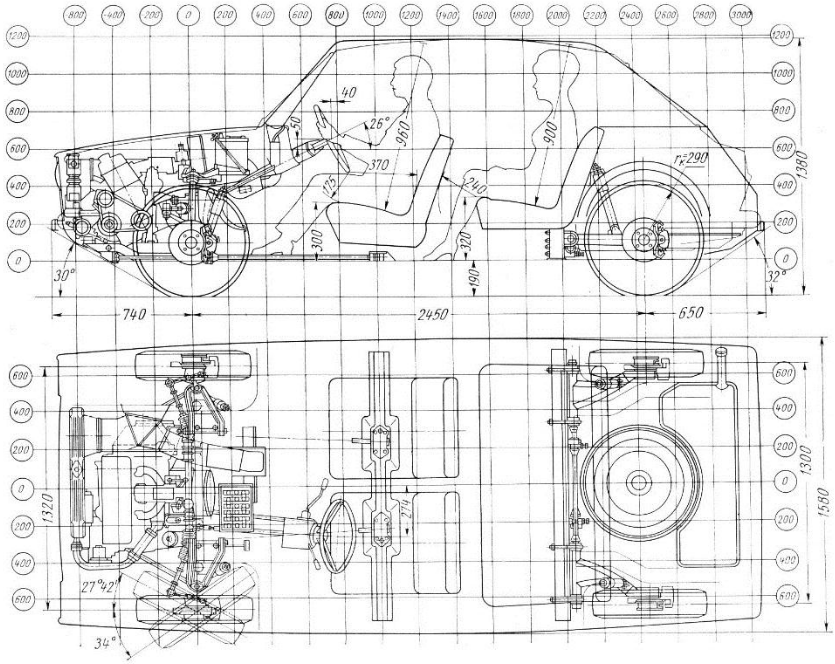


Fig. 6.2. The chassis of a particularly small car with front-wheel drive

During the development of the preliminary layout, designers draw on existing experience from previous car models, utilizing linkage diagrams, general view drawings, test reports, and measurement data from vehicles that share similarities with the projected model.

For newly created units, preliminary 'dimensional' drawings are generated based on drawings of comparable units from previous car models.

Additionally, study and measurement of analogous models, along with illustrations and diagrams from relevant publications and brochures, are used to adjust their dimensions appropriately.

It is essential to recognize that not all components that contribute to the overall layout of the vehicle may be sufficiently developed at this stage.

Consequently, further detailed work may be necessary for certain components during the design process.

The elements that wield the most significant influence on the vehicle's performance, impact the design of neighboring parts, and dictate its external shape include the engine, front and rear suspensions, steering, frame (if applicable), and body. Conversely, compact units or those partially integrated within other components, which do not significantly affect the overall layout of the vehicle, may be omitted from this specific stage of the design process.

6.4 Vehicle shape model

At the preliminary design stage, the level of detail in the development of the layout can vary, depending on the complexity of the customer's requirements and the difficulty of the layout solutions.

The mandatory elements that define a preliminary design are models of the exterior body shapes made at a 1:1 scale, models of the interior trim made at the same scale, and a seat arrangement.

Master pattern is a three-dimensional sample of a part, replicating its contours, surface, and cutouts within a high level of accuracy, often around ±0.25 mm.

The surface of samples, assembly guides, and control devices is directly copied from the master pattern using specialized copying machines.

Typically, the surface of the master pattern corresponds to the internal surface of the part, allowing the part to fit precisely onto the master model. However, some exceptions to this rule may be permitted depending on the specific requirements and design considerations.

Master patterns are crafted from well-dried wood (such as valuable wood or alder) with a moisture content of 6-8%. In some cases, light alloys and plastics may also be used.

The construction lines and grid lines specified in the working drawings of the parts are applied and marked on the master pattern usually on the side opposite the front surface.

6.5 Modelling techniques, control checks

The materials for models and layouts are plasticine, plaster, wood (linden, alder) and plastic (Fig. 6.3)

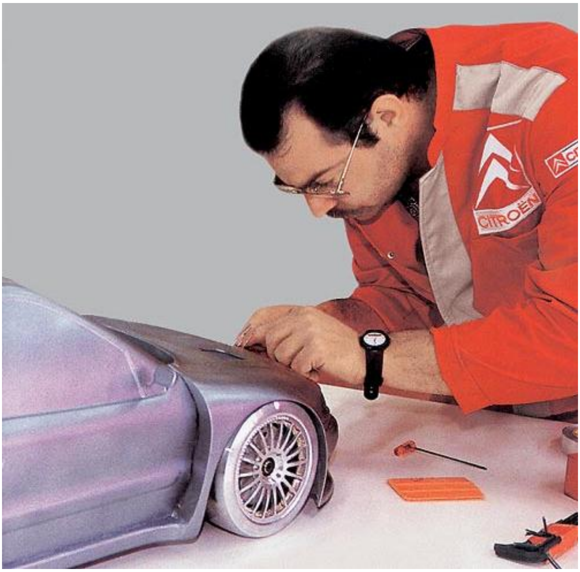


Fig. 6.3. Working on a scale model of a car

Plasticine is softened by applying gentle heat. Gypsum is used in powder form and mixed with water until it forms a liquid doughy mass.

To create a 1:5 scale model of a car, in addition to approximately 30-50 kg of plasticine, you will need the following tools and materials:

A metal marking plate, at least 1500x800 mm in size, with a grid of 40x40 mm cells drawn on it. The plate should be placed on a horizontal table at a height of 1.2 m from the floor.

Large and small marking gauges.

A rectangular prism, approximately 400 mm high.

Metal squares and templates.

Cardboard or thin plywood for making templates.

Scrapers, spatulas (stacks), celluloid strokes, a knife, and needles for modeling.

A trough and tiles (or lamps) to provide heat for softening the clay.

A metal measuring ruler and fine sandpaper.

A ruler with a needle at the end for drawing a grid on the prism.

Working with a large amount of clay can be physically demanding due to its higher specific gravity and increased viscosity when it cools (see Figs. 6.4-6.5).

Fig. 6.4. Work on the car body mock-up

Therefore, it is advisable to construct a wooden box or a blank that roughly corresponds to the internal dimensions of the car body, as derived from the layout drawing. This blank can be mounted on sharpened wooden, aluminum, or plaster wheels, facilitating the process of working with clay and reducing the overall amount of clay required.

Prior to commencing work, the clay needs to be softened through heating. Subsequently, a thick layer of clay is applied to the model blank. Once the plasticine has cooled and solidified, the model blank is positioned on the marking plate along the grid. Excess plasticine is carefully removed using a knife, and the main outlines of the model are adjusted to match the contours specified in the preliminary mold drawing.

To achieve this, cardboard or plywood templates are taken from the drawing and used as references. With these preparations in place, sculptors can begin crafting the model using spatulas, needles, squares, rulers, and templates. Throughout the process, particular attention should be paid to smoothing the protruding surfaces to achieve a polished finish and accurately observing the glares and reflections on these surfaces.

Fig. 6.5. Designing a dashboard layout

To simplify the work and achieve a closer resemblance of the model to the future car, several techniques can be employed:

- Drawing sharp lines or using light wires along the contours and boundaries of the openings to highlight them.
- Applying foil or strips of paper to accentuate decorative overlays, buffers, and glass in their appropriate places.

Plaster templates are quite useful in the process. To create them, plasticine walls are placed on the model, with one wall coinciding with the grid line drawn on the model. To reinforce the future template, one or two steel bars (or wires) are placed between the walls, and then liquid plaster is poured into the space. Once the plaster has hardened, the template is removed, and the sides are planed.

To enhance the appearance of the model, it is recommended to paint it with nitro varnish. This brilliant coloring significantly changes the model's appearance compared to an unpainted one, making glares more noticeable. Plasticine is easy to paint, allowing for greater customization and realism.

For life-size models, either plasticine (1.5-2 tonnes) or plaster can be used. The plasticine is heated, liquefied, and then applied with spatulas to the wooden base of the model. It is then leveled and smoothed using scrapers with teeth of different sizes.

Protrusions of constant cross-section (seals, window frames, decorative overlays) are made separately on a board or sheet of plywood by dragging a metal template with the corresponding profile through the liquefied clay. After cooling, these profiles are applied to the model's surface.

When working with plaster models, a blank with wire scraps nailed to it is prepared. The plaster is poured into the blank, and preliminary templates are placed around it on a grid. Once the gypsum hardens, the templates are removed. To prevent them from sticking, the templates are lubricated with a mixture of kerosene and oil. The surface is then treated and finished using ordinary carpentry tools and sandpaper.

To prevent paint layers from swelling and peeling off and to aid in drying the plaster, channels are made in the thickness of the gypsum to drain moisture from the surface. Wooden round rods are inserted into the plaster for this purpose and are later removed.

For some purposes, a special demonstration model is made, often combined with a seat arrangement. This demonstration model resembles a real car with one or two opening doors, interior equipment, seats, and glass. It is carefully painted and finished and is almost indistinguishable in appearance from an actual car.

Until recently, demonstration models were made of wood and then painted. Nowadays, it is possible to make the main part of a demonstration model from plastic, with the corresponding surface being obtained using plaster or plastic dies taken from a sculptural model. This process is simpler, and the model is lighter and its surface exactly matches the surface of the sculptural model.

In the workspace for creating life-size car models, it is essential to have enough space for the sculptor and observer to view the model from various perspectives, at a distance of at least 10 meters. To aid observation in a smaller room, a rotating circle can be used to mount the model, ensuring its normal position relative to the floor. Additionally, larger windows and diffused daylight lamps are advisable in the model room to enhance visibility and lighting.

6.6 Technical Design, Linkage Diagram, Chassis Layout

The linkage diagram serves as a comprehensive reference document in the technical design phase and must contain detailed information about the defining dimensions of the units, dimensional chains, strokes of moving parts, clearances, and overall dimensions. All calculations related to the vehicle design are summarized in the linkage diagram.

The linkage diagram is typically drawn at a scale of 1:5 or 1:10 and is accompanied by a coordinate grid. It includes side views, top views, front views, and necessary cross-sections. Additionally, the dimensions of the seat contours and body contours are shown and agreed upon in the linkage diagram, along with the chassis dimensions.

In some cases, the linkage diagram is presented in the form of a 'layout passport.' This format organizes the dimensions in a specific system, making it easier to use the diagram but increasing its overall size.

The layout passport provides a clear visual representation of how changes in one dimension within a chain affect other associated dimensions. At the technical design stage, the accuracy requirements for all graphical constructions and calculations related to geometric parameters are significantly higher compared to the preliminary design stage.

Chassis mock-ups (fig. 6.6) Chassis mock-ups are essential in minimizing layout errors, streamlining the process of building prototypes, and refining the vehicle design. Chassis modeling commences once the relative position of the main vehicle components is determined in the preliminary layout. The modeling process continues throughout the design development, allowing adjustments to be made as needed.

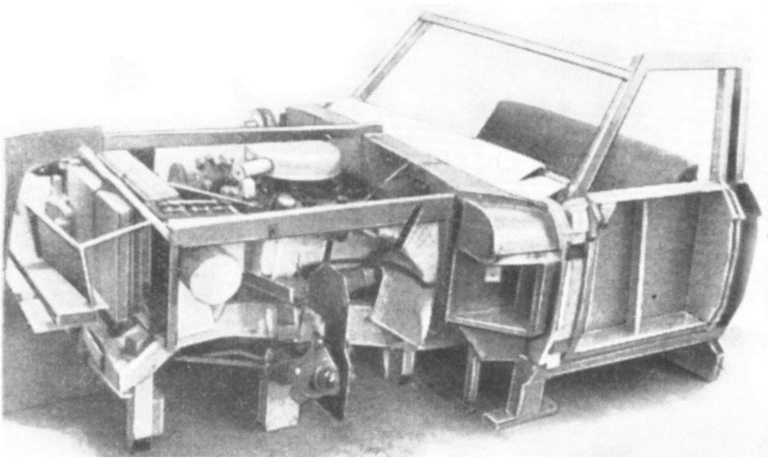


Fig. 6.6. Mock-up of a front of the chassis

The mock-up is gradually supplemented and refined as the project becomes more detailed and new problems arise during the design process. The work on chassis modelling lags slightly behind the design development of the units, but allows the necessary adjustments to be made to the design at this stage. The chassis mock-up is constructed on a cast-iron or wooden plate that features a coordinate grid with a spacing of 200 mm. This grid facilitates precise measurements using rulers, squares, and marking gauges.

Test yourself

1. List the main stages of car design.
2. What is the role of artistic design analysis in the design of a new car?
3. What is a preliminary analysis and drawing up of technical specifications?
4. What do the designer's supervision and examination of the product include?
5. What is the purpose of a master pattern of a car shape?
6. Explain the purpose of perspective representations in artistic

design.

7. What is the purpose of the general layout?
8. What is a preliminary design?
9. Briefly describe the layout technique.
10. What sections does the technical specification consist of?
11. What is a master pattern?
12. What is a layout passport?
13. What does the general layout stage of a car begin with?
14. Name the most commonly used materials for the manufacture of models and models of cars.
15. What is the scale of the linkage diagram?
16. What items should be included into customer's technical specifications?

7 LAYOUT OF THE DRIVER'S WORKPLACE

7.1 General Information on the Layout

The layout of the driver's workplace refers to the main geometric dimensions that define its position within the cab and the arrangement of controls.

During the preliminary stage of driver placement in the cab, a two-dimensional sitting dummy of the 95th level of representativeness (GOST 20304-90) is used.

This ensures accurate representation while working at a scale of 1:5 (sometimes 1:10), resulting in compact graphic images.

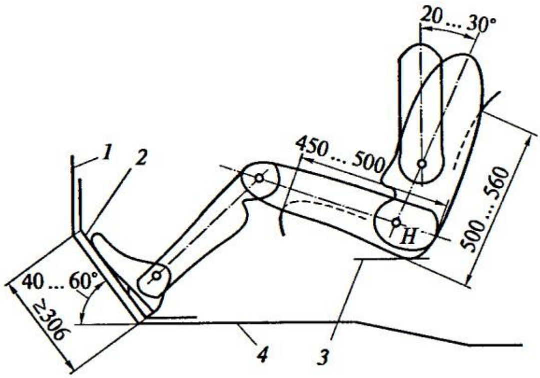
When utilizing computer design programs, the scale becomes inconsequential, as the image can be printed at any scale without sacrificing accuracy, facilitating ease of discussion and approval.

The choice of driver sitting position depends on the vehicle type. In a passenger car, the driver's seat is positioned low, with the legs almost fully extended, and the seat back is tilted at a significant angle away from the vertical.

This arrangement enables a low vehicle height, leading to reduced aerodynamic drag. Conversely, in trucks and tractors, the driver is seated on a higher seat, with the legs bent more at the knees and the seat back nearly vertical.

This configuration minimizes the cab's length, and its height is not crucial from an aerodynamic perspective, given the larger overall dimensions of the vehicle in height (truck) or lower speeds (tractor). An illustration depicting the principal approach to the layout of the driver's workplace using a two-dimensional sitting dummy can be found in Fig. 7.1.

The process of driver's placement starts with establishing internal floor boundaries and partitions, facing the driver. According to GOST R 41.35-99, the term «partition» encompasses any permanent structural element, such as a tunnel projection above the driveshaft or gearbox, wheel casing, side body panel, etc.



1 – engine compartment partition; 2 – carpet;
3 – level of the compressed seat cushion; 4 – floor

Fig. 7.1 Using a two-dimensional sitting dummy for the layout of the driver's workplace

Then, based on the type (category) of vehicle, the seat height is determined, considering the cushion deformation, which is approximately 80 to 100 mm for a passenger car and less for a truck and tractor, respectively. If a sprung seat is used, its movement under the weight of the driver is also considered, accounting for static deflection and the elasticity of the seat suspension.

The diameter of the steering wheel typically ranges from 350 to 420 mm, but on sports cars, it can be as small as 280 mm, and on heavy trucks and buses, it may go up to 600 mm.

As the diameter increases, the torque the driver can apply to the steering wheel with the same force on the rim naturally increases, but it leads to a decrease in the achievable steering wheel rotation speed («steering speed»).

Thus, small steering wheels are used in sports cars, while large ones are used in heavy vehicles to enhance safety in the event of power steering failure. The diameter of the steering wheel rim is usually about 20 to 30 mm.

The force that the driver can apply to the steering wheel rim is significantly affected by the angle of the steering wheel rim (Figure 7.2). For example, at a nearly vertical steering wheel position (10° relative to the vertical), the achievable force is considered as 100%, while it increases by about 25% at a nearly horizontal position (80°) due to human anatomy.

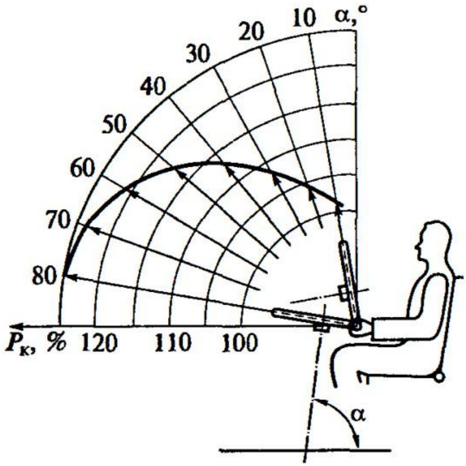


Fig. 7.2. Dependence of the force Pk on the steering wheel
on the angle of its inclination α

On passenger cars, the control pedals are arranged in accordance with Fig. 7.3 (GOST R 41.35-99), and the numerical values of the parameters indicated in this diagram can be found in the reference literature. The arrangement of controls is checked for compliance with applicable standards.

After determining the geometric parameters of the driver's workplace, it is possible to design passenger seats in the rear of a passenger car, assuming that a passenger sitting in the front seat is seated in the same way as the driver.

The methodology for the layout of passenger seats is similar to that used for the driver's workplace, except that there is no need to place controls (Fig. 7.4).

For more comfortable passenger cars, a two-dimensional seating dummy of the 95th level of representativeness is used in the layout of passenger seating, while for small cars, a dummy of the 50th level of representativeness is often used.

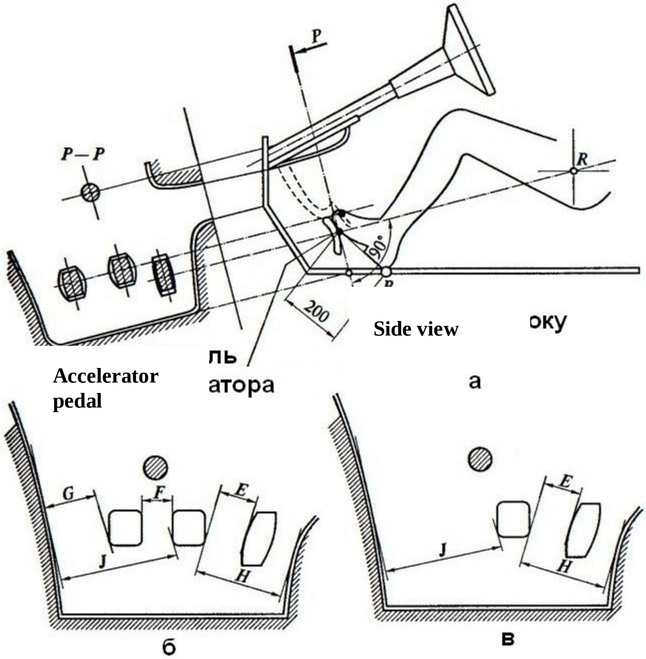


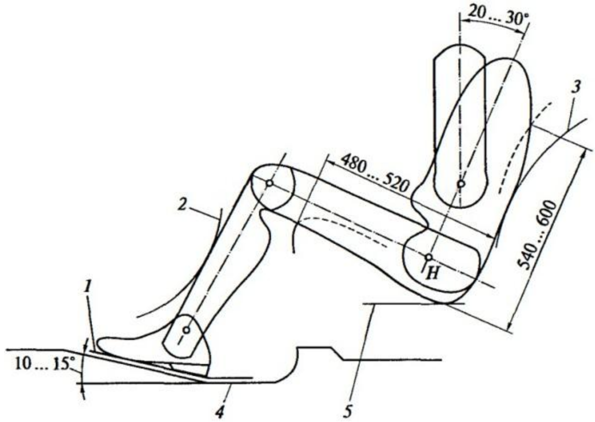
Fig. 7.3. Positioning of the passenger car control pedals

The thickness of the front seat backrest is determined approximately: from 60...80 mm for small cars and up to 100...120 mm for larger cars.

It is necessary to provide a free space under the front seat where the passenger can place the front of his feet.

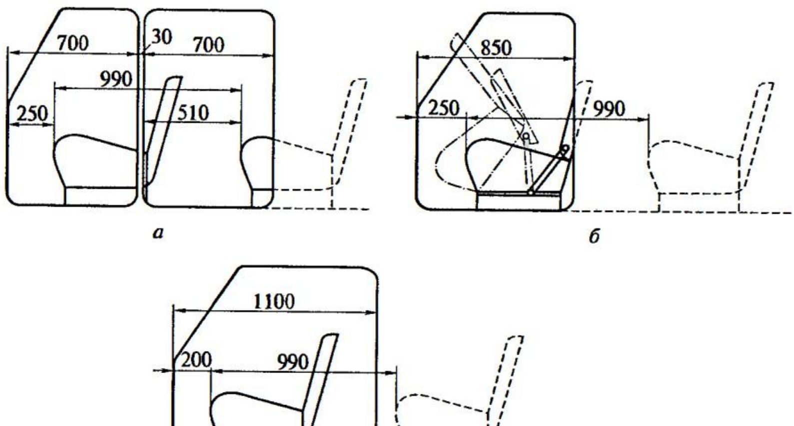
To ensure comfortable seating of the driver and passengers in the vehicle, the doorways must be of sufficient size and rationally positioned relative to the seats. The minimum dimensions of doorways (for passenger cars) are shown in Fig. 7.5.

For trucks, the width of the door opening at floor level must be at least 250 mm and at shoulder level at least 650 mm.



1 – carpet; 2 – rear side of the driver's seat; 3 wheel cover;
4 - floor; 5 - level of the compressed seat cushion

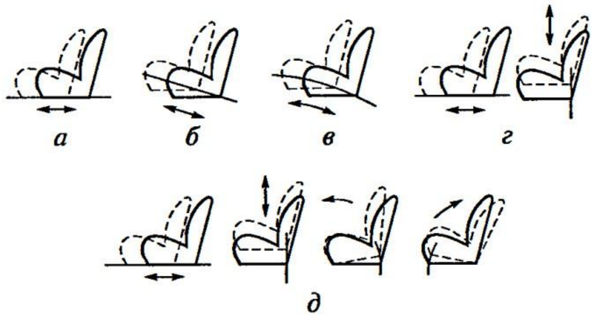
Fig. 7.4. Seating position of a passenger



a - for a four-door body;
b - for two-door body with front folding seats;
c - for two-door bodywork with non-reclining front seats

Fig. 7.5. Recommended relative positioning
of door openings and seats for passenger cars

To ensure a comfortable working posture for a driver of short stature in passenger cars, a 10th-level sitting dummy is placed in the driver's seat. The seat is then adjusted, usually moving it forward and upwards, to achieve the desired comfort. The amount and direction of the required displacement determine the range of seat position adjustment. Fig. 7.6 illustrates the applicable directions of seat adjustment shifts:.



a - adjustment in the horizontal direction
b - adjustment along an inclined trajectory
c - adjustment along an arcuate trajectory
d - separate adjustment in the horizontal and vertical directions
e - separate adjustment in the longitudinal, vertical directions, and angle of inclination

Fig. 7.6. Possible directions of displacement of the driver's seat during adjustment

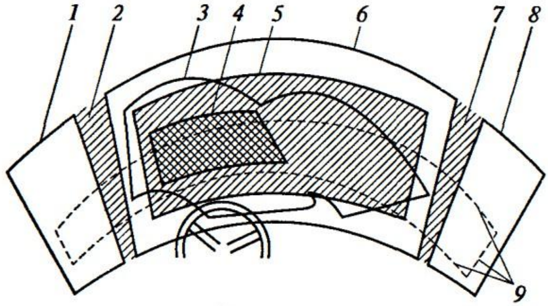
For trucks, the range of adjustment of the longitudinal position of the driver's seat should be at least 100 mm (or 150 mm with a sprung seat), while the vertical position must be at least 60 mm, according to OST 37.001.413-86.

The position of the front pillar of the body or cab determines the placement of the windscreen pillars, allowing designers to choose their shape. However, this decision should align with the general concept of the external architectural design of the body or cab.

7.2 Visibility. Methods of Measurement and Assessment

Visibility is an essential design aspect of vehicles and tractors, defining the driver's ability to perceive visual information required for safe and efficient driving.

The visibility parameters of a vehicle vary depending on its category. Assessing visibility through the windscreen involves identifying conventional zones A and B on the outer surface of the vehicle glass (Fig. 7.7).



1 - boundary of the transparent part of the left side window; 2 - left side pillar of the front window; 3 - front window cleaning contour; 4 - boundary of regulatory zone A; 5 - boundary of regulatory zone B; 6 - boundary of the transparent part of the front window; 7 - right side pillar of the front window; 8 - boundary of the transparent part of the right side window; 9 - traces of planes that are the boundaries of the of the normative field of view P

Fig. 7.7 – Location of regulatory zones A and B of the front window and the normative field of view P

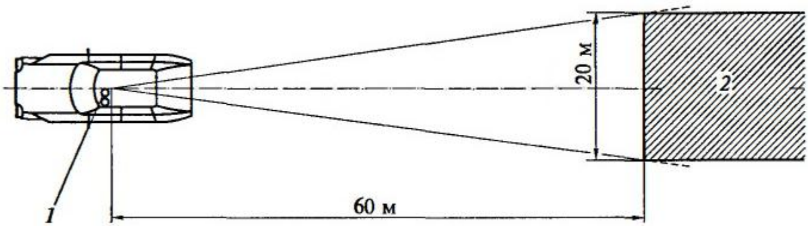
The regulatory zone A is situated inside the regulatory zone B, directly in front of the driver. The regulatory field of view P represents a conditional forward visibility area in a 180° sector between the horizontal plane at the level of the driver's eyes (upper boundary of the field) and three other planes, collectively forming the lower boundary of the field.

Non-viewing areas are not allowed within the regulatory field of view P, except for those created by window posts, frames of swinging windows, rear-view mirrors, wiper parts, and external radio antennas. Additionally, the standard specifies the definition of non-visible areas caused by windscreen pillars, considering human binocular vision.

Every motor vehicle must be equipped with rear-view mirrors that enable the driver to observe the road behind and to the sides of the vehicle in a normal working position.

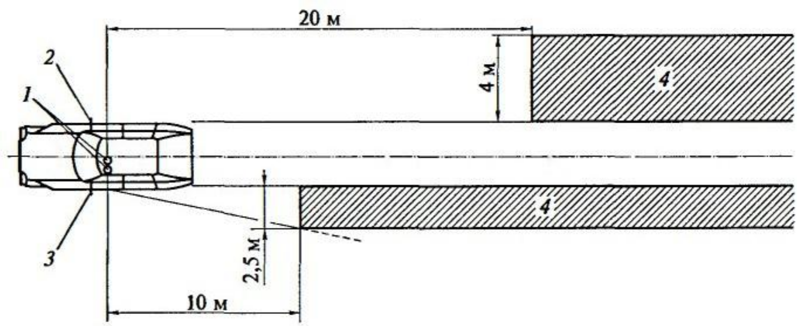
Geometric constructions for determining the field of view through the mirrors are performed from the ocular points corresponding to the driver's eye location, following the procedures described in GOST R 41.46-99. The dimensions and parameters of the mirrors are also specified in the standard.

Fig. 7.8 displays the field of view through the internal rear-view mirror of a passenger car, while Figs. 7.9 and 7.10 illustrate the field of view through the external rear-view mirrors.



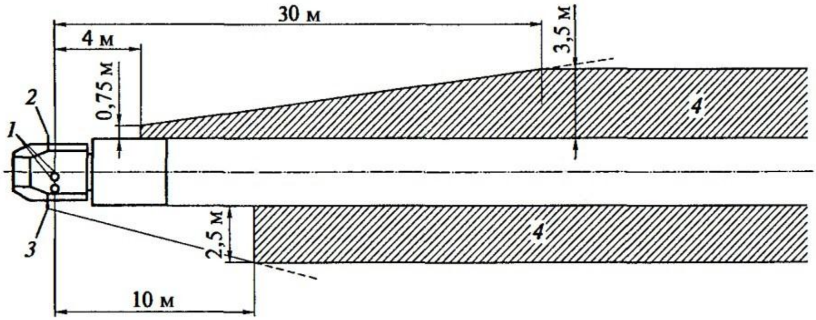
1 – Driver's eyepoints 2 - Field of view at road level

Fig.7.8. Field of view through the internal rear-view mirror



1 - driver's eyepoints; 2 - right exterior rear-view mirror;
3 - left exterior rear-view mirror; 4 - field of view at road level

Fig. 7.9 – Field of view through the external rear-view mirrors of vehicles of categories M1 and N1 weighing up to 2 t



1 - driver's eyepoints; 2 - right exterior rear-view mirror;
3 - left exterior rear-view mirror; 4 - field of view at road level

Fig. 7.10 – Field of view through the external rear-view mirrors in trucks

Based on the information provided, the sequence of actions in the layout of the car driver's workplace can be briefly formulated as follows:

- Place a two-dimensional sitting dummy of the 95th level of representativeness. Select the height of the seat based on the type of vehicle.
- Determine the position of the steering wheel, pedals, and other main controls.
- Arrange the seating position of a passenger in the rear seat (for a passenger car).
- Roughly determine the geometric parameters of the doorways.
- Place a two-dimensional sitting dummy of the 10th level of representativeness on the driver's seat and ensure its comfortable working posture by adjusting the seat position. Determine the required range of seat position adjustment.
- Determine the parameters of visibility through the windscreen and the standard field of view.
- Place rear-view mirrors and ensure visibility through them.
- Proceed to the next stages of designing the interior space of the cab: assemble the dashboard, seats, and other interior elements.

7.3 Sitting Dummies

A human operator sitting on a seat can adopt various postures, which creates a challenge in choosing a suitable reference point to determine the dimensions characterizing the person's position on the seat.

This point should slightly adjust when the operator's working posture changes during driving a car or tractor and should represent typical characteristics of the human body. Additionally, the position of seated passengers can also be determined relative to this point.

In some cases, the point of intersection of the overall outlines of the seat cushion and backrest, facing the body of the seated person, is used as the origin in the side view. However, with soft seats and backrests, this point shifts significantly, making measurements difficult and less reliable.

According to current standards, the starting point for measurements to determine the position of a person's body on the seat in the cab is the point of intersection of the geometric axis connecting the centers of the right and left hip joints with the longitudinal vertical plane of body symmetry.

This point is denoted by the Latin letter H (in design work, it is denoted by the Latin letter R).

The position of the H point remains relatively stable not only during normal working movements of the operator but also when people of different heights and builds are seated on the seat, even if their body sizes differ significantly.

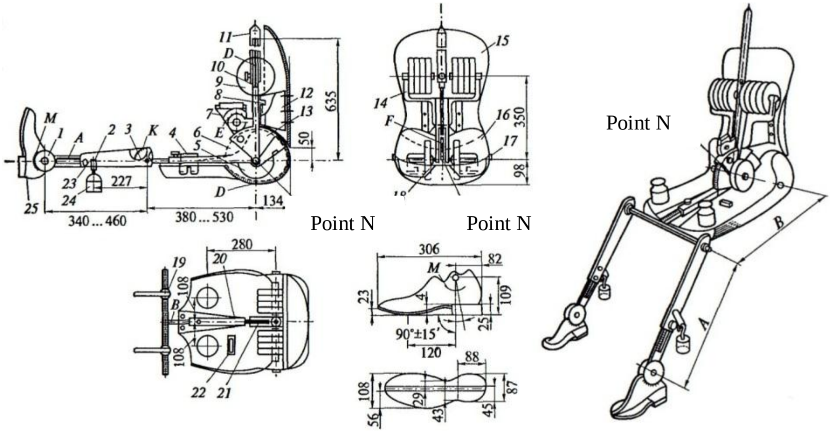
Finding a person whose height exactly corresponds to a specific percentile is not difficult, but the size of individual body parts may differ from that percentile's average.

To facilitate the design process and ensure representative seating positions, mannequins have been developed and standardized (GOST 20304-90) with anthropometric characteristics corresponding to certain percentiles.

These seating dummies are used to determine working postures and other parameters characterizing the position of a human operator on a seat. There are three-dimensional and two-dimensional sitting dummies.

A three-dimensional sitting dummy is used to determine the position of a person in a real car or tractor. It helps determine the actual position of the H-point of the seat.

The dummy is composed of plastic buttock and back panels resting on the seat back, along with steel elements simulating body parts. A three-dimensional sitting dummy is a complex device made with high accuracy (Figure 7.11).



1 - ankle joint; 2 - ankle weight bracket; 3 - knee joint; 4 - hip load; 5 - hip load; 6 - sector; 7 - longitudinal level bracket; 8 - adjusting screw; 9 - back load; 10 - pivot rod; 11 - pivot rod tip; 12 - back panel bracket; 13 - torso skeleton; 14 - bracket of back weights; 15 - back panel; 16 - gluteal panel; 17 - removable stopper; 18 - hip joint axis; 19 - knee joint bracket; 20 - hip skeleton; 21 - longitudinal level; 22 - transverse level; 23 - tibia; 24 - tibial weight; 25 - foot;
A, B, D, E, F, K, M - linear and angular scales

Fig. 7.11 Constructive scheme of a three-dimensional sitting dummy

The dummy is positioned on the seat with a plastic buttock panel, and the back panel, also made of plastic, is placed on the seatback. The standard specifies the shape of these panels.

Other parts of the dummy are constructed from steel. The back panel can be rotated around the axis of the hip joint, relative to the buttock panel.

The skeleton of the hip part extends forward from the hip joint axis and is telescopic, allowing its length to be adjusted to achieve a specific level of representativeness.

At the front end of the hip skeleton, there is a transverse axis simulating the knee joint, and elements mimicking the lower leg are installed on the right and left sides.

These components of the dummy are also telescopic. Weights are added to different parts of the dummy to match the mass of these parts to the masses of corresponding human body parts. The total weight of the dummy is 75.6 kg.

A rotary rod with a tip extends upward from the hip joint axis. The angle of the seat back is measured relative to this rod when it is positioned vertically.

To measure the angle of inclination of the gluteal panel relative to the horizontal, levels are mounted on this panel. The elements of the seating dummy are equipped with linear and angular scales (A, B, D, E, F, K, M), which are used to set their dimensions and relative position accurately.

After placing the dummy on the seat, the first step is to check if the coordinates of the point H coincide with the coordinates of the point R, which are marked in the design documentation.

Then, the actual angle of the seat back is determined using the angular scale of the vertically mounted pivot rod. The angular scales in the dummy's «joints» enable the measurement of angles between these elements.

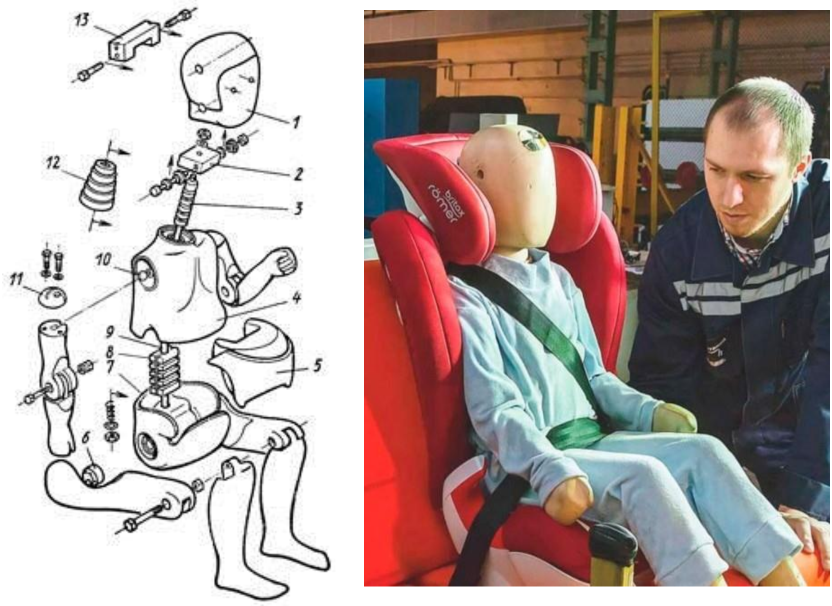
7.4 Dummies for Testing Child Personal Protective Equipment

A child personal protection system is a combination of elements that may include a set of straps or flexible elements with buckles, an additional seat and a shock absorbing device attached to the vehicle body.

Each of the child protection systems is subjected to rollover, frontal and rear impact tests. The dummies used in these tests (Figures 7.12 - 7.14) correspond (in terms of weight) to a 50% level of representativeness of children aged 9 months, 3, 6 and 10 years.

The parts of the dummy are made of polyurethane and attached to a frame made of metal and polyester. The dummy's head is made of polyurethane reinforced with metal bands. Inside the head there is measuring equipment.

The neck is made of polyurethane, the lumbar vertebrae are made of polyamide, and the chest is a frame consisting of a tubular steel frame covered with polyurethane.



1 - head; 2 - hinge block of the first cervical vertebra; 3 - head attachment rod; 4 - upper body; 5 - abdominal liner; 6 - hip ball cylinder; 7 - lower body; 8 - lumbar vertebrae; 9 - spinal column; 10 - shoulder ball joint; 11 - semicircular shoulder joint; 12 - neck elements; 13 - sensor installation unit

Fig. 7.12. Design and general view of the dummy for for testing personal protective equipment for children in a car

The measuring equipment is installed in the recess provided in the chest. The arms and legs of the dummy are made of polyurethane, reinforced with metal elements in the form of square tubes, strips and plates, and the pelvis is made of polyester, reinforced with fibreglass and coated with polyurethane. The shape of the upper part of the manikin pelvis is important for determining the forces acting on the abdominal cavity and corresponds closely enough to the shape of the child's pelvis.

Fig. 7.13. Positioning the child dummy on the seat

Fig. 7.14 Child dummy during testing

7.5 General Principles for the Design of Controls

The following general principles apply to the design of all types of controls, regardless of their purpose or method of operation. The maximum force, speed, accuracy or range of motion required to operate a control should not exceed the capabilities of the weakest and least capable operator, and the normal requirements for operating a control should be well below the maximum capabilities of most operators.

The number of controls should be kept to a minimum and their movement during operations should be as simple and easy as possible. Control movements that follow the operator's «natural» movements are more efficient and less tiring than movements that are awkward or difficult. Control movements should be as short as possible, consistent with accuracy requirements and the «feel» of the control.

Controls should have sufficient resistance to reduce the possibility of accidental activation under the weight of the hand or foot. For controls that require a single application of force or continuous application of force for short periods, a reasonable maximum resistance is half the maximum force developed by the operator. For controls to which forces are applied continuously or over longer periods of time, the resistance should be significantly lower..

On high-speed aircraft or spacecraft where the operator cannot apply sufficient force to the controls without assistance, and where power-assisted or fully automated control systems are required, an artificial semblance of control resistance must be created.

The design should ensure that the controls are within reach of a driver of minimum height, but that the workplace is still spacious enough for a person of maximum height.

Ergonomic requirements for the arrangement of controls

control elements:

- the number and trajectory of working movements should be reduced to a minimum;
- the required function should be performed with the minimum number of operations;
- avoid placing controls that are used in sequence at different heights;
- all controls should be placed in such a way as to reduce the working movements to the movement of the forearm, hand, fingers, allowing shoulder joint movements only in exceptional cases;
- the most important and frequently used controls are placed in the optimal working space, limited to the radius of the arc in the elbow joint - 340 mm;
- emergency and critical controls must be located within optimal reach of the hands;
- secondary controls and indicators shall be located within the maximum reach of the arm (arc radius at the shoulder joint - 550 mm).

If the controls and indicators are to be used sequentially, the following principles of arrangement should be followed:

- The sequence of arrangement should match the sequence of use.
- Controls can be placed in the horizontal plane from left to right, or in the vertical plane from top to bottom. Alternatively, they can be organized in rows from top to bottom and from left to right within each row.
- Controls should be installed at the minimum available intervals to ensure easy access and operation by the driver.
- Indicators and controls should be placed in the same order.

For example, if indicators are arranged horizontally, the corresponding controls should also be placed in the same horizontal order.

When controls are located next to their associated indicators, the driver's hand must not cover the indicator when using the control. For controls operated by the driver's right hand, they should be placed to the right or below the corresponding indicator. Similarly, controls operated by the driver's left hand should be placed to the left or below the corresponding indicator.

If controls and associated indicators are located on different panels, their relative positions on both panels should be the same. Additionally, the direction of movement of the control knobs should coincide with the direction of movement of the indicator arrows to avoid confusion during operation.

Test yourself

1. What is meant by the organization of the driver's workplace?
2. What is the purpose of anthropometric evaluation of projects in their ergonomic study?
3. What characterizes visibility from the driver's workplace?
4. List the methods for measuring and evaluating visibility.
5. What requirements must meet the driver's seat of the car?
6. What are the layouts of the interior space of the car body?
7. What are the purposes of three-dimensional sitting dummies?
8. What are the requirements for vehicle controls?
9. Name the ergonomic requirements for the order of placement of vehicle controls.
10. Tell the general principles of designing controls..

8 DESIGNING THE DASHBOARD

8.1 General Layout of the Dashboard

In principle, driving a car or tractor is the process of continuously adjusting the trajectory and speed by means of controls based on information that the driver receives from the object being controlled and the environment through their senses.

The primary channel for receiving this information is human vision. A substantial portion of this information is obtained by the driver from information display devices (IDD).

Information display devices can come in various types: analogue and digital devices, displays, warning lights, indicators, light boards, and more.

These devices should be positioned in front of the driver, in easily accessible places for inspection. The main collection of these devices is typically placed on a panel commonly known as the dashboard.

When designing the dashboard layout, two key issues must be addressed initially: the positioning of the dashboard and the information it should provide to the driver, i.e., the means of displaying information it should contain.

For vehicles equipped with a steering wheel, the dashboard is usually placed behind it, which may limit the driver's visibility (Fig. 8.1). This relative positioning of the steering wheel and dashboard is common in cars.

To determine the approximate location of the instrument panel in the driver's workplace, the constructions shown in Fig. 8.2 can be used.

The characteristic points V_1 and V_2, representing the driver's eye position, are marked on the side projection of the vehicle.

The position of the steering wheel should also be indicated in the layout drawing. The dashboard must be positioned so that it is visible to the driver only in the space between the top of the steering wheel rim and the steering wheel hub. This forms the basis for the following arrangement.

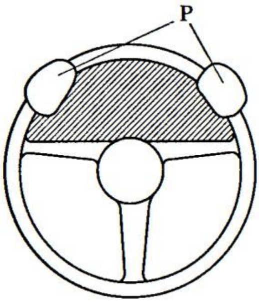


Fig. 8.1. Steering wheel visibility area

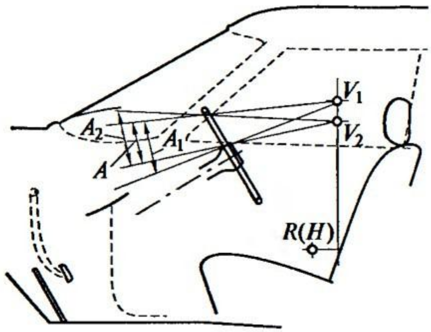


Fig.8.2. Positioning of the dashboard

Two rays are drawn from the upper characteristic point of the driver's eye position V_1: one through the lower edge of the steering wheel rim and the other through the upper edge of the steering wheel hub.

These rays intersect to form segment A1, which will be visible from point V_2. Similarly, two rays are drawn from point V_2, forming segment A_2, which will also be visible from point V_2.

The region of overlap, segment A, as shown in Fig. 8.2, will be visible from both points. The central part of the dashboard should be located in this area.

The longitudinal dimensions determining the position of the dashboard are guided by the following considerations: placing it as close to the driver as possible will make it easier to see small details on the instrument scales, but this may reduce the free space between the panel and the steering wheel to an unacceptable amount.

On the other hand, in a real car layout, the area at the top of the front body panel is extremely saturated with various devices. As a result, it is difficult to place devices that have significant depth dimensions here, especially since the dashboard is usually covered by a visor.

The usual location of the dashboard in depth is determined on the basis of a compromise. The construction shown in Fig. 8.2 shows only the approximate position of the dashboard. The designer should bear in mind that the visibility of the panel will be limited not only from above and below (by the steering wheel rim and its hub in the middle section), but also from the sides.

Fig. 8.1 provides an idea of the actual visibility, including obstructions caused by the steering wheel rim, wheel hub, and the driver's hands in their normal position on the steering wheel (indicated by the letter P). The main means of displaying information should be located in the area highlighted in Fig. 8.1.

However, the shaded area in Fig. 8.1 does not fully represent the real area where the dashboard should be placed, as human binocular vision results in wider side borders of the panel's visibility area. To precisely determine the optimal placement of the dashboard, modern graphic computer programs can be used, but the final decision is usually made after producing the seating layout of the car cabin.

While the traditional location of the dashboard is behind the steering wheel, there are alternative placements for information display devices. These include spaces to the left and right of the steering wheel, on the console in the middle of the vehicle under the front body panel, and in the front of the cabin ceiling. Indicator lights may also be placed above the dashboard, near the lower edge of the front window.

When laying out the instrument panel of a tractor, it is essential to follow the current standards for the placement of information display devices (GOST 12.2.019-86).

The reference point for visibility parameters K is crucial for the layout of the instrument panel, and its position is determined relative to the reference point of the seat. The distance from point K to the surface of the devices with scales and alphanumeric alphabet should fall within the range of 500 to 850 mm, according to applicable standards.

However, in technically justified cases, the tractor's information display devices may be located in other places, as permitted by the standards. The designer must consider the actual layout of the machine and ensure that the dashboard does not obstruct the tractor's visibility, especially considering possible obstructions caused by the steering wheel or levers constantly operated by the driver.

8.2 Information Content of the Dashboard

An important issue that the designer must address is the selection of specific instruments and other information devices to be equipped in a car or tractor, as well as the optimal arrangement of these devices on the dashboard within the limited space of the information field.

The driver primarily receives essential visual information about the road situation, including moving and fixed landmarks from the external environment. The driver uses the instruments occasionally, with each use lasting approximately 0.5 to 0.8 seconds, and the total time of instrument use typically does not exceed 1% of the working time.

During these brief interactions, the driver must quickly identify and select the relevant information from the entire set of data presented on the panel, read and comprehend it, and then apply this information to control the car or tractor using the appropriate controls. Reading the information takes place under conditions of acute time pressure, which further increases with higher speeds and traffic density.

Each time the driver accesses the dashboard, they unconsciously engage in a search task. The time it takes to complete this task depends on several factors, including:

- The total number of elements present in the information field.
- The density of these information field elements and the nature of the background.
- The structure of the information field.
- The route of eye movement while scanning the dashboard.
- The variety of elements in the information field.

One of the primary recommendations is to keep the number of devices on the dashboard minimal yet sufficient to provide necessary information to the driver.

Devices placed on the dashboard should not overlap and should be easily distinguishable, even if they are located under a common glass or covering. The distance between individual devices should be adequate to allow the driver to focus their attention on a specific device without confusion. Additionally, the background of the dashboard should not distract the driver's attention. For example, using dials with different colored pictures, like on wrist or wall clocks, can be a negative example of distracting design.

To reduce the time the driver spends searching for specific information, it is advisable to group different devices (indicators, warning lights, etc.) into separate functional areas on the panel. For instance, information about engine operation, such as crankshaft speed, temperature, and oil pressure, is best obtained from devices that are located close to each other. This area can be highlighted using design techniques such as borders, colors, or other visual cues.

Similarly, the means of displaying information about the parameters of the vehicle's movement, like speed, distance traveled, and total mileage, should be clearly emphasized and streamlined in the information field.

When the device reflects a dynamic process, such as the tachometer indicating an increase in engine crankshaft speed during acceleration, an analog arrow moving smoothly along the scale is more intuitive and easily predictable for the driver. In contrast, a digital device with rapidly changing numbers may be harder to follow. Standards recommend that the frequency of digit changes should not exceed two per second.

Therefore, for dynamic processes like acceleration, an analog device is more suitable. On the other hand, digital devices are convenient for displaying values that change slowly over time, where high accuracy of assessment is desirable. For instance, digital displays are suitable for vehicle mileage, diesel engine hours, etc.

8.3 Design Rules for Gauge Dials

A digitization module represents numbers corresponding to scale distributions. Several types of modules exist:

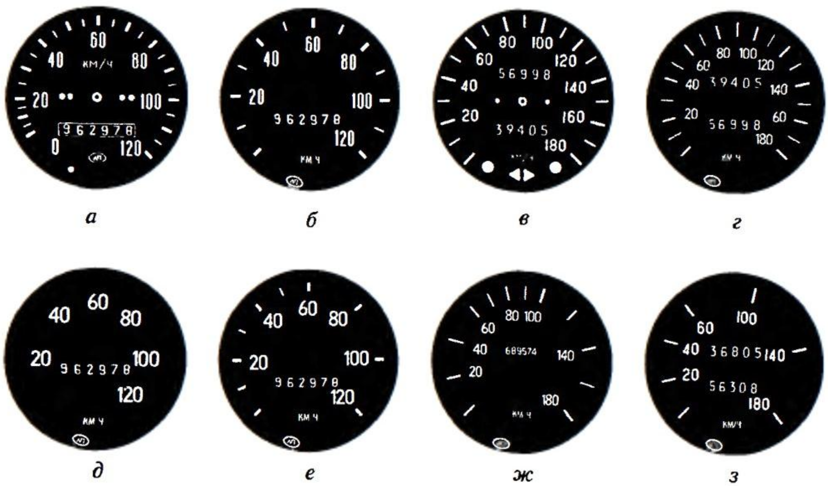
- Single (1...2...3...4...)
- Quinary (5...10...15...20...)
- Decimal (10...20...30...)

The most convenient and least prone to reading errors is the decimal module. When the measured value is expressed in larger numbers, the scale uses the decimal digitization module and indicates a common multiplier, for example, x100. For a tachometer, a unit module with a common multiplier of x1000 can be used, making it easy for the driver to estimate speed in thousands of revolutions per minute.

Fig. 8.3 displays several variants of speedometer scales along with information on the percentage of erroneous readings.

The number of scale divisions should be kept to a minimum and correspond to the actual accuracy of the measuring system. For instance, a fuel level gauge in a tank usually provides an approximate reading due to the complex shape of the tank and the nonlinearity of the float level sensor. In such cases, three divisions on the scale (0 - 1/2 - 1) are sufficient.

The orientation of the digits should be horizontal, especially for stationary scales with a moving arrow. In some cases, the scale can be made rotary, with readings taken as the scale division approaches the stationary pointer. In this case, the orientation of the digits on the scale is radial, but they appear vertically in the reading window.



a - 2% error; b - 6% error; c - 6% error; d - 3% error;
e - 10% error; f - 4% error; g - 10% error; h - 0% error

Fig. 8.3. Different variants of speedometer scales and the readout errors obtained in the tests

When using a rotary scale, at least two numbers should be visible in the window at the same time to allow the operator to predict the next number.

Uniformity of the scale is an important ergonomic requirement. However, some measuring devices in cars and tractors, and their scales, may have significant nonlinearity. In such cases, digitization is made uniform, and main distributions are applied to indicate corresponding values. Although the scale may become slightly uneven, design techniques can often smooth out these irregularities. For example, speedometer scales in the area of very low speeds (where nonlinearity is especially large) may have no distribution, and the arrow may begin to deviate only from a speed of 10 km/h or more.

The direction of the gauge readings is explained in Fig. 8.4. When the readings increase, the arrow (pointer) should move as follows: with a circular scale - clockwise; with an arc and rectangular horizontal scale - from left to right; with a rectangular vertical scale - from bottom to top.

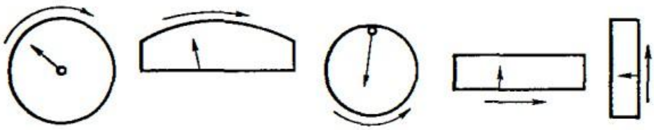


Fig. 8.4. Direction of movement of the device arrow with increasing readings

For gauges of the same size placed side by side, **the system of divisions and numerals** should be the same. If, for example, the speedometer and tachometer are placed in the middle part of the dashboard information field, their scales should have the same size of numerals, basic and additional strokes. The «degree of detail» of the scale should also be consistent. If one of the scales has intermediate divisions of five units in the decimal digitization module, the other scale should have the same divisions.

The location of the pointer and scale divisions should allow the end of the arrow (pointer) to be as close as possible to the scale divisions without overlapping the digitization. It should be noted that this recommendation is often violated in automotive and tractor gauges with a circular scale due to space limitations on the dashboard. However, as long as the location of the main scale divisions is easy to remember and the thin end of the arrow does not completely overlap the digitization, it usually does not cause inconvenience to the driver.

The dimensions of the digits and lines are chosen based on the distance between the gauge and the driver, as well as the overall design of the panel. The usual height of the digits on the scales is 6...10 mm with a line thickness of 0.5...1.0 mm. The width of the stroke most often ranges from 1 to 2 mm, with a length from 5 to 10 mm. Digitized strokes should be significantly thicker and longer than others.

The size of the gauge dials depends on the information displayed: the desired diameter of the scale for instruments carrying the most important information is 120...130 mm, for less important information - 70...80 mm, and for others - 50 mm.

The color scheme is crucial as it significantly affects the reliability of information reading. The optimal color for a car or tractor gauges is matte black with white numbers and strokes. Slightly ‘muted’ white numbers also provide good results, and sometimes the arrow is made orange. Standards require maximum contrast between the colors of the scale (background) and symbols.

Illumination of the gauge dials should ensure good visibility in the dark. This is often achieved by incandescent bulbs located inside the device, illuminating the scale with diffused light. Alternatively, scales can be illuminated by bulbs located behind the scale, which illuminate transparent numbers and strokes. The arrow is illuminated separately. Light guides made of transparent plastic are sometimes used to distribute light inside the device, allowing multiple gauge dials or devices to be illuminated from a single light source.

Buttons and other controls are often illuminated similarly. The brightness of the backlight should be adjustable, as outdoor lighting conditions at night can vary greatly, for example, between city streets and rural roads. Normally, the instrument cluster illumination is automatically switched on when the exterior lights are turned on, but on many vehicles, it can also be independently switched on when the engine is started.

8.4 Warning and Signalling Devices

Very often, drivers only need a warning of a dangerous situation or a signal that a machine is not working properly. The most common devices used to provide simple, unambiguous information are warning lights, mechanical «flags,» and audible signals.

A good warning device should meet the following three requirements:

- Clearly operate and attract the attention of a busy or tired driver.
- Clearly convey what has happened and what actions the driver should take.

- Avoid distracting the driver's attention when they are focused on other important activities.

Attracting attention. For a signal to instantly attract the attention of a busy or tired driver, it must have a high degree of «visibility.» This is especially important if such signals are rare and therefore unexpected. Attention to a signal increases when its size, brightness, volume, or movement increases. However, the signal should not be so intense that it blinds or frightens the driver.

Grouping of signals. The designer can assist the driver in understanding the problem by grouping warning lights or mechanical flags accordingly. Grouping creates a signal that is sharply different from the others, making it easier to detect.

Additionally, by showing the positions of switches, valves, etc. as part of an overall diagram, their operation becomes more apparent. The driver can determine at a glance whether each switch is in the appropriate position and easily notice any changes.

Selecting the type of signals. When selecting a warning signal for a specific application, the designer should consider the urgency of the information, the driver's other duties, and other warning devices in the workplace. Too many warning devices of the same type can confuse the driver, leading to potentially missing critical signals.

Audible warnings are very attention-catching and independent of the driver's eye direction but may be less convenient than visual warnings in conveying specific information. Audible signals should be used only for the most urgent warnings. Signal lights can be quite effective.

By way of location, markings, colours or other types of coding, they can tell the driver what to do, but the driver must always look in the direction of the lights. Other visual signals, such as mechanical flags, are less attention-grabbing. They are good for providing «on/off» information, not for warning. Alarms addressed to other sensory channels (smell, vibration, electric shock) can also be used for warning purposes and are sometimes used for this purpose.

Selecting signal colours. Warning light signals indicate a dangerous situation that requires immediate driver intervention. Red is the most commonly used signal color for danger, as it is widely recognized. Any other signals in the driver's environment should be of a different color. The location, degree of attention-grabbing, and brightness of the signal should also be considered.

Design of the scale. To ensure the clarity of the readings, sufficient intervals between the marks on the scale should be provided. The distinguishing features between large and small graduations should be chosen appropriately. Specific recommendations for scale size depend on the level of illumination of the scale surface.

Scales with normal illumination. For indicators that are sufficiently well-illuminated and do not require low light levels for dark adaptation, the following recommendations can be made under specified conditions: high contrast between the graduation marks and the dial surface, sufficient illumination of the dial surface, and a reading distance of 33-71 cm (Fig. 8.5). The minimum width of the large graduation mark should be 0.32 mm. Although the graduation marks may be spaced 0.9 mm apart, the distance between them should never be less than twice the width of the mark for white numerals on a black dial or less than one mark width for black numerals on a white dial.

The minimum distance between large graduation marks should be 12.7 mm. The height of the large, medium, and small scale markings should not be less than 5.6, 4.0, and 2.3 mm, respectively.

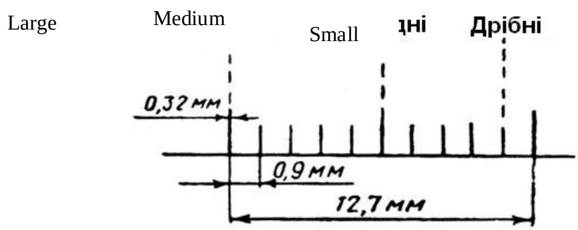


Fig. 8.5. Scales with normal illumination

Scales with low illumination. When the indicator scales need to be read in conditions other than normal (in a dimly lit cab), special measures must be taken to ensure maximum readability. In these conditions, it may be important to vary the thickness of the large and small graduation marks.

The minimum recommended dimensions of the marks and the distances between them (in mm) are depicted in Fig. 8.6, and they are used for the design of scales in low light conditions.

However, these dimensions should not be considered constant and independent of the scale size, the number of graduations on the scale, and the degree of importance of the indication. Instead, they serve as recommended dimensions that should be treated as models for relative scale sizes.

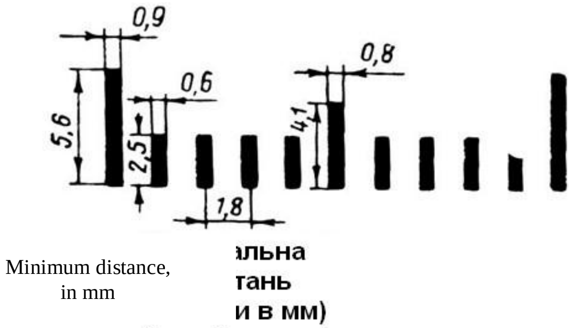


Fig. 8.6. Scales with low illumination

For instance, for the sizes shown in Fig. 8.6, a reading distance of 71 cm is adopted. For other distances, recommended dimensions should be adjusted proportionally to changes in distance.

Design of digital meters. When designing indicators in the form of digital counters, the following recommendations should be taken into account:

- The values of the numbers should change instantly (in a jump), not in a slow, uninterrupted motion.
- Clockwise rotation of the rotary knob of the control should cause an increase in the numerical indication on the counter. The values of the numbers on the counter should increase when the scale moves upwards to ensure compatibility with the movement of the rotary knob of the control (Fig. 8.7a).
- Avoid placing digits too far apart or too close together (Fig. 8.7b).
- Avoid using windows that limit the angle of view and increase the distance between digits (Fig. 8.7c).

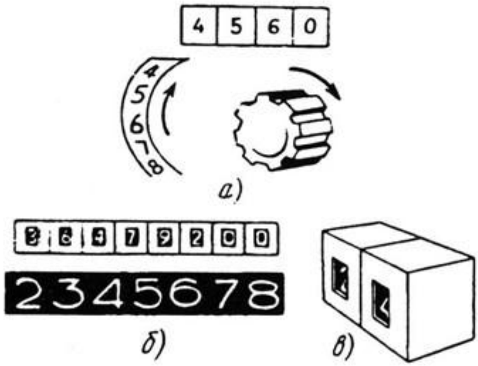


Fig. 8.7. Digital meters

Test yourself

1. What ergonomic requirements should be taken into account when designing a vehicle dashboard?
2. List the main ergonomic requirements for the designed means of displaying information.
3. List the ways to combat the reflection of glass indicators located on the dashboard.
4. List the general principles of indicator design.
5. What recommendations should be taken into account when combining indicators?
6. List the devices for presenting simple ambiguous information.
7. What are the requirements for the placement and grouping of warning lights on the dashboard?
8. What are the advantages of using indicator lights?
9. List brightness requirements for light signals.
10. What is the relationship between the brightness of a light signal and the degree of driver attention?
11. What are the ergonomic requirements for symbolic indicator scales?

9 VEHICLE COMFORT

9.1 Driver (Operator) Fatigue

As a person performs a specific job, various processes take place in their body that can eventually lead to a more or less sharp decline in performance. This condition, influenced by the work being performed, which affects the level of performance, is known as fatigue.

Fatigue is a complex and diverse phenomenon. It may not directly impact the effectiveness of labor activity but can manifest in other ways.

For example, tasks that were previously performed effortlessly, without tension or effort, may require additional focus, effort, and attention after a few hours of work. Although labor productivity may not decrease, the increased effort and tension can be indicative of fatigue.

Another characteristic sign of fatigue is the occurrence of seemingly insignificant mistakes. In certain professions, these errors may not have significant consequences and may not disrupt the production process. However, in some types of work, even small mistakes can lead to serious outcomes, especially in driving professions.

Based on research conducted by experts in engineering psychology, the following **phases of changes in driver (operator) performance** can be observed.

The mental and physiological state of a person in a period preceding work differs from that requires for work. Therefore, in the initial period, there is some «initial mismatch» between the new requirements for the driver and their condition at this moment, the degree of which determines the duration of ‘work induction’ (**the first phase**).

The second phase involves the relatively stable performance occurring once the driver has become accustomed to the job. The duration of this phase depends on the driver's training level and their dynamic and static adaptation.

The third phase implies decrease in performance and reliability due to fatigue. Fatigue is not merely a result of wasted potential but an expression of changes in the central nervous system's functional state.

It affects complex mental processes, leading to deterioration in inductive thinking.

The driver builds a simplified model with a limited number of expected events instead of a full probabilistic model of the road situation. If the situation on the road is different from the (simplified) one assumed by the driver, the probability of an accident increases dramatically. In addition, the motor action performed by the driver also deteriorates, which is manifested in a decrease in accuracy, speed and consistency of movements when driving a car (tractor).

The rate of fatigue development depends on several factors, including dynamic and static adaptation, visual comfort, and the working environment.

Fatigue can adversely affect a driver's ability to navigate the road correctly, quickly, and safely. Research proved that it is not solely a physiological phenomenon; psychological factors and the tension of the human nervous system also play crucial roles in the fatigue process.

In the practice of working as a car (tractor) driver, there are two types of fatigue:

- Natural fatigue, whose effects disappear the next day.
- Excessive fatigue caused by improper organization of work.
- Harmful fatigue, the consequences of which do not disappear on the second day and accumulate unnoticed until they suddenly appear.

Driver fatigue and other deviations during work can be caused by various main factors, such as:

- The duration of continuous driving of the vehicle (tractor).
- The driver's psychophysiological state before starting a trip or shift.
- Driving a vehicle (tractor) at night.
- Monotony and uniformity of driving.
- Working conditions at the driver's workplace..

The most objective evidence of driver fatigue while driving is the number of road accidents, which is closely related to the duration of driving and other fatigue-related conditions. There is a clear correlation between the number of accidents and the duration of work.

It has been shown that the relative number of road accidents increases after 8 hours of work. Initially, the increase is slight, occurring within a period of up to 10 hours. However, beyond the 11-hour mark, the increase becomes particularly intense. During the first hour of work, approximately 12% of road accidents are attributed to the fault of drivers. After 8 hours of work, this percentage rises to about 26%.

The driver's psychophysiological state before departure significantly influences their fatigue, which can worsen due to factors such as lack of sleep and the driver's workload before starting work, leading to mental tension, nervous conflict situations, or mental trauma.

Long-term driver fatigue intensifies when driving at night. This is because the brain is required to perform two simultaneous functions: the first is driving the car, and the second, more challenging task is resisting the natural inclination to sleep.

Monotonous and uniform movement can lead to a particularly dangerous type of fatigue, causing an inhibited state of the driver's higher nervous activity.

This condition can lead to weakness, drowsiness, and falling asleep at the wheel, resulting from the prolonged repetition of the same action.

Experiments have shown that a significant number of road accidents, where the specific cause cannot be determined, occur due to a loss of attention caused by driving on monotonous roads. Interestingly, neither moral nor material incentives, nor the creation of optimal hygienic conditions for some drivers, seem to reduce the number of mistakes made

Thus, driver fatigue should be considered as a combined experience involving physical, mental, and emotional factors. Driving involves elements of physical labor combined with intense mental activity and pronounced emotional stress.

The driver's high neuro-emotional stress results from their constant readiness to respond to sudden changes in road situations, their responsibility for the lives of passengers and pedestrians, and the safety of valuable assets.

Modern car drivers must master high-speed driving, necessitating wide distribution and quick switching of attention, high emotional stability, and strong-willed qualities.

At times, drivers are compelled to perform necessary operations at a very fast pace, pushing their psychophysiological capabilities to the limit. Additionally, working conditions (working position, rhythm and pace of work, work breaks), microclimate (temperature, pressure, air humidity, gassiness, lighting, radiation), and noise and vibration levels also play significant roles in accelerating fatigue and affecting the driver's psychophysiological state.

9.2 Types of Comfort: Climatic, Vibrating, Acoustic

Abnormal climatic conditions inside the cab of a car or tractor can have harmful effects on the driver's health and contribute to accidents. Extreme temperatures, whether too high or too low, can lead to reduced focus, decreased visual acuity, slower reaction times, and increased fatigue in the driver, which may result in errors and accidents.

The most acceptable temperature range in the cab of a vehicle (tractor) is typically considered to be 20...22°C. Deviations from this range, such as temperatures dropping to 13°C or rising to 27°C, can increase the relative risk of accidents (1.5 and 1.6 times respectively).

One of the requirements of occupational safety and hygiene is to prevent the entry of exhaust gases containing various toxic components, including carbon monoxide, into the driver's cabin.

The impact on the driver depends on the proportion of carbon monoxide in the air and the duration of their work as a driver (or operator) in such an atmosphere.

The most characteristic signs of mild poisoning include drowsiness, feelings of fatigue, intellectual passivity, impaired spatial coordination of movements, errors in determining distances, and an increase in the latent period for sensorimotor reactions.

Studies have revealed that even a small amount of carbon monoxide can cause individuals to experience sensations of burning, dizziness, headaches, drowsiness, and loss of orientation.

These deviations can lead to dangerous outcomes such as veering off the road, making unexpected turns of the steering wheel, or falling asleep while driving.

Carbon monoxide can be drawn into the cabin during technical malfunctions, as it travels along with exhaust gases. Being devoid of any smell or color, carbon monoxide remains completely invisible for an extended period. Additionally, a person working in such an environment can be poisoned three times faster than someone at rest.

It's essential to consider that carbon monoxide can also enter the driver's workplace through the exhaust gases emitted by other vehicles' engines.

This poses a significant risk, particularly for drivers of passenger cars, taxis, city buses, and trucks, as they regularly operate in conditions of intense and dense traffic in cities, where highways are filled with exhaust gases.

Air quality studies conducted in driver's cabs and bus passenger compartments have revealed that in some cases, the carbon monoxide content can reach 125 mg/m^3, which is several times higher than the maximum permissible concentration for the driver's working area.

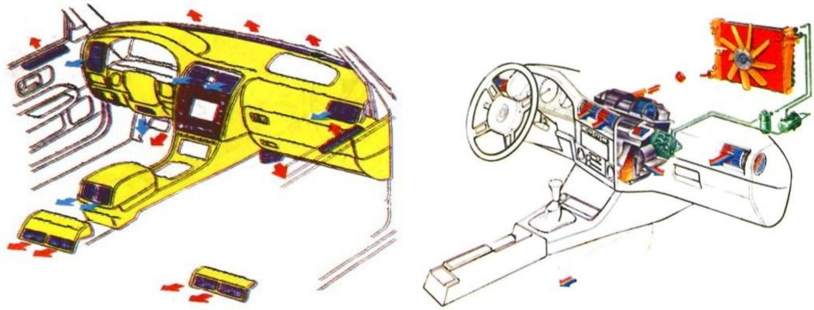
Consequently, prolonged driving for more than 8 hours in urban areas is extremely dangerous due to the potential risk of carbon monoxide poisoning.

Comfortable thermal conditions for a person in the cab involve avoiding overheating or hypothermia, as well as minimizing sudden air movement and other discomforts. Comfortable conditions can vary slightly between winter and summer due to different clothing requirements.

The main factors determining thermal comfort include temperature, humidity, air velocity, surface temperatures of surrounding objects, and radiation levels. Comfortable conditions in both seasons can be achieved through a combination of these factors.

Because heat exchange between the human body and the environment is diverse, selecting a single criterion to characterize comfortable conditions based on environmental parameters is challenging.

As a result, comfortable conditions are typically expressed through a set of indicators that limit individual parameters: temperature, humidity, air velocity, maximum temperature difference between the air inside and outside the body, temperature of surrounding surfaces (floor, walls, ceiling), radiation level, air supply to confined spaces (e.g., body, cab) per person per unit of time, or air exchange rate (Fig. 9.1 a, b).



a b

Fig. 9.1. Examples of multi-zone climate systems in passenger cars

The comfortable values of air temperature and humidity recommended by different researchers are slightly different. For example, the Institute of Occupational Health and Diseases recommends a temperature of 20...22°C in winter and 23...25°C in summer with a relative humidity of 40...60. An acceptable air temperature is 28°C with the same humidity and low air velocity (about 0.1 m/s).

According to the results of French researchers, for light winter work, an air temperature of 18...20°C with a humidity of 50...85% is recommended, and for summer work, 24...28°C with a humidity of 35...65%.

According to other foreign data, car drivers should work at lower temperatures (15...17 °C in winter and 18...20 °C in summer) with a relative humidity of 30...60 % and a speed of 0.1 m/s.

In addition, the temperature difference between the outside air and the inside of the body in summer should not exceed 10°C. The temperature difference inside a limited volume of the body should not exceed 2...3°C to avoid human colds.

Depending on the working conditions, the temperature in winter can be set at 21°C for light work, 18.5°C for moderate work, and 16°C for heavy work to ensure comfortable conditions.

It should be noted that microclimatic conditions in cars and tractors are regulated. For cars, the air temperature in the cab (body) should not exceed 28°C in summer and should be at least 14°C in winter (at an outside temperature of -20°C). During summer, when the vehicle is driven at a speed of 30 km/h, the difference between the internal and external air temperature at the level of the driver's head should not exceed 3°C at an external temperature of 28°C and not more than 5°C at an external temperature of 40°C.

In winter, the temperature in the area of the driver's legs, waist, and head should be at least 15°C at an outside temperature of -25°C and at least 10°C at an outside temperature of -40°C. The air humidity in the cab should range from 30% to 70%. The supply of fresh air to the cab should be at least 30 m3/h per person, and the air velocity in the cab and the vehicle interior should be between 0.5 m/s to 1.5 m/s. The maximum concentration of dust in the cab (cabin) should not exceed 5 mg/m3.

In the tractor cab during the warm season, the air temperature should not exceed 28°C for all zones, with a relative humidity of 40-60%. At the same time, during the warm season (outside temperature of 10°C and above), for areas with an estimated average temperature at 1 p.m. of the hottest month up to 25°C, the air temperature in the cab should not exceed 28°C.

For areas with an estimated average air temperature at 1 p.m. in the afternoon of the hottest month between 25°C and 30°C, the air temperature in the cab should not exceed 31°C. For areas with an estimated average air temperature at 1 p.m. in the afternoon of the hottest month above 30°C, the air temperature in the cab should not exceed 33°C.

The temperature difference in the tractor cab should not exceed 3°C, and the relative humidity should not exceed 60%. In areas with high humidity, a 10% increase in relative humidity is permitted.

During periods when the outside temperature is below 10°C, the air temperature in the cab must be at least 14°C. The direction and speed of air movement in the cab shall be adjustable, and the air velocity in the driver's (operator's) breathing zone should not exceed 1.5 m/s.

The average temperature of all internal surfaces of the tractor cab (except for glass surfaces and the panel located under the dashboard) should not exceed 35°C. Ventilation system devices must create an overpressure of at least 10 Pa in the closed cab. The temperature conditions and air mobility in the cabs of cars and tractors are ensured by heating, ventilation, and air conditioning systems..

9.3 Ventilation and heating systems for the vehicle interior

Currently, there are various ventilation and heating systems used in car and tractor cabs and interiors, each with its own layout and design of individual components. One of the most common and economical heating systems in modern cars utilizes the heat from the engine's water cooling system (Fig. 9.2).

By combining the heating and general ventilation systems, it becomes possible to increase the efficiency of the entire complex of devices to maintain a suitable microclimate inside the cabin throughout the year.

Heating and ventilation systems differ mainly in the location of the air intake on the outer surface of the vehicle, the type of fan used, and its location relative to the heater radiator (at the inlet or outlet of the radiator), the type of radiator used (tubular-plate, tubular-belt, intensified surface, matrix, etc.), the method of controlling the heater operation, and the presence or absence of a bypass air channel, recirculation channel, etc.

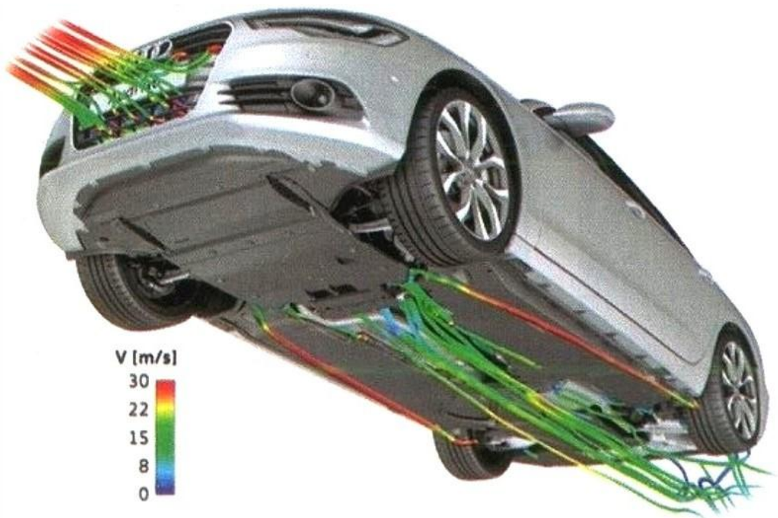


Fig. 9.2. Computer visualization of air flow direction of the engine cooling system of an AUDI car, performed in CATIA to analyze their speed, direction and temperature

Air is drawn from outside the cab to the heater at the point of minimum air dustiness and maximum dynamic pressure arising from the vehicle's movement. In trucks and tractors, the air intake is located on the roof of the cab. The air intake is fitted with water-reflective baffles, louvres, and covers that are operated from inside the cab.

An axial, radial, diametric, diagonal, or other types of fans are used to supply air to the cab and overcome the aerodynamic resistance of the radiator and air ducts. Currently, the most common type is the two-cone radial fan, as it has relatively small dimensions and high performance.

DC electric motors are used to drive the fan. The speed of the electric motor and, accordingly, the fan impeller, is regulated by a two- or three-stage variable resistor included in the electric motor power supply circuit.

The efficiency of the radiator's heat transfer surface depends on its design, technological features, and aerodynamic resistance. To enhance the heat transfer efficiency from the radiator, the channels through which air moves are designed with complex shapes, and various turbulators are used.

The air distributor plays a crucial role in achieving efficient and uniform distribution of air temperatures and velocities within the cab. Air distributor nozzles come in various shapes such as rectangular, round, oval, etc. They are strategically placed in front of the windscreen, near the door glass, in the center of the dashboard, at the driver's feet, and other locations based on the requirements for the desired air flow distribution in the cabin.

The nozzles incorporate various dampers, rotary louvers, control plates, etc., and the drive for these components is often integrated into the air distributor housing.

Air ducts leading to the air distributor are constructed using thin sheet steel, rubber hoses, corrugated plastic pipes, etc. Some cars may use cabin parts or the dashboard cavity as air ducts, but this is not a rational design approach as it may compromise tightness and lead to increased air consumption.

Ensuring the safety of the vehicle and the quality of the technological processes performed by the tractor unit significantly depends on the reliable and effective protection of the windscreen from fogging and icing. This is achieved by evenly blowing warm air onto the windscreen, raising its temperature above the dew point.

Although structurally simple and non-intrusive to its optical properties, this method requires increased performance from the ventilation system and a high heat capacity of the glass. The effectiveness of jet glass protection against fogging is determined by the temperature and air velocity at the nozzle's outlet located in front of the glass edge. Higher air velocity at the nozzle outlet results in minimal temperature differences between the glass area and the nozzle outlet.

The layout of the ventilation and heating system depends on the design of the vehicle (tractor), cab, individual components, and their locations. Unlike automotive heating and ventilation systems, tractors place more emphasis on cleaning the air entering the cab. This is because during tractor operations, such as tillage, a cloud of dust is created around the tractor cab.

During ploughing, sowing winter and spring crops, cultivating, and harrowing, mineral dust with particles ranging from 1 to 5 microns in size and a concentration of up to 1400 mg/m3 near the tractor cab is prevalent in spring and autumn. However, during transport operations, air dustiness near the tractor cab is significantly lower.

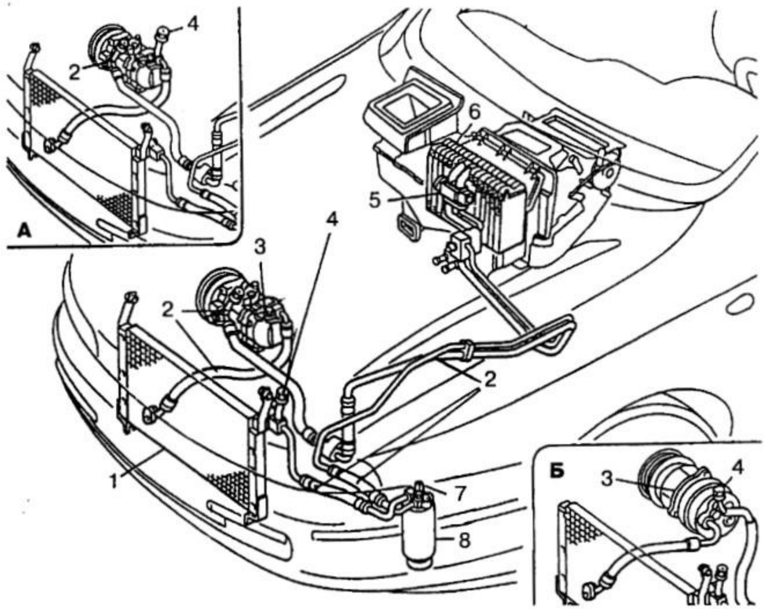
When evaluating the efficiency of a device for cleaning the treated air from dust in the cab heating and ventilation system, an initial dust concentration of 50 to 150 mg/m3 can be used for calculations, with its dispersed composition characterized by dust particles of 5 μm or less.

It should be noted that particles of such highly dispersed dust, being carriers of harmful impurities present in the soil (herbicides, pesticides, mineral fertilizers, etc.), can penetrate deep into the human lungs and accumulate, leading to corresponding negative consequences.

Other harmful impurities in the treated air, such as carbon monoxide, may occur due to improper positioning of the engine exhaust pipe relative to the air intake or air conditioning device or during special technological operations. Reducing the concentration of carbon monoxide in the cab air is primarily achieved through well-known design measures, while special measures are required to protect against other aggressive substances..

9.4 Organisation of the Microclimate at the Driver's Workplace

Nowadays, air conditioners are widely used as devices for artificially cooling the air entering the vehicle cab (or body). Based on their principle of operation, air conditioners are divided into compression (Fig. 9.3) with an air cooler, thermoelectric, and evaporative types.



1 - condenser; 2 - pipelines, hoses; 3 - compressor; 4 - service valves service valves; 5 - thermostatic valve or capillary tube (with diaphragm) of constant cross-section; 6 - evaporator; 7 - pressure switch; 8 - receiver-dryer or accumulator A and B - design variants

Fig. 9.3. Composition of a vapour-compression air conditioner for a passenger car

In some vehicles (tractors), the automatic control of the heater operation mode is achieved by regulating the flow of water or air through the heater radiator. When automatic control is done by varying the air flow rate, a bypass air duct is created in parallel to the radiator, where an electric motor-driven damper is installed.

As we have already noted, an essential aspect of the ventilation system in a vehicle cab (especially in a tractor) is cleaning the ventilation air from dust due to specific working conditions. The most common method for this purpose is to use filters made of cardboard, synthetic fiber materials, modified polyurethane foam, etc. However, for the effective use of such filters, which have low dust capacity and require less maintenance, it is necessary to reduce the dust concentration at the filter inlet. For preliminary air purification, inertial-type dust separators with continuous removal of trapped dust are installed at the filter inlet.

The basic principles of ventilation air dedusting are based on the use of one or more mechanisms of dust particle deposition from the air: the inertial separation effect and the effects of entrapment and deposition.

Inertial deposition occurs during the curvilinear movement of dusty air under the influence of centrifugal and Coriolis forces. Particles with significant mass or velocity are thrown onto the deposition surface and cannot follow the air along the flow line as it bends around the obstacle.

Inertial deposition occurs when obstacles such as filter media made of fibrous materials, the ends of flat sheets, inertial louvers, etc., are encountered by dusty air.

When dusty air moves through a porous partition, particles suspended in the air are retained on it, and the air passes through it completely. Studies of the filtration process aim to establish the dependence of dust collection efficiency and aerodynamic drag on the structural characteristics of porous partitions, dust properties, and air flow regime.

Among the variety of filter materials used in the filters of the cabin ventilation air dedusting system, three groups can be distinguished: woven filters made from natural, synthetic, and mineral fibers; non-woven filters such as felt, paper, cardboard, etc.; and cellular filters made of materials like polyurethane foam, sponge rubber, etc.

A significant disadvantage of filters made of any filter material is the need to replace or maintain them for regeneration (restoration) of the filter material. Partial regeneration of the filter can be carried out directly in the ventilation system by blowing back the filter material with purified air from the vehicle cabin or by jetting local air from the compressor with preliminary purification of the compressed air from water and oil vapors.

The design of filters made of woven or non-woven filter media for cabin ventilation systems should have a maximum filtration surface with minimum dimensions and aerodynamic drag. The installation of the filter in the cab and its replacement should be convenient and ensure reliable sealing around the perimeter of the filter.

Test yourself

1. What is fatigue and what are the signs of driver fatigue?
2. What are the main phases of driver performance change?
3. How does the microclimate in the driver's workplace affect the safety of the vehicle?
4. What regulations define the ventilation system of the car interior?
5. List ergonomic requirements for heating and ventilation systems of the car interior.
6. How do noise and vibration affect the comfort of movement?
7. List constructive measures to suppress noise and vibration in vehicles.
8. Which temperature conditions in the car interior meet the conditions of comfort?
9. What are the basic principles of dedusting ventilation air?
10. Name the main types of filter materials.
11. What is the difference between tractor heating and ventilation systems and automotive systems?

10 BODY AND CAB INTERIOR

10.1 Body and Cab Interior Layout

When designing the interior of a passenger compartment or a car or tractor cab, it is necessary to determine the geometric parameters of the space in which people will be located, arrange sufficiently comfortable seats, and finish the interior surfaces.

The designer involved in the layout of the car or tractor cab faces a complex and contradictory task.

On the one hand, they should strive to reduce the space since it would require fewer materials to make the vehicle, resulting in a lighter and more cost-effective product.

On the other hand, providing a sufficient level of comfort for the person in the cab or body, especially a comfortable driving position, is essential. The layout of interior spaces in passenger cars, buses, and tractors significantly differs, and each must be considered separately.

10.2 Passenger Compartment Layout

Figure 10.1 illustrates a schematic side view of the passenger compartment. The position of the driver is determined by the coordinates of point H1(R1) relative to the body elements (a and f in Fig. 10.1).

In the layout drawing, designers try to place a two-dimensional dummy of a passenger representing the 95th percentile in such a way that their knees do not rest against the back of the front seat, and the seat height provides a comfortable fit without excessively reducing the distance from point H2(R2) to the roof.

For a middle-class car, the following dimensions can be considered (Fig. 10.1): b=650 mm; c=345 mm; e=850 mm. The size of g will be close to 800 mm.

However, please note that these are approximate dimensions, and their specific values are determined in the actual layout process. These dimensions depend on factors such as the intended body silhouette, driver's seat height, and other considerations, primarily the class of the car.

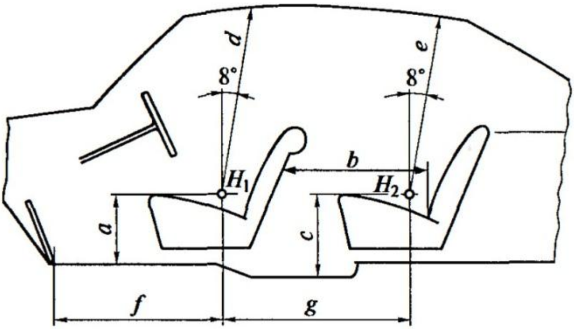


Fig. 10.1. Passenger Compartment Layout

The coordinates of the points H1 and H2 are determined while considering the deformation of the seat cushion and backrest due to the weight of the seated person. In the layout of a small car, the passenger seat will be placed closer to the driver's backrest, and a dummy of the 50th level of representativeness may be used.

As an indication, we also provide dimensions related to the front seat: a = 260 mm; f = 800 mm; d = 875 mm. The depth of the seat is usually 480...520 mm, and the actual height of the backrest in contact with the passenger's back is 540...600 mm. For the driver's seat, the depth is 450...500 mm, and the actual height of the backrest is 500...560 mm.

All dimensions mentioned in the above layout should be considered as minimum permissible values. The constructions made in accordance with Fig. 10.1 allow us to determine the side projection of the passenger compartment. The width of the passenger compartment, and consequently of the entire vehicle, is significantly dependent on the width of the seats

10.3 Bus Interior Layout

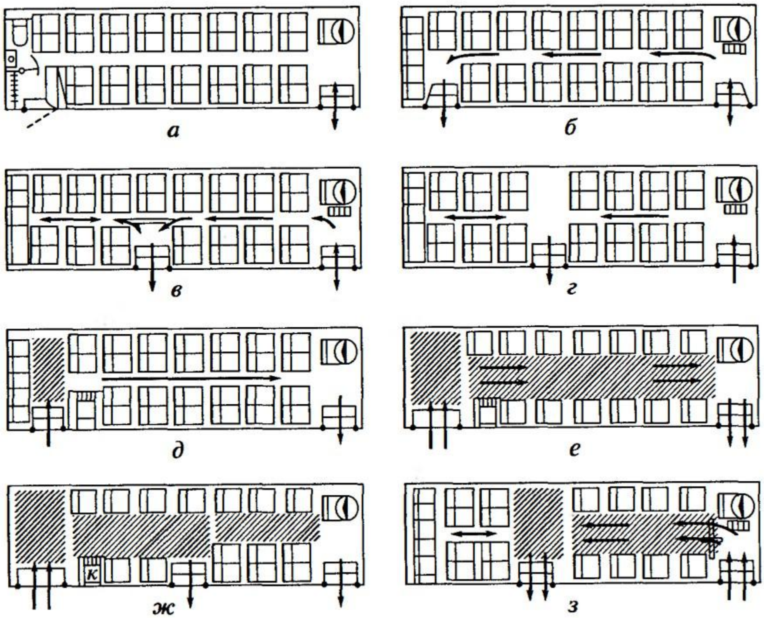
According to applicable standards, buses can be categorized into large and small capacity buses. Large-capacity buses, designed for the transportation of more than 22 standing or seated passengers, have an overall width exceeding 2.3 meters and are divided into three classes:

I - city buses;

II - intercity buses;

III - tourist buses.

Suburban buses occupy an intermediate position between city and intercity buses; they are not allocated to a separate class and exhibit features of both. Public transport vehicles designed to carry less than 22 passengers, excluding the driver, are often referred to as small buses. Some of the possible bus layouts are depicted in Fig. 10.2.



a - tourist buses; b, c - intercity buses; d, e - suburban buses; f, g, h - city buses; (arrows indicate the movement of passengers during boarding and alighting; shaded area for standing passengers)

Fig. 10.2. Bus interior layout

City buses are designed to provide seats for standing passengers and ensure their unimpeded movement. Intercity buses are primarily used for the transportation of seated passengers, but they may also allow passengers to stand in the aisle and/or in designated areas. Tourist buses, on the other hand, are exclusively intended for the transportation of seated passengers and are equipped with comfortable seats, a toilet, a bar, or a buffet.

For weight considerations, it is assumed that a passenger on a city bus has an average weight of 68 kg, while a passenger on a tourist or intercity bus weighs 71 kg (including 3 kg of hand luggage). A standing passenger on a city bus occupies an area of 0.125 m^2, while on an intercity bus, the area is 0.15 m^2.

Buses are required to have a specific number of doors, including service doors, which are used by passengers during regular operation, and emergency doors, utilized in exceptional circumstances or during emergencies. Emergency exits, such as windows or hatches, are also provided.

The standard regulates geometric parameters and the number of exits, passages, and stairs. The minimum number of service doors depends on the number of passenger seats and the class of the bus. Each bus must have at least two doors. The width of a single service door must be at least 65 cm, while the width of a double door must be at least 120 cm..

To check the width of the aisles in buses, a special control device is used, consisting of two coaxial cylinders with a cone between them (Fig. 10.3). The device should move freely in the aisle.

Bus passenger seats can be individual or directly adjacent to each other in width. The dimensions of the width of bus passenger seats are shown in Fig. 10.4.

For all classes of buses, the minimum dimension G for a double seat is 225 mm, and for an individual seat, it is 250 mm. The dimension F, which characterizes the width of the seat cushion, is 200 mm for buses of classes I and II, and 225 mm for class III.

The longitudinal dimensions are of great importance as they determine the size of the seats themselves and the pitch of their location along the cabin. These parameters also determine the size of the cabin or, if its length remains unchanged, the passenger capacity of the bus. The distance between the seats H and the height of the seat cushion I are shown in Fig. 10.5.

Usually, seats are arranged so that passengers face the direction of travel. The floor of the city bus is made as low as possible, but the wheel covers of the rear wheels protrude above the floor and prevent the placement of seats. In the area of the wheel covers and in the front of the cabin, some seats are installed facing backward to accommodate additional seating.

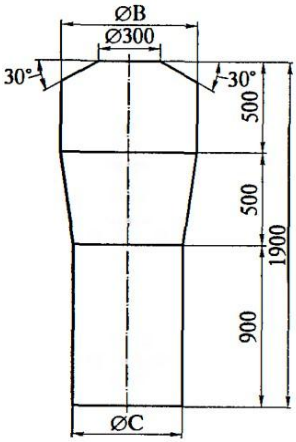


Fig. 10.3. Control device for checking aisles in the bus cabin

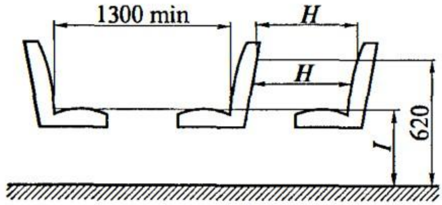
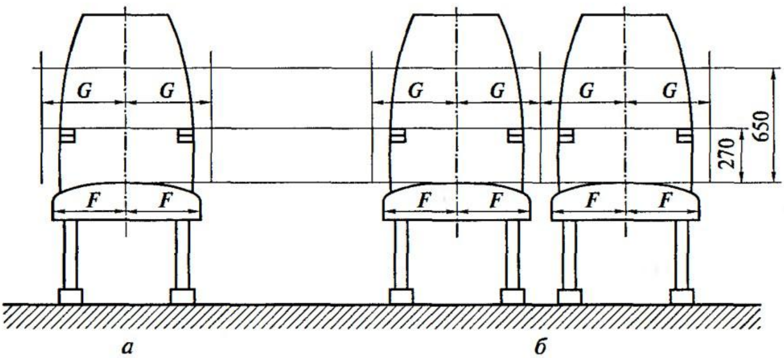


Fig. 10.5. eat spacing H and seat cushion height I



a - single seat; b - double seat

Fig. 10.4. Dimensions of the width of bus passenger seats

10.4 Seats

Automotive and tractor seats differ from seats intended for use in homes and public places (armchairs, sofas, chairs, etc.) primarily because they are part of a moving object and are subject to dynamic influences. These differences define the specific requirements that car and tractor seats, especially the driver's seat, must meet.

These seats must ensure:

- A comfortable posture for the driver and passenger.
- A favorable distribution of pressure on different body parts.
- Protection of a person from vibrations and other dynamic impacts.
- ransmitting the necessary dynamic influences to the human body (driver) so that they can perceive and «feel» the car or tractor.
- Fixation of the body in a certain position, especially against horizontal dynamic forces.
- The ability to change posture for increased comfort during extended periods of use.

The seat upholstery material should be vapor-permeable to allow air circulation, while also providing necessary thermal insulation. Additionally, the seat upholstery should be resistant to dirt, easy to clean, wear-resistant, and not cause wear to clothing. These factors contribute to the longevity and comfort of the seats in automotive and tractor applications.

Test yourself

1. How does the process of laying out the interior of a car begin?
2. How do the shape and size of car seats affect the comfort and safety of driving?
3. What are the ergonomic requirements for the design of vehicle seats?
4. What are the functions of the seat in the vehicle?
5. What are the basic requirements for placing a dummy in the passenger compartment of a car during layout?
6. What factors determine the design and overall dimensions of the seats?
7. Name the most common layouts of bus interiors.

11 STRUCTURAL SAFETY OF VEHICLES

11.1 Factors and Causes of Road Traffic Accidents

The constant growth of the vehicle fleet leads to an increase in the density and intensity of vehicle flows on the roads. The increased dynamic properties of vehicles, coupled with a rise in the number of passenger cars driven by individuals lacking sufficient driving skills, contribute significantly to the escalation of emergency situations leading to road accidents.

Every year, over 10 million people worldwide are killed or injured in road accidents. Road traffic accidents are one of the most critical socio-economic problems faced by many countries with a large number of road transport vehicles.

Road traffic accidents cause substantial socio-economic damage to society. According to the World Bank, the global economic losses from these accidents amount to approximately $500 billion per year.

In accordance with the Rules for recording road accidents, they include events that occurred during road traffic and involved vehicles, resulting in casualties, injuries, damage to vehicles, cargo, or structures.

11.2 Active and Passive Safety

Active safety is a property of a vehicle that reduces the likelihood of an accident. The analysis of active safety features allows us to group them into the following main categories with a certain degree of conventionality:

- Properties that are largely dependent on the driver's actions in driving the vehicle (traction and speed, braking, stability, controllability, information).
- Properties that do not depend or depend to a small extent on the driver's actions in driving the vehicle (reliability of structural elements, weight, and dimensions).
- Properties that determine the possibility of effective driver activity in driving a vehicle (driver's workplace).

Passive safety, on the other hand, is a vehicle's property that reduces the severity of the consequences of an accident. Passive safety comes into play when the driver, despite taking safety measures, cannot change the nature of the vehicle's movement and prevent an accident.

The impact process in the event of a collision between vehicles (tractors) either with each other or with a fixed obstacle is divided into three phases. During the first phase, the colliding bodies deform as they approach, converting part of their kinetic energy into potential energy and partially consuming it by the destruction, displacement, and heating of parts..

In the second phase, the accumulated potential energy is again converted into kinetic energy, and the bodies begin to move apart as they rebound. During the third period, the bodies are no longer in contact, and their remaining energy is spent on overcoming external resistance.

In the most severe accidents, such as collisions with other vehicles or hitting fixed obstacles, the car body, truck frame, and tractor frame are deformed first, and ***the initial impact*** occurs. The kinetic energy is used to break and deform these parts.

The person inside the body (cab) of the vehicle continues to move by inertia at the given speed. The forces that hold their body (muscle forces of the limbs, friction forces on the seat surface) are relatively small compared to the inertial loads, and they cannot prevent movement.

When a person comes into contact with vehicle parts (such as the steering wheel, dashboard, windshield, etc.), a ***secondary impact*** occurs. The parameters of the secondary impact depend on the speed and deceleration of the vehicle, the movement of the human body, and the shape and mechanical properties of the parts that the person hits.

At high vehicle speeds, ***a tertiary impact*** is also possible, involving an impact on the internal organs of a person. The resulting overloads can lead to serious damage to internal organs and the destruction of blood vessels and nerve fibers. Most injuries to drivers and passengers occur during the secondary impact.

In oncoming car collisions and when a car hits a stationary obstacle, the deceleration is particularly large in the area of the front bumper and can reach values of (300...400)g, gradually decreasing towards the rear of the car (Fig. 11.1). The average deceleration value at the center of mass of the vehicle can be around (40...60)g.

However, instantaneous values of the deceleration at the center of mass are higher than the average and can reach (80...100)g.

During the secondary impact, the deceleration of the human body is even greater, leading to additional forces and stresses on the body. This can result in more severe injuries to drivers and passengers.

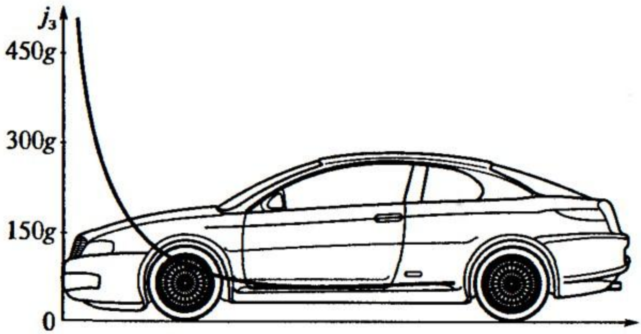


Fig. 11.1. Changes in deceleration along the length of the car when it hits a stationary obstacle

To ensure the safety of the driver and passengers in the passenger compartment of a car body, it is essential to create conditions that allow individuals to withstand a rapid change in kinetic energy.

This is achieved through controlled deformation of the car body during a collision, which creates a protective zone around the driver and passengers (Figure 11.2).

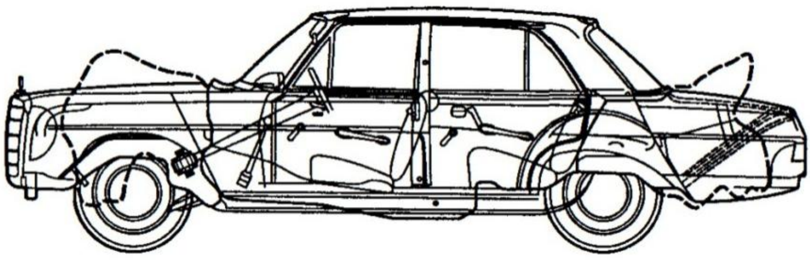


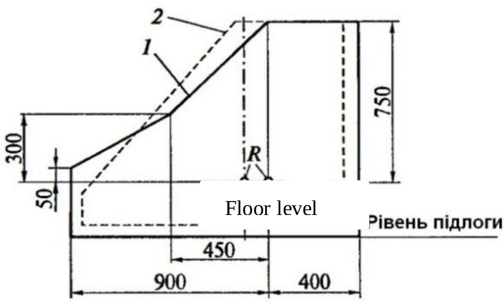
Fig. 11.2. The optimal nature of the deformation of the front and rear parts of the car, when hitting an obstacle and during a rear impact, respectively

11.3 Life Space

The life (residual) space refers to the protective zone around the person sitting in the vehicle (tractor), into which parts must not penetrate in the event of an accident.

The required size of the life (residual) space is achieved through the impact resistance properties of passenger car bodies, truck and tractor cabs, and by eliminating the possibility of injury to people by interior elements.

Fig. 11.3 shows the recommended life space for passenger cars. Additionally, in a frontal collision of a car (tractor) with an obstacle, the driver and passenger may be propelled against the front dashboard and windshield, potentially leading to injury (Fig. 11.4). Measures are taken to minimize such risks and protect the occupants during an accident



1 – in Italy; 2 – in the USA

Fig. 11.3. Recommended life space in a passenger car

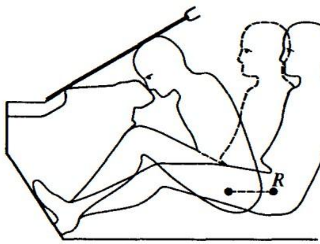


Fig.11.4. Relative head and knees positions during the impact

To enhance safety, parts that could limit the life space within the vehicle should be designed with consideration for occupant protection. This includes avoiding sharp edges and corners, and ensuring that protruding parts such as buttons, switches, and handles are recessed and covered with soft upholstery.

Furthermore, levers, switches, conventional and pull-out buttons located on the dashboard, within the potential impact zone of the driver and passengers, and protruding 3 to 9.5 mm above the dashboard surface must have a minimum cross-sectional area of 200 mm^2 and rounded edges with a radius of curvature of at least 2.5 mm.

The life space in the truck cab is determined through simulated rollover and frontal collision tests. In compliance with GOST R 41.69-99 (UNECE Regulation No. 66), the results of the side rollover tests are used to establish the life space, as shown in Fig. 11.5.

11.4 Protective Systems

Head restraints. In most cases, the effects of inertial forces in the front and rear directions on a person when the vehicle is hit from behind do not cause injuries, as the seat and backrest cushions act as good shock absorbers.

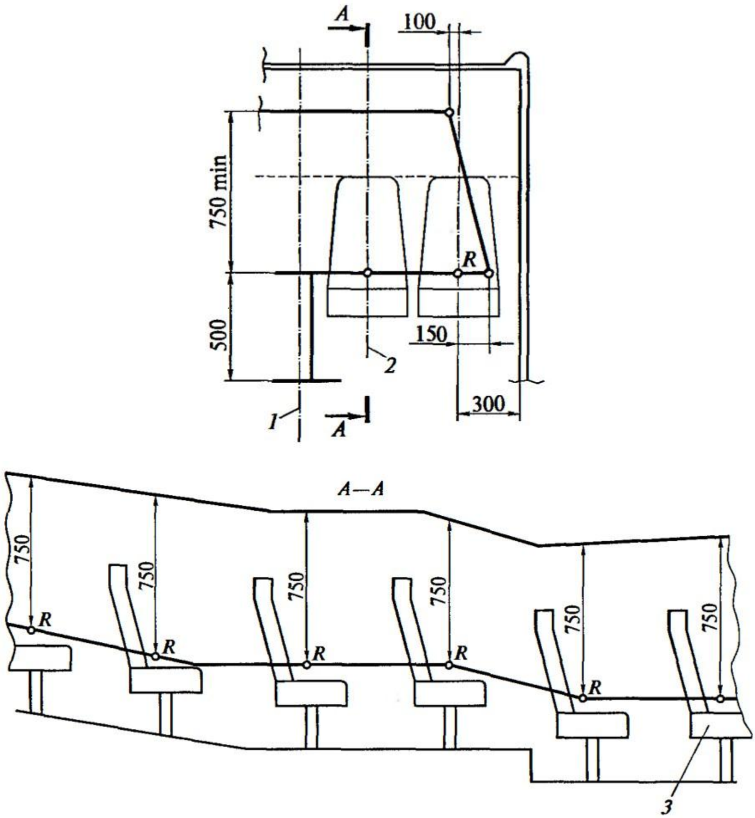
However, in the event of a sharp rear impact, the head may move backward abruptly, potentially damaging the ligaments in the neck and cervical vertebrae.

More severe injuries to the cervical vertebrae can occur if the edge of the backrest is excessively high, reaching shoulder or neck level. To prevent serious consequences, head restraints are used. Currently, head restraints are mandatory in passenger cars.

11.5 Seat Belts

Among the various protective systems available, the most commonly used ones are seat belts and airbags. Other systems, such as safety nets, padded interior linings, or inflatable belts, are not yet sufficiently developed.

Figure 11.6 shows different designs of seat belts, including the diagonal lap belt with three-point anchorage - known as the three-point belt, as well as double shoulder and lap belts.

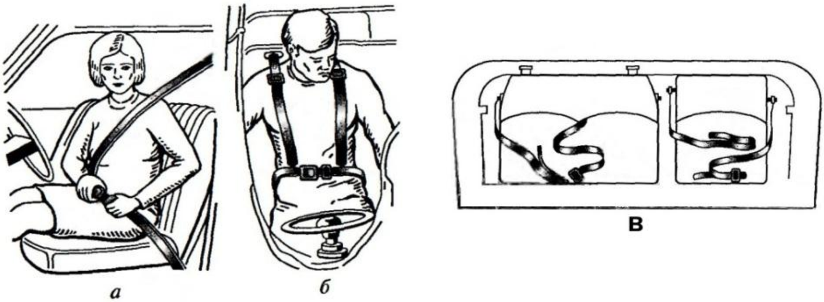


1 – center line of the vehicle; 2 - center line of the seats;
3 - front passenger seat of the vehicle

Fig. 11.5. Life space in a bus

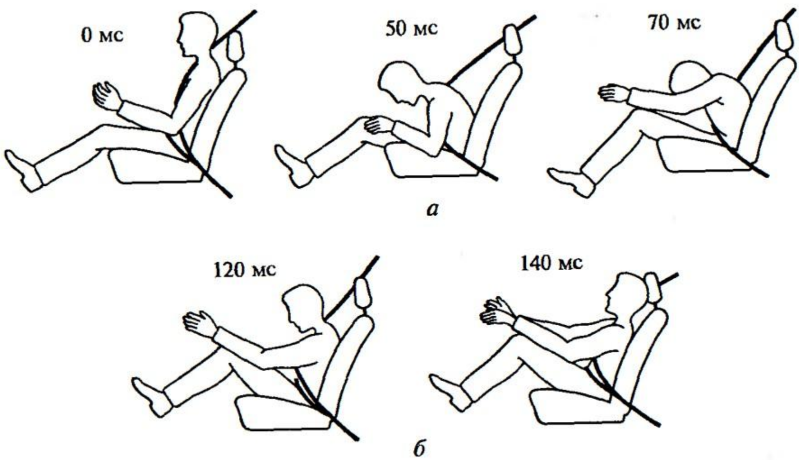
Three-point belts are primarily used in passenger cars, while lap belts are commonly found in trucks, and double shoulder belts are often used in racing cars. The movement process of a person secured with a three-point safety belt during a frontal collision of a passenger car is illustrated in Fig. 11.7.

Studies on seat belt usage have demonstrated significant safety benefits. The reduction in the number of fatalities in road accidents with the use of seat belts is approximately 73% in a frontal collision with an obstacle at an initial speed of 64 km/h, 30% in a side impact, and 50% in a rollover.



a - diagonal lap belt with three-point anchorage (three-point);
b - double shoulder harness; c - lap harness

Fig. 11.6. Seat belts



a - forward movement; b - reverse movement

Fig. 11.7. Phases of movement of a dummy secured with a three-point safety belt in a frontal collision

The optimal position of the three-point seat belt is shown in Fig. 11.8. The seat belt strap must be made of a single piece of webbing, and any loose ends of the webbing should be cut, melted, or otherwise secured to prevent unraveling. The strap must be elastic and provide the most even distribution of the load on the body, remaining untwisted in both free and tensioned states.

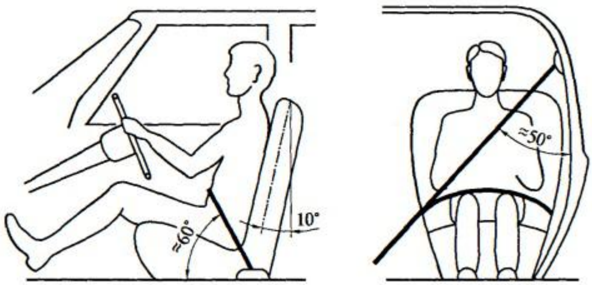


Fig. 11.8. Optimal position of a three-point seat belt

The recommended width of the seat belt strap is 55 mm, with a thickness of 1.5 to 1.8 mm. When subjected to strength testing, the width of the belt measured without stopping the test machine under a load of 9800 N must be at least 51 mm.

Improvements to seat belt designs can be made in the following main areas:

- Implementation of systems that prevent the engine from starting if the belt is not fastened, encouraging passengers to use seat belts for their safety.
- Adoption of systems that do not require fastening the belt when entering the car and automatically unfasten it when leaving the car, simplifying the process for occupants.
- Utilization of inertial reels that enable the seat belt to unwind freely during smooth human movements while effectively locking it during sudden accelerations (0.4...0.5 g). This feature enhances comfort and safety during various driving conditions.

11.6 Airbags

One of the most effective ways to limit the movement of drivers and passengers in a collision is by using airbags. Airbags deploy rapidly and provide protection regardless of the occupants' actions. The operation scheme of airbags is shown in Fig. 11.9, where they not only protect the head but also the upper body in case of oncoming impacts.

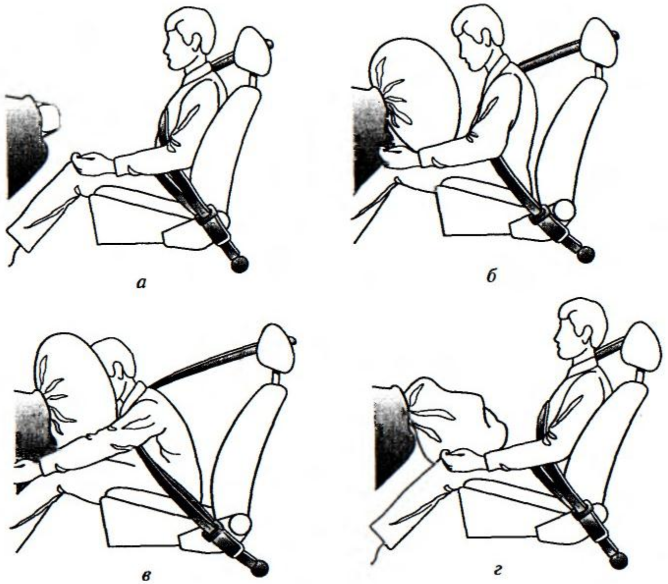


Fig. 11.9. Airbag action diagram

The implementation of inflatable airbags has shown significant results in reducing fatalities. In frontal collisions with an obstacle at a speed of 56 km/h, the use of airbags reduces fatalities by 57%, and at a speed of 48 km/h, the reduction is as high as 64%.

The protective system utilizing airbags comprises sensors, a drive device with an energy source, a gas generator, a distribution device, and inflatable bags. These sensors detect the onset of an impact by measuring either the deformation of parts or the deceleration of the vehicle. To ensure reliability, two sensors are often installed: one on the front of the car and one inside the body. Once an impact is detected, the sensor signal is transmitted to the drive device, which usually contains a detonator ignited by an electric spark.

Gas generators play a crucial role, and they are cylinders containing nitrogen or argon compressed to 200...250 MPa, or pyro cartridges with solid fuel. The detonator, when triggered, ruptures the metal partition in the cylinder or ignites the pyro cartridge. This process takes approximately 0.05...0.015 seconds, after which the gas is expelled at high speed into inflatable bags. Sometimes a single compressed gas cylinder is used in combination with one or two pyro cartridges to achieve the desired effect.

The inflatable bags, typically made of thin rubber or nylon with a thickness of 0.3...0.4 mm, are strategically placed in the steering wheel hub, dashboard, and front seat backs when folded. Upon deployment, the airbags inflate rapidly, filling the space in front of the driver and passengers within 0.015...0.020 seconds, effectively protecting them from impacts.

To prevent occupants from being thrown back by the force of the inflated airbags and to maintain road visibility, the gas inside the airbags is designed to escape through special calibrated holes within 0.4...0.5 seconds after a person hits them. This controlled release of gas ensures that the airbags provide sufficient protection while allowing for a gradual deflation to avoid hindering the driver's vision and further injury to occupants.

11.7 Protective Cabins and Protection Systems

To ensure the safety of tractor drivers (operators) during tractor rollovers, protective cabs or ROPS (Roll-Over Protective Structures) and FOPS (Falling Object Protective Structures) devices are installed. ROPS protects the operator in all possible rollover situations, under the following conditions: driving at speeds up to 16 km/h on clay surfaces with a maximum slope of 30°, and the tractor rolling over 360° relative to the longitudinal axis without losing contact with the ground.

Protective cabs come in different designs, including two-post (arched) and multi-post (four- and six-post) frames. Based on operating conditions and typical emergencies, agricultural tractor cabs are often equipped with four- and six-post frames. However, some tractors may have two-post frames with a reinforced front roof and front cab pillar.

For industrial tractors, two- or six-post frames with a ROPS protective arch integrated into the cab structure or located outside the cab are commonly used to ensure the safety of the operator in case of rollovers or falling objects. These protective structures play a crucial role in preventing injuries and providing a safer working environment for tractor operators.

Test yourself

1. Name the factors and causes of road accidents.
2. What is active safety?
3. Tell about the loads that occur in a collision.
4. Describe the design of seat belts.
5. How is driver safety ensured in the event of a vehicle rollover?
6. What is passive safety?
7. Name the main protective systems used in cars.
8. What is the life space and what does it provide?
9. Name the main directions of improvement of seat belt designs.
10. What are the use of airbags?
11. Tell about the protection systems of tractor cabs.
12. Why are head restraints used on seats?

12 MAN-MACHINE-ENVIRONMENT SYSTEM

12.1 General Information About The Human-Machine System (HMS)

The movement of a car or tractor on a road or any other terrain can be understood as the functioning of a human-machine-environment system (HMES). This system, denoted by the abbreviation HMES, consists of the driver, the vehicle (car or tractor), the road, and the surrounding environment, all of which work together in a cohesive manner.

When these components function together, they exhibit emergent properties that are not present in each individual component of the system. Each component of the HMES can be seen as a lower-level system, creating a hierarchical structure where parts are organized from the highest to the lowest level.

The HMES system is part of a higher-level system, the Vehicle and Transport Systems (VTS), which includes various transport modes such as railways, waterways, and air transport, in addition to road-based vehicles.

Furthermore, the VTS system is also connected to even higher-level systems like the transportation systems of a region, country, and the entire world.

The key attribute of the entire system, including the ATCS (Automotive and Tractor Control System), is its reliability. Reliability refers to the ability of the entire system to perform its designated functions while maintaining specific performance indicators within predetermined limits.

These limits correspond to the specified modes of operation, conditions of use, technological maintenance, and repair requirements. A reliable system ensures safe and efficient transportation while meeting the desired standards and expectations.

Reliability is a complex property that consists of several simpler properties, including reliability, maintainability, durability, and preservation. The specific meanings of each of these terms are discussed in relevant regulatory documents.

Depending on the type of facility, its reliability may be determined by all or some of the listed properties. For a VTS facility, reliability primarily depends on the faultless operation. ***Faultless operation*** refers to the property of an object to continuously maintain its operable state for a certain period.

Within the HMES system, the human component is often considered the least reliable element. Human errors, both by drivers and pedestrians, contribute to more than 80% of road accidents according to some reports.

12.2 VTS Components and Their Features

Driver. There is a significant difference between a human pedestrian and a human driver as the main road users: a pedestrian performs natural movements and moves at a natural speed while walking, while a driver performs peculiar working movements with a relatively small load, and his or her speed is ten times higher than natural. A driver in traffic is forced to act at a pace imposed on him, the consequences of his decisions are in most cases irreversible, and mistakes have severe consequences.

The ability to assess and predict the development of a traffic situation is determined by many characteristics of a human driver. The abilities of a particular person to drive a car, i.e. to act as a professional or amateur driver, are different.

Every person who receives a driving license undergoes a medical examination, which assesses them in terms of visual and hearing acuity, musculoskeletal system capabilities, etc. The reliability of each human driver as an element of the VTS system is not the same, and in most cases, fortunately, they do not have to assess it directly.

It is well known that a certain percentage of people lack an ear for music, and, conversely, some people have outstanding musical abilities. In the same way, some people are capable of achieving high results in a sport, such as soccer, but are weak as partners in a game of chess. Likewise, each person in the population who is medically fit to drive a car has a greater or lesser natural aptitude for the activity.

Professional driver training can be quite different. Usually, a school or course for training category «B» drivers develops certain skills, but their level is low. It would be futile to demand, for example, that a person who has successfully completed such courses be able to maneuver successfully in reverse with a two-axle trailer. Improving driving skills can be achieved through special courses and training.

A person can learn how to drive a car in extreme conditions (ice, difficult off-road conditions) and special driving techniques (cornering at high speed with four-wheel slip and drifting, overcoming certain obstacles in a jump, shifting gears without dropping fuel, turning with the parking brake, etc.). Such training is available only at special courses or in sports sections.

The experience that comes with regular driving over time is a very significant and sometimes decisive factor in determining the reliability of a driver as an element of the VTS system. The more experienced and observant a driver is, the more complete the dynamic model of the traffic situation and the prediction of its development that they create.

An experienced driver is more resilient to surprises and can have a greater impact on the situation. Additionally, they are less likely to find themselves in dangerous conditions as they anticipate the possibility of such situations occurring.

In the face of sudden changes in the road situation, an experienced driver does not succumb to emotional stress; they retain the ability to evaluate, think, decide, and act based on similar situations stored in their memory. For instance, surveys of a large number of taxi drivers revealed that they develop stable safe driving skills after an average of 6-7 years of work.

Driver's age is a factor that affects the reliability of the VTS system, and it is assessed by the probability of drivers getting into accidents. There are concepts of «younger dangerous age» and «older dangerous age».

Young drivers are characterized by two tendencies: inexperience, excitement, and emotional excitability, as well as the ability to make quick decisions and implement them. The first trend is negative, while the second is positive.

With increasing age, driver reliability generally improves, but this happens differently for men and women. The lower limit of the conditionally safe age for men occurs at about 26-34 years, and for women, it is at 23-27 years.

As age increases, female drivers reach the conditionally safe age earlier than male drivers. The older dangerous age, with the same danger factor, occurs at the age of 63 for women and at 69 for men. At these age limits, the experience gained does not fully compensate for the slower reactions.

The driver's physiological state The driver's physiological state is influenced by various factors such as fatigue, illness, medication, drunkenness, etc.

Fatigue can lead to reduced auditory, visual, and tactile sensitivity, increased duration of motor reaction latent period, and distracted attention. This is a natural response of the body to protect itself from external stimuli and to restore vital functions through rest.

Medical conditions can affect a person's ability to drive in two ways: directly by deteriorating health and corresponding changes in reactions, and indirectly through the effects of medications.

Many drugs taken by the driver to treat or reduce painful symptoms can impact reaction times. Therefore, the annotation for each drug must indicate the possibility of its use in conditions where the driver operates a vehicle.

The automobile, as an element of the VTS system, can be considered from various perspectives, including design development, operational assessment of failures, maintenance and repair, and its role in the system of economic relations during operation. For active safety, which relates to the likelihood of an accident, certain properties of the car play a crucial role.

The power of an automobile engine plays a significant role in its dynamic properties, including acceleration intensity. Higher engine power results in reduced acceleration time, which positively impacts active safety.

Vehicle controllability refers to the ability of the vehicle to accurately maintain the trajectory set by the driver. A vehicle with good controllability is more likely to respond effectively to driver inputs, enhancing safety.

The technical condition of the vehicle refers to the serviceability of its components, assemblies, and systems. It is essential to maintain all aspects of the vehicle's functionality, including systems unrelated to core safety features, as they can also impact overall reliability and safety.

The characteristics of the **road**, such as smoothness, adhesion properties of the road surface, width of the roadway, presence of turns and slopes, etc., have a direct impact on traffic safety.

The environment affects all elements of the VTS system, with the road being constantly exposed to various environmental influences like daily weather, seasonal changes, and climatic conditions. These factors can significantly influence driving conditions and safety.

Test yourself

1. What is the VTS system?
2. What are the elements of the VTS system?
3. What is reliability?
4. Briefly describe the driver as an element of the VTS system.
5. What is fault tolerance?
6. What is the professional training of drivers?
7. How does the physiological state of the driver affect traffic safety?
8. Name the main properties of the automobile as an element of the system VTS.
9. How does the environment affect the other elements of the system of VTS?

13 AERODYNAMIC PROPERTIES OF THE VEHICLE. COLOR IN THE AUTOMOTIVE INDUSTRY

13.1 Aerodynamic Properties of a Wheeled Vehicle

Improving the aerodynamic characteristics of high-speed vehicles can significantly improve their technical and economic performance. Reducing the coefficient of aerodynamic drag provides an increase in fuel efficiency and speed properties of motor vehicles (MVs), and thus their productivity.

Decreasing the coefficient of lateral and lift forces enhances the handling and stability of the vehicle. Optimizing the flow pattern of the underbody and rear area also contributes to reducing the aerodynamic drag and pollution level of vehicles, leading to an improved environment.

The shape resistance is the main component of the aerodynamic drag of a vehicle (Fig. 13.1). The design of the car body determines the size and location of high and low-pressure zones, as well as the generation of vortices when the body interacts with the air flow.

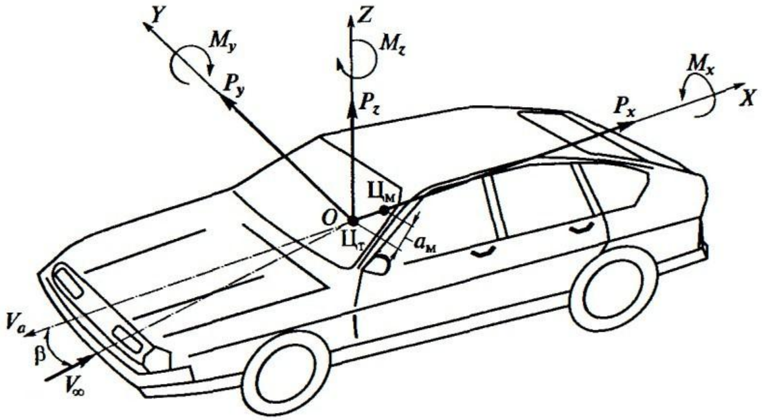
The formation and dissipation of vortices from the body surface consume a significant amount of energy, requiring the engine to use additional fuel. Hence, when designing streamlined bodies, it is crucial to eliminate areas of high and low air pressure, detachable flows, and vortex formation.

The goal is to ensure a continuous airflow around the body during the vehicle's motion across the entire range of operating speeds, considering the influence of side winds. Such measures will lead to improved vehicle performance and energy efficiency.

For this reason, when designing the body, special attention should be paid to the shape of the bow, as it, along with the stern, determines the airflow of the car.

The streamlined shape of the nose depends on the angles of the radiator, hood and windshield cladding.

In addition to the angles of the radiator, hood and windshield cladding, the degree of rounding of the upper and side front edges of the hood affects the streamlined nose.



Cm is the center of mass of the vehicle; C is the metacenter; am is the application arm of aerodynamic force; β - angle of airflow; Rx is the frontal drag force; Ru is the lateral force; Pz is the lifting force; Mx - rolling moment; Mu - overturning moment; Mz - turning moment

Fig. 13.1. Diagram of aerodynamic forces and moments, acting on the car

If the frontal edges of the vehicle are sharp or have a small radius of curvature, the airflow behind them can create tear-off flows, leading to increased aerodynamic drag of the vehicle. To counter this, rounding the front edges of the hood is done to eliminate these tear-offs and improve the streamlining of the nose of the body.

The shape of the rear bodywork also plays a significant role in achieving a streamlined appearance for the vehicle. The shape of the rear body panel and the angle of its inclination, along with the shape of the roof, influence the air flow around the aft part of the car, affecting the velocity and pressure fields in its wake, and thus determining the overall aerodynamic drag of the car.

The primary methods of improving the aerodynamics of passenger cars include:

- Increasing the angles of inclination of the radiator cladding, hood cover, windshield, and radii of curvature of the front edges of the body to optimize the contour factor and reduce the proportion of detachable flows.
- Giving the front of the car and its windshield a cylindrical

shape in plan to improve aerodynamic efficiency.

- Removing all protruding structural elements from the body surface or thoroughly aerodynamically refining them, including glazing close to the body, elimination of gutters, etc.
- Creating teardrop-shaped bodies with a continuous flow to minimize aerodynamic resistance.
- Developing systems for organized and dosed air intake and exhaust for cooling the radiator and engine, as well as ventilation and cooling of the cabin to improve airflow management.
- Using a smooth underbody with the organization of vortex-free air flow in the underbody area to reduce drag.
- Installing a body with a negative pitch angle in combination with optimal ground clearance, adjustable depending on driving conditions, to improve airflow under the vehicle.
- Thoroughly sealing the joints and contact points between the hood, doors, and trunk lid panels and the body to minimize air leakage and turbulence.
- Optimizing the shape of the front buffer with its transition to the lower panel and radiator cladding, along with using a low-height front spoiler to reduce aerodynamic drag.
- Utilizing rear spoilers to improve rear-end aerodynamics.
- Installing special aerodynamic wheel covers and partially overlapping the rear wheels to reduce drag.
- Developing and applying special structural elements and solutions to reduce pollution and aerodynamic noise of vehicles..

In addition to reducing the coefficient of drag, it is crucial to reduce the area of the midline section F of the designed vehicle, as the power consumption and fuel consumption required to overcome its aerodynamic drag depend on the value of the drag coefficient F.

It's worth noting that the possibilities of reducing the aerodynamic drag of buses are significantly lower compared to passenger cars, primarily due to their larger frontal areas.

The main areas of work to reduce aerodynamic losses and improve the streamlining of intercity buses are as follows:

- Working out the nose section with an increase in the radii of curvature of the front edges of the body to reduce aerodynamic resistance.

- Eliminating air intake areas for engine cooling and sources of additional drag from the front panel to minimize turbulence and streamline the front of the bus.
- Increasing the degree of smoothness of the body with the use of glued glass installed close to it to improve airflow over the surface.
- Improving the flow of air in the underbody area by carefully working out the underbody in combination with optimizing ground clearance and installing a negative pitch body to reduce drag and improve aerodynamics.

Among all the design factors that affect the aerodynamic drag of buses, the shape of the frontal body in combination with the size of the radii of curvature of its front edges is crucial in determining the overall aerodynamic performance.

For mainline road trains, one of the most effective constructive measures to improve aerodynamics is to enhance the streamlining of their head part, which is heavily influenced by the type and shape of the cab.

Currently, there is a trend of using cabs of increased height on mainline road trains, which exhibit significantly better streamlining characteristics than serial low cabs.

This improvement is achieved through a more sophisticated shape of their frontal panel, including its plan form, as well as larger radii of curvature of the front edges. Additionally, the rounding of the lower front edge is achieved by installing a lower fairing under the front buffer to further enhance aerodynamics.

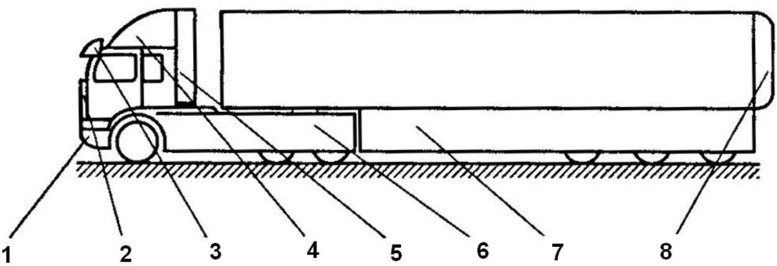
A tall, streamlined cab with a properly designed windshield can facilitate smooth airflow, and when it matches the width and height of the body, it helps minimize the gap between them, allowing airflow from the cab surface directly to the roof and side walls of the body.

The use of a high cab results in a significant reduction in the aerodynamic drag of the road train across various angles of flow. The most substantial reduction in the coefficient Cx of the aerodynamic drag of a road train is achieved by installing a high cab with an elliptical frontal surface and significant radii of curvature of the side front edges.

Additionally, another effective method to improve the streamlining of mainline road trains is by using external aerodynamic devices. These attachable aerodynamic elements can significantly enhance the aerodynamic characteristics of mainline road trains without altering the main formative elements of the cab and body, and without significant investments.

The effectiveness of using external aerodynamic devices depends on their appropriate installation on a specific road train, as well as the correct selection of the type and location of the device.

Figure 13.2 illustrates the areas for installing attachable aerodynamic elements on a road train, as well as the corresponding reduction of aerodynamic drag ΔC_X achieved in this configuration.



1 – lower frontal fairing ΔC_X=5%; 2 – front aerodynamic flaps (side edges of the cabin) ΔC_X=2%; 3 – front aerodynamic flaps flaps (upper edge of the cab) ΔC_X=2%; 4 – upper frontal fairing ΔC_X=16%; 5 – rear side flaps on the cab ΔC_X=4%; 6 – lower side shields of the tractor ΔC_X=2%; 7 – ower side shields of the trailer ΔC_X=3%; 8 – rear wall fairing of the trailer, ΔC_X=7%

Fig. 13.2. – Scheme of aerodynamic devices installation on a fifth-wheel road train, and achievable values of reduction of the aerodynamic drag coefficient ΔC_X at the same time.

The installation of sets of coupled aerodynamic elements on the fifth-wheel and trailed road trains reduces the value of their coefficient of aerodynamic drag at zero flow angle by 41 %. It should be noted that a significant reduction in the coefficient of drag at oblique airflow is achieved by installing rear side shields on the cab and body, and lower side shields on the tractor and trailer.

Aerodynamic drag is one of the main components of the power and fuel balance of high-speed vehicles. The proportion of power and fuel consumption to overcome the aerodynamic drag of a vehicle depends on its type, degree of streamlining, frontal area, speed, atmospheric parameters and the incoming air flow.

13.2 Color - Concepts and General Information

Color is an inherent property of everything around us. There is no object in nature that lacks color. Humans inhabit a diverse world of colors, ranging from vivid and distinct shades to pale and subtle ones that are difficult to name. People perceive only those objects that possess a particular color.

The perception of color does not require verbal explanation or knowledge of language. It is an exceedingly complex concept, involving various disciplines such as physics, physiology, psychology, lighting engineering, medicine, science, technology, and art.

Color can be described as the property of objects to evoke specific visual sensations based on the spectral composition and intensity of the reflected or emitted visible radiation. The human eye can perceive light vibrations with wavelengths ranging from 380 to 760 nanometers (nm), where 1 nm equals one billionth of a meter.

Light waves vary in oscillation amplitude and length, and each spectral color corresponds to a specific wavelength.

The sequence of colors in the spectrum is as follows: red, orange, yellow, green, cyan, blue, and violet. The perception of color is a reflection of the quality of the radiant flux entering the eye, which depends on its spectral composition.

The color of many machines and devices, control panels in their relation to the background, the combination of colors of many controls - in accordance with the requirements of ergonomics should depend on their three-dimensional structure, which causes the saturation of forms with shadows, which in turn cannot but affect the choice of color for painting, especially tonality and lightness.

13.3 Basic Principles Applied in Artistic Design

In artistic design, one of the fundamental conditions for using color is that **it should be harmoniously associated with the three-dimensional structure of the object.** Color is closely interrelated with other elements of composition, such as proportions, scale, and nuances.

Color can be employed to highlight essential elements of a form or compositionally subdue them, bringing unity to the elements that cannot be effectively subordinated using other methods.

In some cases, color can help rectify proportions that may not be ideal, especially when altering the physical volumes is not possible. Color plays a crucial role in achieving the desired artistic expression of a product. A well-chosen color palette can reveal the essence of an object, either accentuating its nature or providing a more neutral appearance when necessary.

It is important to recognize that the perception of color is both subjective and objective. The feeling of color that arises in our minds is subjective, while color itself represents an objective property of radiant energy entering the eye. Hence, two categories of color concepts must be clearly distinguished: physical and psychological..

The physical characteristics of color encompass various aspects such as brightness, brightness ratio, reflectance, color purity, dominant wavelength, and more.

Color tone is a fundamental characteristic that differentiates one chromatic color from another, giving rise to names like red, yellow, and so on. The primary natural range of color tones is known as the spectrum. Reds, oranges, and yellows are commonly referred to as warm colors, while blues and greens are considered cool colors. Greens and purples lie in between, occupying an intermediate position between warm and cool.

The lightness, or **brightness** of chromatic colors refers to the property that determines whether a color appears lighter, brighter, or darker and duller. Lightness is considered a fundamental and general property of all colors, both achromatic and chromatic.

Saturation, also known as the purity of color, measures how much a color differs from an achromatic color of the same lightness. It is determined by the degree of proximity to the most saturated spectral color. Saturation decreases when a color is diluted with white or water, in the case of water-based paints.

Saturation is usually expressed as a percentage, with 100% corresponding to the maximum saturation of the spectral color, and zero representing an achromatic color, such as white.

Test yourself

1. What is the main component of the aerodynamic drag of a car?
2. What is the relationship between the design and aerodynamics of a wheeled vehicle?
3. How does aerodynamics affect the consumer properties of a wheeled vehicle?
4. Name the main areas of work to reduce aerodynamic losses of intercity buses.
5. List the main areas of installation of coupled aerodynamic elements on the road train.
6. What is the color body?
7. What is a chromaticity graph in coordinates?
8. Give the definition of color tone, saturation, what are their symbols?
9. What is adaptation in color perception and how does it affect the color scheme of the product?
10. What is the color wheel, its color characteristics?
11. What are the color circles?
12. What are the established laws of color mixing?
13. What is functional coloring?
14. How does lighting affect the color of the product?
15. Explain the effect of color on a person in psychophysiological terms.
16. List the instruments for measuring color..

14 APPLICATION OF CAE IN AUTOMOBILE DESIGN

14.1 The State of the CAE Market in the World and Modern Systems Used in the Automotive Industry

Computer-aided engineering (CAE) systems, consisting of computers, graphic input and output devices, and various software packages, are becoming increasingly effective tools for ergonomic design.

Automated ergonomic design systems are developing in parallel with the general process of design automation. As computer hardware, software, and the human-computer interface improve, an increasing number of ergonomic design tasks are being solved using these systems.

In the competitive automotive industry, there is a strong drive to reduce the time required for car design and manufacturing while simultaneously improving the overall quality.

This pressure has led to the development and application of computer-aided engineering systems, including those focused on ergonomic design.

Computer-aided engineering systems offer fast and reliable ergonomic design and evaluation of a driver's workplace through the use of various components such as a three-dimensional human model, reach zones, and fields of view.

The reach zones are dependent on the actions a person performs at their workplace. The system can display different reach zones based on the driver's gender and selected percentile.

The possible reach zones include ideal, physiologically maximum, and geometrically maximum reach areas. These zones are essential for designing a comfortable and efficient workspace for the driver.

A special software module enables the simulation of the driver's actions at the workplace. A biomechanical three-dimensional model of a person is positioned at the workplace based on the selected gender and percentile.

Various human movements are characterized by measuring the time of individual motion moments of the animated images.

The human model can be placed in a sitting or standing position, and the joint loads during the movements are calculated and graphically documented.

Additionally, to assist the user, there is a reference book (hypertext) providing essential information on environmental issues, ergonomic standards, safety instructions, etc., accessible through keywords. The content of the directory can be modified and supplemented by the user.

The developed automated ergonomic design system enhances designers' productivity, reduces design time, improves the quality of design work, and minimizes errors in implementation.

Some experts consider two-dimensional drawings containing anthropometric data as outdated in today's context. This is because special programs act as dynamic partners to designers, displaying a vast bank of anthropometric and biomechanical data on the display screen in an easily understandable form.

These programs are based on 10 million data points, including percentiles from 2.5 to 97.5. On the screen, the designer selects a variant of the three-dimensional solution for the desired structure, and then a moving three-dimensional image of a person begins to «live» within it, following the designer's commands, even accounting for age-related changes in joint mobility.

14.2 Definition of CAD, CAM and CAE

Computer-aided design – CAD is a technology that utilizes computer systems to facilitate the creation, modification, analysis, and optimization of projects (Figure 14.1).

Hence, any program working with computer graphics, as well as any application used in engineering calculations, belongs to computer-aided design systems.

In other words, the range of CAD tools extends from geometric programs for working with shapes to specialized applications for analysis and optimization.

Between these extremes are programs for tolerance analysis, calculation of mass-inertial properties, finite element modeling, and visualization of analysis results.

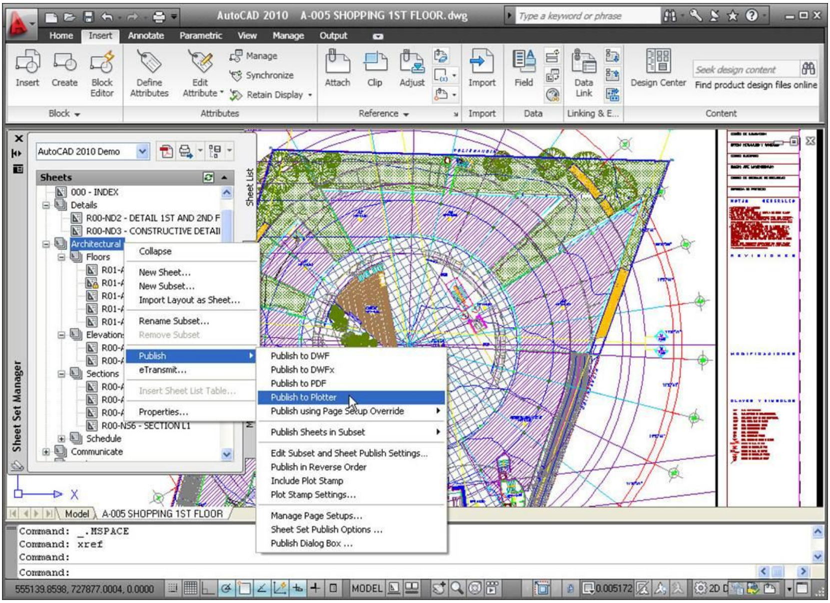


Fig. 14.1. AutoCAD interface

The most fundamental function of CAD is to determine the geometry of a structure (mechanical parts, architectural elements, electronic circuits, building plans, etc.), as geometry dictates all subsequent stages of the product life cycle.

For this purpose, systems for developing working drawings and geometric modeling are commonly used. Hence, these systems are typically considered computer-aided design systems.

Moreover, the geometry in these systems can be used as a basis for further operations in CAD and CAM systems.

This is one of the most significant advantages of CAD, saving time and reducing the number of errors associated with the need to determine the structure's geometry from scratch every time it is needed in calculations.

Automated systems for developing working drawings and geometric modeling systems are the most crucial components of computer-aided design (Fig. 14.2, 14.3, 14.4).

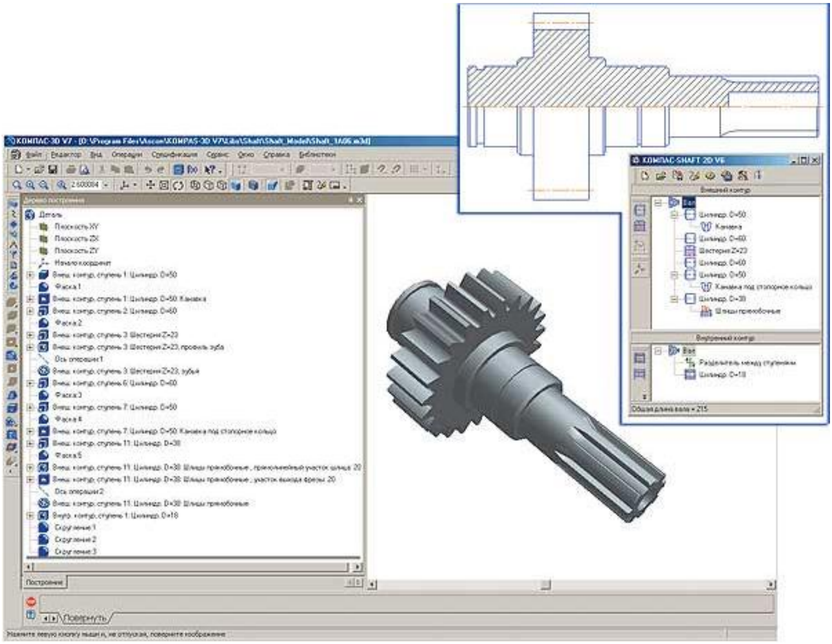


Fig. 14.2. Developing part geometry and creating working drawings in the Compass program

Computer-aided manufacturing – CAM Computer-aided manufacturing (CAM) is a technology that involves the use of computer systems to plan, manage, and control production operations through a direct or indirect interface with the company's production resources (Figure 14.5).

One of the most mature approaches to production automation is numerical control (NC). CNC involves the use of programmed commands to control a machine that can grind, cut, mill, stamp, bend, and otherwise transform blanks into finished parts.

Nowadays, computers are capable of generating large programs for CNC machines based on the geometric parameters of products from a CAD database and additional information provided by the operator. Research in this area is focused on reducing the need for operator intervention.

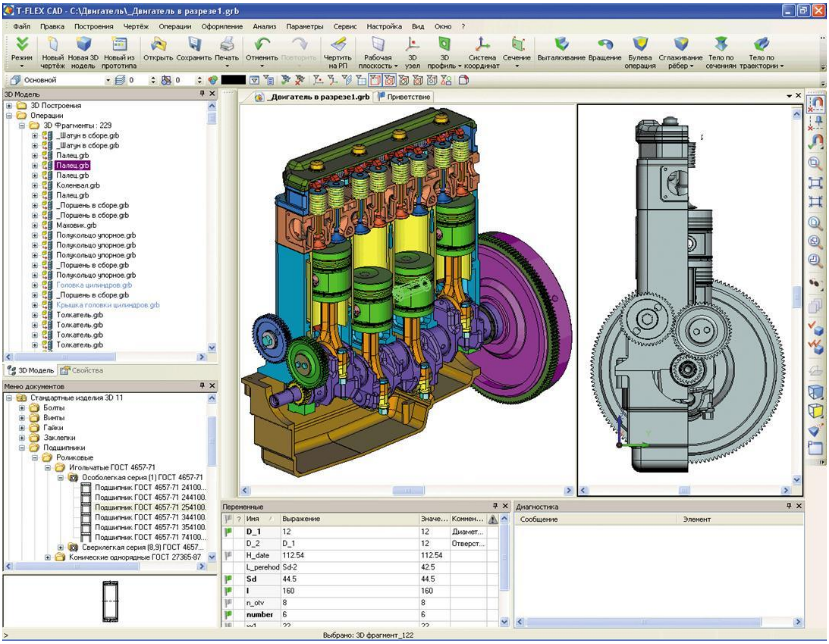


Fig. 14.3. Engine design developed in the T-FLEX system

Another important function of automated manufacturing systems is the programming of robots that can work in flexible automated areas, selecting and installing tools and workpieces on CNC machines. Robots can also perform their own tasks, such as welding, assembling, and moving equipment and parts around the shop floor.

Process planning is also gradually being automated. A process plan can define the sequence of operations for manufacturing a device from start to finish, using all the necessary equipment.

Although fully automated process planning is practically impossible, a machining plan for a specific part can be generated automatically if there are already plans for machining similar parts. For this purpose, grouping technology has been developed that allows you to combine similar parts into families.

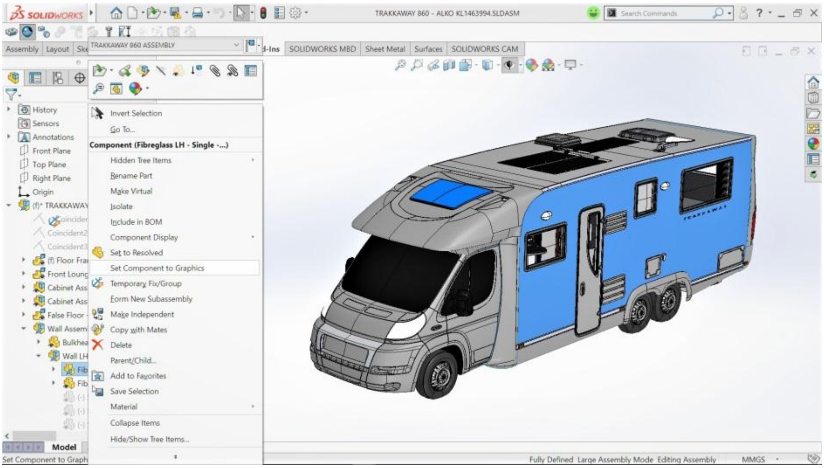


Fig. 14.4. SolidWorks 2018 program window

Parts are considered similar if they have common manufacturing features (slots, grooves, chamfers, holes, etc.). To automatically detect the similarity between parts, the CAD database must contain information about such features. This task is performed using object-oriented modeling or feature recognition.

Additionally, the computer can be used to identify the need to order raw materials and purchased parts, as well as determine their quantity based on the production schedule. This activity is called material requirements planning (MRP). The computer can also monitor the status of machines in the shop and send them the appropriate tasks.

Computer-aided engineering – CAE is a technology that uses computer systems to analyze CAD geometry, model, and study product behavior to improve and optimize its design (Figure 14.6).

CAE tools can perform many different types of analysis. Kinematic calculation programs, for example, can determine the trajectories and speeds of links in mechanisms. Dynamic analysis programs can be used to determine loads and displacements in complex devices such as automobiles. Logic and synchronization verification and analysis programs simulate the operation of complex electronic circuits.

As you can see, **the finite element method (FEM)** is the most widely used of all computer analysis methods in design. It is used to calculate stresses, deformations, heat transfer, magnetic field distribution, fluid flows, and other problems with continuous media that are simply impractical to solve by any other method.

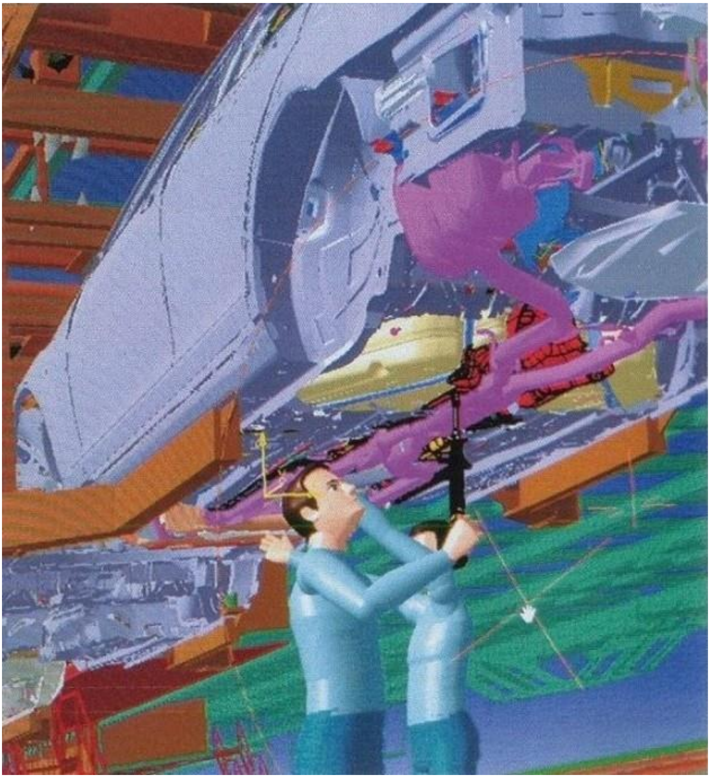


Fig. 14.5. Design and optimization of workflow in CATIA

In the finite element method, the analytical model of a structure is a connection of elements so that it is divided into separate parts that can already be processed by a computer.

As noted earlier, to use the finite element method, you need an abstract model of a suitable level, not the structure itself. An abstract model differs from a structure in that it is formed by eliminating unimportant details and reducing dimensions (Figure 14.7).

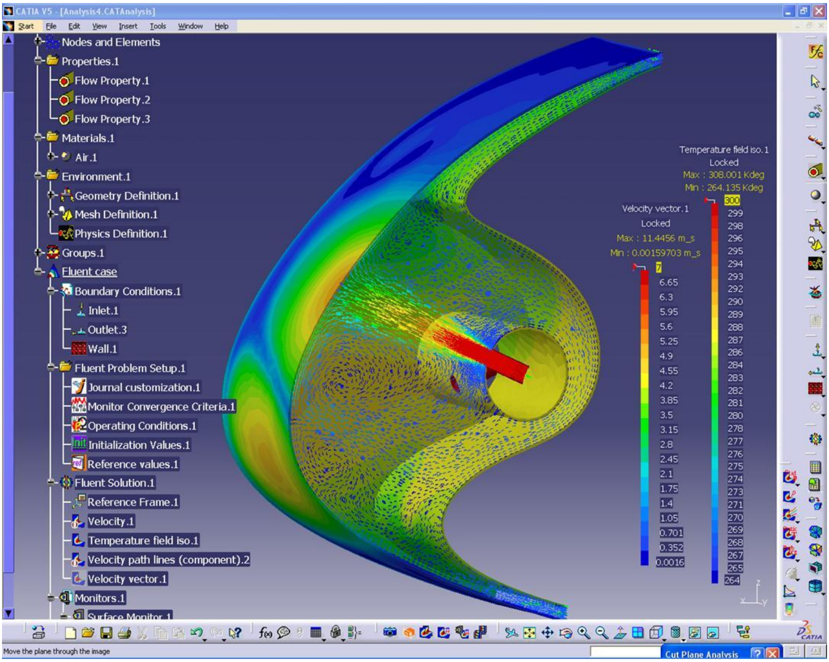


Fig. 14.6. Analysis of a part design in CATIA

For example, a three-dimensional object of small thickness can be represented as a two-dimensional shell. The model is created either interactively or automatically. The finished abstract model is divided into finite elements that form an analytical model.

Software tools that allow you to construct an abstract model and break it down into finite elements are called preprocessors. After analyzing each element, the computer assembles the results into a single whole and presents them in a visual format.

The advantage of design analysis and optimization methods is that they allow the designer to see the behavior of the final product and identify possible errors before creating and testing real prototypes, thus avoiding certain costs.

Since the cost of designing at the last stages of product development and production is growing exponentially, early optimization and improvement (possible only with the help of analytical CAD tools) pay off in a significant reduction in development time and cost.

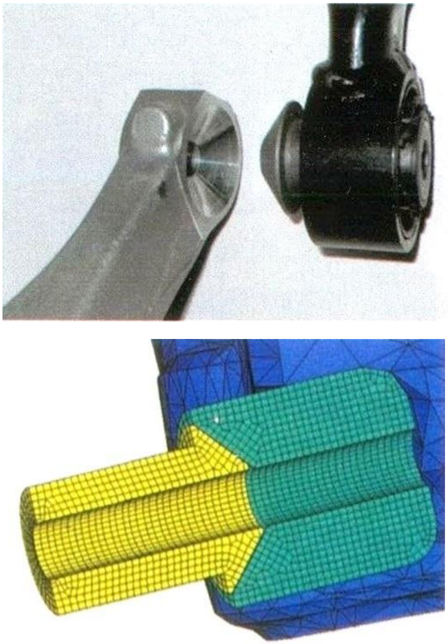


Fig. 14.7. Calculation of the suspension elements of the Ford Mondeo using the finite element method

Thus, CAD, CAM, and CAE technologies are designed to automate and improve the efficiency of specific stages of the product life cycle. Developing independently, these systems have not yet fully realized the potential of integrating design and manufacturing.

To solve this problem, a new technology called computer-integrated manufacturing (CIM) has been devloped. CIM tries to connect the «islands of automation» together and turn them into a smoothly and efficiently running system. CIM involves the use of a computer database to manage the entire enterprise more efficiently, including accounting, scheduling, shipping, and other tasks, not just design and manufacturing, which were covered by CAD, CAM, and CAE systems. CIM is often referred to as a business philosophy rather than a computer system..

14.3 Prospects for the Use of Virtual Reality Modeling in Ergonomic Design

The creation of the world of virtual reality (VR) presents fundamentally new opportunities for ergonomic modeling and design. Through the analysis of works focused on studying virtual reality, three of its most characteristic features have been identified.

Firstly, virtual reality is generated by the activity of some other external reality, which is why it is termed artificial or created.

Moreover, virtual reality only exists in the «here and now» moment. Secondly, virtual reality allows interaction with all other realities, including the generated one, as independent entities (Figure 14.8).

Fig. 14.8. Analysis of air flow direction and temperature using VR technologies

The hardware used for virtual reality includes glasses, gloves, a computer mouse, and a helmet. This collection of devices enhances the user experience, making it more immersive and natural. Actuators attached to the helmet and gloves enable the VR computer to detect the user's head and body movements, adjusting the virtual environment accordingly.

The development of a new generation of computers and innovative modeling principles has enabled the simulation of virtual realities. Each use case of virtual reality is based on a database utilized by a computer to create and demonstrate graphical programs. However, unlike other graphic programs, the VR computer's unique hardware and interface facilitate a more dynamic and interactive user experience.

Using a glove, joystick, mouse, or other devices, a person interacts with the images on the screen, overcomes feelings of distrust, and the spectacle created becomes real.

The ultimate goal of virtual reality is to give the user a sense of the reality of the computer-generated world and their presence in it. The term «virtual reality» was coined in the early 80s of the twentieth century.

The combination of virtual vision with physical feedback opens up wide opportunities for application in ergonomic research and design (Figure 14.9).

For the first time, virtual reality capabilities were used in aviation when engineers created an airplane simulator to demonstrate the latest advances in virtual reality. By wearing a «virtual» helmet and gloves, users can interact with the simulator, such as opening maintenance hatches to check mechanical components, exploring the cockpit and cargo compartment, and studying the location of control systems and passenger seats.

The integration of virtual reality in computerized design departments brings various benefits. For instance, all functional units can be strategically placed within easy reach for repairs before the aircraft is physically assembled, optimizing maintenance processes and reducing potential design flaws.

Virtual reality has also revolutionized customer experience. Customers can now inspect the designed vehicle by «sitting» at the driver's workstation, examining the dashboard, interior, turning the steering wheel, engaging gears, and pressing the brake pedal, allowing them to ensure their satisfaction with their future car.

Fig. 14.9 Analysis of the results of a «virtual» car crash test

In case of dissatisfaction, customers can request changes, and the computer generates detailed sketches to meet their preferences.

14.4 Rapid Prototyping and Manufacturing

Rapid Prototyping – RP is a cutting-edge technology actively developing in the design and manufacturing industry. It enables the creation of physical parts and models without the need for traditional tooling, achieved by converting data from a CAD system into 3D representations at the push of a button.

Once the design work on a CAD workstation is complete, a simple «print» command initiates the production of a physical model of the product within a few hours or days, depending on its size.

The introduction of RP systems revolutionized the industry compared to older methods that relied on manual craftsmanship or CNC machines to produce models made of foam, wood, or wax, which often took several weeks.

Today's market offers various RP systems that utilize different technologies and materials to create models. However, all these systems operate on a common principle: layer-by-layer construction of physical models, which involves three steps:

- reading three-dimensional geometry from 3D CAD systems in STL format (conventional solid models or models with closed surface contours). All solid modeling CAD systems can produce STL files;
- dividing the three-dimensional model into cross-sections (layers) using a special program supplied with the equipment or used as an application;
- building cross-sections of the part layer by layer from the bottom up until a physical prototype of the model is obtained. The layers are arranged from the bottom up, one above the other, and physically connected to each other. The prototype construction continues as long as the data on the CAD model's cross-sections are received.

Some RP systems use photopolymerization, where a liquid resin turns into a solid polymer when exposed to ultraviolet or visible light. Other systems employ thermal processes, such as extruding thermoplastic material through injection heads to form layers or sintering powdered materials through heat. There are also processes that involve «gluing» sheet materials together. The wide range of rapid prototyping processes corresponds to the number of manufacturers and their technological innovations.

Rapid prototyping technologies empower engineers and designers to explore creative possibilities and create cost-effective three-dimensional models. The surface of the prototype can be finished to enable evaluation of the product's aesthetic properties by customers and staff. This capability enhances the design process and accelerates product development, making rapid prototyping an invaluable tool in the modern design and manufacturing industry.

Fused-deposition modeling – FDM is relatively simple, but its application is limited to thermoplastic materials. The commercial implementation of this method was made by Stratasys.

During the FDM process, each layer of the object is formed by extruding a thermoplastic material in a liquid state (as shown in Figure

14.10). The part is built by stacking these successive layers. The temperature of the extruded material is kept slightly higher than its solidification temperature, similar to creating inscriptions on a cake with chocolate cream.

The shape, assembly, and functionality of the products. Prototypes built using technologies that provide sufficient model strength are convenient in applications requiring the evaluation of the shape of parts and checking the assembly of products, because all changes can be made to CAD drawings before production begins.

Investment casting. Prototypes can act as one-off models for precision casting if they are made of materials that burn out under high temperatures. Because such objects do not expand or crack during firing, it is possible to use traditional casting methods in which molds burn out when it is filled with molten metal.

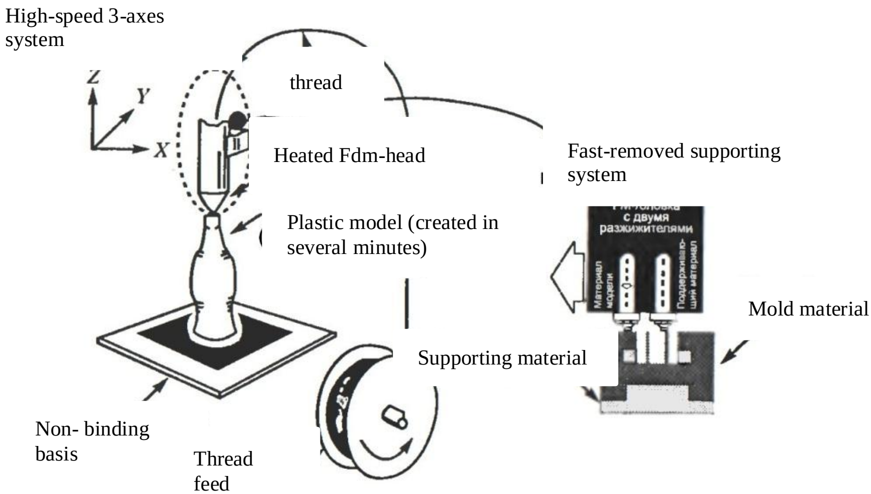


Fig. 14.10. Modeling by deposition molding (Stratasys Inc.)

Vacuum casting of plastics. is an excellent method for producing prototypes with high strength and rigidity, making them suitable for applications in small and medium production volumes. The robustness of modern prototypes allows them to withstand significant stresses, ensuring their reliability in practical use.

Production of molds.

Prototypes with sufficient strength are used for the rapid production of molds for investment casting from paraffin-stearin compounds at low and medium production volumes. To improve the quality of the castings and increase the life of the molds, metal coatings can be applied to the working surfaces.

Casting of gypsum molds. The geometric stability of the prototypes and their inherent accuracy make them suitable for casting gypsum molds.

Silicone rubber molds. Prototypes are often used in silicone rubber molding to produce polyurethane or epoxy castings.

Cost. Developers of RP systems have recently been focusing on the production of low-cost and high-speed machines, reducing the cost and increasing the volume of the working chamber. Thus, new prototyping technologies can significantly reduce the time required to produce models for visualization, fitting, tooling, and other applications, which ensures: shorter development cycles; improved design; higher quality; reduced product and production costs; and faster design changes.

Rapid prototyping has become an essential part of the CAD/CAM process. RP technologies allow users to verify CAD data in a short time.

The increasing use of solid modeling is driving the spread of rapid prototyping technologies. The quality of materials and the accuracy of prototypes are improving.

All of this suggests that rapid prototyping technologies and systems will take an increasingly important role in computer-aided design. In the near future, RP systems will be available to any user and will become a common tool for designers, improving the quality of design and reducing the time to market.

Test yourself

1. What is CAE?
2. What are the prospects for the use of computer-aided design technologies in the automotive industry?
3. Briefly describe the technology of computer-aided engineering (CAE).
4. What is the design work on the shape of the car body?

5. What is included in the complex of technical means of CAE?
6. What are the main stages of using machine graphics tools at the stages of car body development?
7. How is the computer connected with the technological process of production?
8. What are the modern technologies of manufacturing models and physical parts without their tooling?
9. Name the structure of CAD software for the automotive industry.
10. What is the technology of automated production?
11. What calculations are performed using finite element methods?
12. What are the prospects for the use of virtual reality modeling in the ergonomic design of vehicles?
13. Briefly describe the use of virtual reality technology in the ergonomic design of a car..

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FOR NOTES

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Educational publication

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BASIC ERGONOMICS IN AUTOMOTIVE ENGINEERING

Study guide

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Computer aided design: Oleksandr Artyukh, Maria Kuzmina

Computer layout: Kateryna A. Lut, Oleksandr Artyukh,
Maria Kuzmina

Signed for publication on 2023/12/04. Format 60×84/16. Printed pages. 9,3.
Edition of 100 copies. Signed. № 976.

National University «Zaporizhzhia Polytechnic»
Ukraine, 69063, Zaporizhzhia, Zhukovskogo str. 64
Tel.: (061) 769-82-96, 220-12-14

Certificate of the subject of publishing DK № 6952 from 22.10.2019.