MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Department of aircraft design

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MASTER THESIS
(EXPLANATORY NOTE)
GRADUATE OF EDUCATIONAL DEGREE
«MASTER»

ACCORDING TO THE EDUCATIONAL PROFESSIONAL PROGRAM
«AIRCRAFT EQUIPMENT »

Theme: «Aircraft armoring system for protection the aircraft crew from light firearms»

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Ph.d., associate professor ___________**L.I. Pavliukh**

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Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Faculty aerospace
Department of aircraft design
Educational degree «Master»
Specialty 134 «Aviation and space rocket technology»
Educational professional program «Aircraft equipment»

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TASK

for the master thesis

DENYS DIETKOV

1. Topic: «Aircraft armoring system for protection the aircraft crew from light firearms», approved by Rector's order № 1906/ст_ from 5 october 2020 year.

2. Period of work execution: from 5 October 2020 year to 13 December 2020 year.

3.Initial data: development of a system of armoring of aircraft from bullets with masses 7.9, 9.6, 7.4, 10.4 grams and their flight speed – 730 ± 15 m/s, 850 ± 15 m/s, 745 ± 15 m/s, 830 ± 15 m/s, respectively.

4.Content (list of topics to be developed): analysis of the problem of survivability of the aircraft crew during combat operations, review of modern means of protection against fire from the ground and air, methodology, calculation of the fastening element of internal cladding panels to the aircraft structure in the cockpit with superimposed protection elements, analysis of harmful and dangerous production factors, review of the harmful effects of the aircraft on the environment.

5. Required material: The list of obligatory graphic (illustrative) material: the general type of facing panels with fastening and protection elements (A1×1), the drawing of assembly of fastening elements (A1×1), and the drawing of the general look of elements of protection (A1×6). Graphical materials are performed in AutoCad.

6. Thesis schedule

№	Task	Execution period	Done
1	Task receiving, processing of statistical data.	5.10.2020–6.10.2020	
2	Analysis of modern materials and methods of protection.	7.10.2020–15.10.2020	
3	Analysis of the regulatory documents and identification of possible areas of damage.	16.10.2020–20.10.2020	
4	Development of recommendations for the protection of the cockpit.	21.10.2020–30.10.2020	
5	Determination of loads on facing panels and calculation on durability of knot of fastening of panels to a fuselage.	31.10.2020–10.11.2020	
6	Graphic design of protective and fastening elements.	11.11.2020–25.11.2020	
7	Complection of the explanation note.	25.11.2020–05.12.2020	

7. Special chapter consultants

Chapter	Consultant	Date, signature	
		Task Issued	Task Received
Labor protection	Ph.d., associate professor O.V. Konovalova		
Environmental protection	Ph.d., associate professor L.I. Pavliukh		

8. Date of issue of the task: «___»___________2020 year.

Thesis supervisor __________ V.I. Zakiev

Task accepted for execution __________ D.A. Dietkov

ABSTRACT

Master degree thesis “Aircraft armoring system for protection the aircraft crew from light firearms”
76 p., 22 fig., 1 table, 20 references

Object of study – design and layout of aircraft internal equipment.

Subject of study – aircraft modernization for providing protection for crew members.

Aim of master thesis – development of aircraft armoring system for protection the aircraft crew.

Research and development methods – analysis of the structure and internal layout of the cockpit performed using NX software for modeling and strength analysis.

Novelty of the results – for the first time a crew protection system for the An-178 aircraft was proposed.

Practical value – analysis of the selected zones of possible damage showed that the aircraft can be equipped with this system without making changes in the basic structure.

AIRCRAFT, CREW, ARMOR PROTECTION, COMPOSITE MATERIALS, PROJECTILES, METHOD OF PROTECTION

CONTENT

ABBREVIATIONS

ALON – Aluminum Oxynitride
AP – Armor Piercing
API – Armor Piercing Incendiary
APFSDS – Armour-Piercing Fin-stabilized Discarding-sabot
RHA – Rolled Homogeneous Armor
RHAE – Rolled Homogeneous Armor Equivalence
HRC – Rockwell C Hardness
PPS – Personal Protection System
BAE – British Aerospace
US – United States
STANAG – Standardization Agreement
SLAP – Sabot Launched Armor Piercing
VHN – Vickers Hardness Number
MANPADS – Man-Portable Air Defense System
IR – Infrared
OTT – Отдел Технических Требований
BBC – Военно-Воздушные Силы
VDT – Video Display Terminal
CNI – Coefficient of Natural Illumination

INTRODUCTION

The growing need for aircraft protection systems to protect crew and passengers from small arms fire is determined by recent and current conflicts in Iraq, Syria, Central Asia and even in Ukraine while developers are trying to make them as easy as possible. Aircraft protection, more accurately defined as adding bulletproof components to protect crew and passengers during flights in conflict zones, have always been a compromise between installing an additional protection element and adding weight and, accordingly, reducing payload. The main means of increasing survivability is using of armor.

Let’s consider what “armor” means. It is a protective layer of a material that has a high strength, toughness and other parameters, performing the function of a barrier from impact on the object of protection, which is surrounded by this layer. The first prototypes of armor were designed in ancient times and were the armor shields of warriors. Their main purpose of armor was to protect the human body from the effects of weapons (arrows, spears, swords) on it. The progress in the field of military technologies begin to turn into a competition between weapons and protection from them, the growth and intensity of conflicts and simplifies the shape of armor to the most effective design. In the future, the widespread use of iron and steel increases on military vehicles (tanks, ships, aircrafts) and on ground fortified structures. The creation of armor sharply accelerated progress in metallurgy, thermal and mechanical processing of metals. Nowadays, armor is constantly being improved and was created a new types of it, but as before, it is divided into several main types and they will describe in the first part of the thesis.

The second part of the thesis will consider the documents that are required to guide the developers of aviation armoring, in particular the requirements for armor protection (OTT BBC-86) and requirements for composite armor (MIL-PRF-46103E). This is a very important part, since, based on the requirements of the OTT BBC-86, the main parameters for protecting the crew from weapons are determined. The requirements for composite protection regulate the parameters that the armor must comply with, as well as the choice of the crew protection class based on the parameters of the selected weapons. Without taking these requirements into account, it is not possible to further certify the aircraft and use it for its intended purpose. The required thickness of structural elements will also be calculated for a complete stop of the weapon and recommendations for protection in areas where the aircraft structure and internal components do not provide protection against the weapon chosen in the calculation will be given. Following the design assessment, recommendations for the protection of the crew will be provided.

The third part of the thesis is to determine the loads on the cladding panels with the protection hung on them and the strength of the attachment point of these panels to the aircraft fuselage is calculated. This is a very important part of any design work on the modernization of existing aircraft, since initially all elements of the aircraft structure were developed without taking into account the possible additional equipment with protection elements. Accordingly, standard attachment points for structural elements may not withstand the loads that will act on them with an additional protection system.

To perform any design work, an engineer needs a properly equipped workplace, in accordance with state sanitary rules and regulations, which regulate many parameters, such as the correct arrangement of the workplace, hygienic and ergonomic requirements for the organization of workplaces and workplaces. Also, harmful factors affecting a person in the process of performing design work will be considered. More details on this will be discussed in terms of labor protection.

The last part, environmental protection, is devoted to the problems of the negative impact of aviation on the environment and living organisms, as well as ways to solve these problems.

PART 1

MATERIALS AND METHODS OF AIRCRAFT PROTECTION

For the first time, the pilots of the aviation of the First World War faced the problem of the threat of being shot down from the ground, when the majority of air battles took place directly over the combat positions of ground units. This repeatedly caused a lot of trouble for pilots, when it was necessary to think not only about the air threat, but also the threat from the ground, taking into account the peculiarities of the then aircraft, such as the maximum flight altitude and the altitude of combat clashes, which often did not exceed 1000 meters. At the same time, the designers were puzzled by the problem of protecting the crew, but the technical progress of those years could not allow an additional increase in the mass of the aircraft by installing protective elements, since the power plants had a very low thrust-to-weight ratio.

The idea of protecting the crew received a second wind in the interwar period, when advances in science and technology made a huge leap forward in aviation. This paved the way for increasing the combat survivability of the crew in air combat conditions, or in flights in combat zones. At the same time, when developing combat aircraft, the designers initially assumed the use of protective elements in the structure and developed aircraft, mainly fighters, taking into account this requirement. By the time the Second World War began, almost every aircraft had in its design elements of armor protection, such as an armored backrest of the pilot's seat and a windshield of the cockpit. By the second half of the war, the requirement for the protection of the crew was mandatory, based on the experience of using protective elements at the very beginning of combat operations and an analysis of the effectiveness of this very protection.

Progress does not stand still, and scientists began to develop new materials and ways to protect human lives. The most successful solution turned out to be the use of different ceramic materials and their compounds to replace the standard solutions using armored steel. For aviation, this meant the emergence of the possibility of reducing the weight of the entire structure, and consequently an increase in efficiency and mobility.

1.1 Experience of armor application in Second World War

For combat aircraft of the Second World War, a very important factor in successful combat activity was their internal armoring - armored backs, which were the simplest way of protection. They greatly increased the survival of all types of aircraft in air battles. Although some types of aircraft had external armoring (outside the skin of the aircraft), there were very few of these types – the armored attack aircraft Il-2 and the German armored attack fighter Fokke-Wulf-190, Henschel 129. But the internal armoring in many cases saved the lives of pilots.

For example, in the first battles in the Pacific Ocean, the pilots of the American fighters P-40 at the very beginning of the war made sure that 20 mm high-explosive shells from aircraft cannons of Zero did not penetrate the armored backs of their fighters. Because when a high-explosive projectile flying into the tail unit, it immediately exploded, and then its smallest fragments each weighing a fraction of a gram flew further. These fragments could not penetrate the armored backs with the sickness of 8 milimeters. In air battles against the Japanese Zero, they saved their pilots from getting into their bodies not only bullets from machine guns, but even from 20 mm shells of Zero cannons. That is, these high-explosive shells apparently exploded in the rear of the aircraft and immediately flew into tiny fragments that were so small that they did not penetrate the armored back and thereby protected the pilot from death.

In contrast, for example, the Japanese A6M fighter in the initial period had no armored shells at all, so Japanese fighter pilots were killed by the first 12.7 mm bullet from American fighter that hit the Japanese from behind in the back. Therefore, the Americans quite easily killed the almost all the Japanese aces. After all, even before the start of battles in the Pacific Ocean, the Japanese fought on Khalkhin Gol with Soviet fighters, including the I-16, which had armored backs. Example of armored back is shown on Figure 1.1. Moreover, the installation of armored plates on Soviet fighters was considered so important that they were ready to worsen other parameters of I-16 aircraft because of it:

1. An armored back mounted, which reliably protected from rifle caliber bullets.

2. The battery is removed. (They had to sacrifice for the sake of armor). This greatly reduced the efficiency of squadrons equipped with this type of aircraft. But it saved the lives of many Soviet pilots [1].

Figure 1.1 – An armored back of the Soviet LaGG-3 aircraft.

But by the end of World War II in the Pacific War even the Japanese began to install armored backs on their planes. All American fighters from the very beginning of the war had armored backs. Already in December 1941, having received reports on the combat use of Wildcats, the US command ordered all vehicles to be equipped with fuel tank protection and to strengthen cabin armoring. And the more new types of fighters appeared among the Americans F6F and became the more powerful and reliable due to the enhancing of armor.

So, the process of armoring of aircraft went and developed throughout the Second World War and it is completely secret from ordinary people and aviation enthusiasts. That is, in many aviation books on aviation, numerous details are considered of the numerous design features of all aircraft in the world, but armoring of aircraft of the Second World War in most cases remains under the secret. That is, aviation experts consider anything: the engines of the aircraft, their weapons, and the composition of the instruments, but fighter's area is almost never mentioned, nor its thickness, and for bombers, authors of aviation books almost never indicate the location of the armored shells, nor even their thickness. For example, for the famous B-17 bomber, you will never find the location of the armor plates and their thickness. It is only known that the arrows of 12.7 mm machine guns located in the middle of the rear of the B-17 Bombers and firing at two open embrasure windows had bulletproof vests, but apparently did not have armor plates or armored backs to protect their bodies. It also apparently didn't have any armor protection and the shooter of the lower ventral firing system of the B-17. Although the aircraft commander – the pilot and the co-pilot probably had an armored back. By the way: the reservation of each bomber could change greatly during the war. Before the outbreak of World War II, it is likely that not one bomber had a single sheet of armor at all. But it is possible that after the very first heavy losses, bombers began to install separate sheets of armor. Moreover, it is likely that the power of aircraft engines gradually increased (engineers created more and more powerful engines), and because of this, bombers could increase their take-off weight, that is, their weight increased not only from the additional supply of bombs, machine guns, fuel, but also from sheets of armor. However, this is not reflected anywhere in the military historical literature on military aviation. That is, the aviation historians absolutely do not know about the true form of airplane armoring [1].

The question of what thicknesses of armor panels and how many were on the Soviet bomber Il-4 is also hidden from the public. At the same time, it is astounding that even before the start of World War II, Soviet fighters had a standard armor plate thickness of 8 mm, then, in contrast, the first German fighters received at least some thin armor sheets on Me-109 Messerschmitts with thickness only 4 mm.

But actually it is very difficult to do – almost impossible. Because with any increase in weight at the rear of the aircraft, at the same time, its center of gravity shifts back, and from this the aircraft sharply loses stability in flight. At first the Il-2 attack aircraft was single-seat and the pilot had an armored back 12 mm thickness. But when, due to the fact that German fighters could freely shoot him from behind, Ilyushin's design bureau had to urgently redesign this attack aircraft so that it became two-seater – it received the second crew member – the rear gunner. And besides, the inhabitants do not even realize how great the reliability of the initial version of the armor protection of the pilots of single-seat attack aircraft was. Because their armor plate with a thickness of 12 mm did not actually penetrate even at close range. And only if the German fighter was able cut out the wooden tail end of the Il-2 fuselage or again the German was able to cut off the wooden wing consoles, then only in this case the Il-2 fell.

Initially the 12 mm armor plate of the IL-2 pilots was very reliable against German 20 mm cannons. However, the Germans soon began to install more powerful 20 mm guns. That is, as soon as the Germans began to install more powerful air guns on their Messerschmitts, then immediately the IL-2 began to easily penetrate even from behind. But from a long distance, the 12 mm armor still did not penetrate even the more powerful new German 20 mm. Therefore, the designer Ilyushin faced the challenge of how to make German fighters shoot at IL-2 from long distances. The double-sitting armored cabin version is shown in Figure 1.2. And after the appearance of the double-seat IL-2 at the front, the Messerschmitts were afraid to come close to them. At first, they fought from afar, trying to kill the shooter first, and only after his death came close to shoot the pilot. So for example, after the attack, a lone attack aircraft, laden with anti-aircraft guns, slowly returned. And it was attacked by two Messerschmitt. But while the shooter was alive, they were afraid to come close to him, because he drove them away with bursts of his 12.7 mm machine gun. And German fighters fired at him only from a distance - from a distance of about 1 kilometer - which is completely ineffective for hitting an attack aircraft, which must be fired from a distance closer than 50 meters (sometimes the Germans also approached the single-seat attack aircraft by 15-20 m). But the fact is that the cockpit of the gunner of the IL-2 is protected much worse than the cockpit.

Figure 1.2 – Armor case of attack aircraft IL-2.

And if the pilot’s armor plate thickness is 12 mm, then the shooter’s is only 5 mm thick, and of course, this thin armor was easily penetrated by German 20 mm shells and even 7.92 mm bullets from their machine guns. The gunner’s cockpit glazing was generally easily penetrated not only by bullets, but even by fragments. That is, it was enough to get a 20 mm high-explosive German shell to get near the shooter of the Soviet IL-2, as dozens of fragments immediately pierced the shooter [1].

1.2 Evolution of aircraft armor technology

During the period of conflicts, it was established that the use of crew protection equipment should be mandatory for all types of military aircraft. This not only increases the chances of returning the wrecked aircraft back to the airfield, but also protects human lives, which is a decisive factor in war conditions, since it is one thing to build an aircraft, and another is to efficiently perform the assigned tasks, which only a well-trained crew can do. This problem was especially acute for the pilots of the Japanese aviation during the battles in the Pacific theater of operations, which subsequently resulted in a shortage of human resources. Let’s have a closer look to the stages of armor development.

1.2.1 Rolled homogeneous armor

Is a type of armor made from hot rolled single-component steel to improve material performance, as opposed to laminated or cemented armor. Its first common use was in tanks. After World War II, it began to fall out of use on main battle tanks and other armored combat vehicles intended for frontline combat, as new anti-tank weapon technologies were developed that were capable of penetrating rolled homogeneous armor relatively easily even from considerable thickness. Today the term is mainly used as a unit of measure for the protection afforded by armor on a vehicle (often composed of materials that may not actually contain steel or even contain any metals) in equivalent “Rolled Homogeneous Armor (RHA) millimeters” referring to the thickness of the RHA providing the same protection. Typically, modern composite armor can provide the same degree of protection in a much thinner and lighter design than its protective RHA equivalent. Likewise, the term is also used as a measure of the penetration capacity of an armor-piercing weapon in "RHA millimeters" through which the weapon system can reliably penetrate. Metal armor as a class includes armor steels, high strength aluminum and titanium alloys. The most widely used is steel armor. With its help, it is possible to provide protection up to the fifth class with an armor element thickness of 5.0–6.5 mm, which corresponds to a surface density of 39–51 kilograms per square meter. Large thicknesses of steel armor elements are unacceptable due to their high weight in comparison with composite materials [2–5].

After World War II, due to reduced effectiveness against new weapons, the RHA is largely replaced by composite armor, which includes materials such as ceramics or plastics. For testing and calibrating anti-armor weapons, the term Rolled Homogeneous Armor Equivalence (RHAE) is used to assess either the penetration of a projectile or the defensive ability of a type of armor that may or may not be steel.

1.2.2 Multi-layer armor

Also known as composite armor – is a type of armor made up of two or more layers of metallic or non-metallic materials. Being a type of constructive armor, combined armor with a ceramic face layer and a reinforced plastic substrate has a record resistance to the action of armor-piercing bullets when fired at low angles from the normal, which is directly related to the high (at least 70 units on the Rockwell scale, HRC) hardness, low mass density of the ceramic layer. In the conditions of firing the combined armor at angles close to the normal, its mass (compared to the surface density, kg/m²) is 2-3 times less than the mass of equal-resistant high-hardness steel armor. That is why such armor initially, back in the 1960s, was used to protect crews and some vulnerable helicopter assemblies, the low speed of which and the action in the reach zones of infantry weapons, with an almost all-round firing, cause favorable conditions for this armor to interact with the striking means [6;7].

At the moment of impact, ultrasonic waves penetrate into the ceramic and along the bullet. Waves in both of these materials break the structure of the armor, which becomes a problem for ceramics when the wave hits the bonding layer between the ceramic and its protective layer. Most types of ceramic armor are currently created using a polymer bonding material that is naturally low in stiffness and density.

At this time, the material under the piercing means is compressed; tapered cracks emanate from the impact site and this leads to the formation of a cone in the material, which in most cases spreads the load from the bullet over a wider surface area as it can be seen in Figure 1.3.

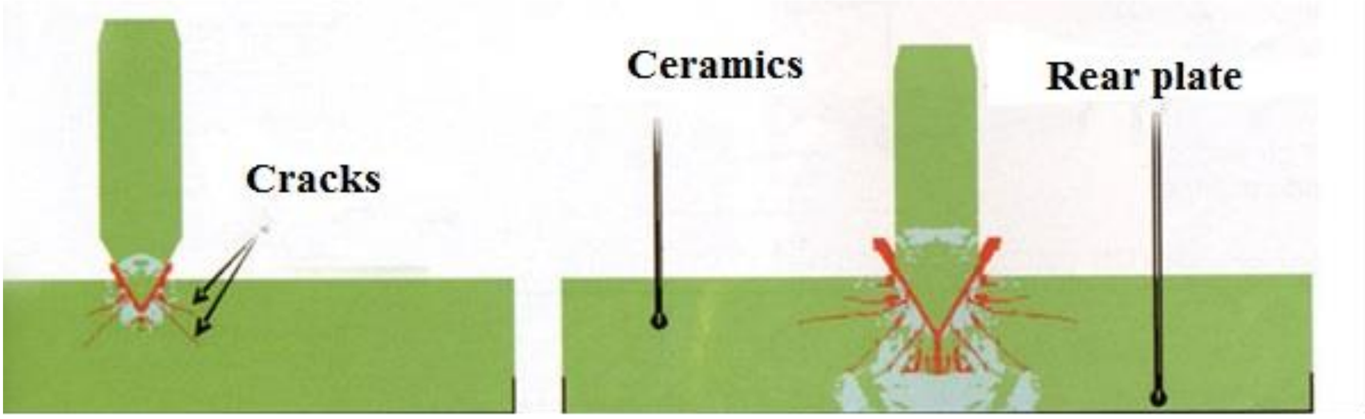


Figure 1.3 – Model that shows the formation of a load cone in ceramics under a piercing bullet.

Green indicates intact material, while red indicates ceramic damage. Blue areas show inelastic deformation. It can be seen that the plastic deformation of the back plate occurs just under the formed ceramic load cone.

This is the first advantage that ceramics provide. As already mentioned, ceramics are very hard and this high hardness provides penetration resistance. High hardness provides great resistance to the projectile, forcing its deceleration. Additional benefits are achieved by the high rigidity of these materials. Engineering ceramics are typically twice as hard as steel; stiffness increases a property called acoustic impedance, which affects the intensity of the supersonic wave, which is directed backward along the projectile rod. This is very important, since ceramics with high acoustic resistance leads to a high intensity of the ultrasonic wave on the projectile, causing it to be damaged when stretched.

For the production of armor, a wide range of structural materials with the necessary mechanical properties are used, the main of which are hardness and strength, elongation, impact strength, elastic modulus. In general, the mechanical properties of materials for the manufacture of armor should be at a high level. The most widely used materials for the production of modern composite armor are:

Aluminum oxide. In the 1980s, most of the ceramic-based defense systems used on the battlefield used aluminum oxide, otherwise known as alumina. Aluminum oxide is relatively inexpensive to manufacture and even fairly thin protection elements based on it could stop small arms bullets fired at high speed. And when using systems with silicon carbide and boron carbide, the additional ballistic performance is low at significant additional costs. There is a cost-effective solution for a relatively small improvement in ballistic performance. However, the main advantage of firearm protection can be tempting if minimum weight is required, such as in aircraft or personal protection systems. Aluminum oxide is widely used in personal protection systems for personnel, as well as in vehicle protection systems. The basic soft protection system, known as Combat Personal Armor (CPA), is a composite and consists of polyamide fiber core which can be added polyamide composite slabs lined with ceramic to provide internal organs protection from high-velocity rifle bullets [7].

Boron carbide. Despite the economic efficiency and the ability of aluminum oxide to stop most small arms bullets with relatively good mass efficiency, other ceramic materials have found their way into the ceramic armor market. The most famous is boron carbide, a material first used in the 1960s. It is incredibly hard, but also incredibly expensive and is therefore only used in the most extreme conditions where it is desirable to compensate for a few grams of armor structure mass, such as in the crew seats of the V-22 OSPREY aircraft [7]. Another example of the use of boron carbide was in the manufacture of an enhanced personal protection system (PPS) is presents in Figure 1.5. On the Figure 1.4 is shown action of the bullet on protective material. Again, a minimum mass was needed for relatively high protection. It was introduced by the British Army to provide protection against 12.7 mm steel-cored.

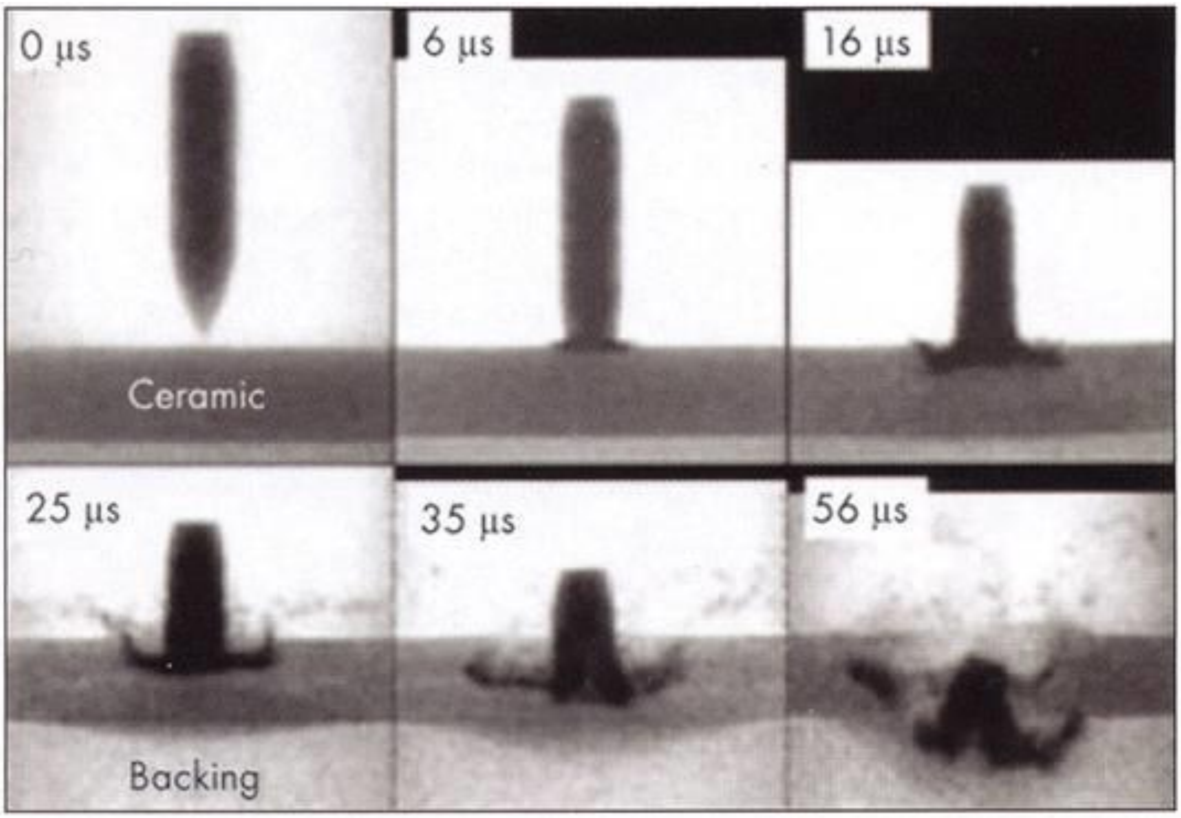


Figure 1.4 – X-ray showing the impact of the 7.62-mm core of the APM2 bullet on boron carbide. Shown are delay, erosion penetration, bullet debris and absorption.

Boron carbide is a high performance material. However, besides the incredible hardness this material has and its incredibly low density and it has one potential drawback. In recent years, there is some reason to believe that it will not perform as well as expected when penetrated by high velocity dense core bullets. This is believed to be due to the physical changes that occur to the material when it is subjected to the strong impact caused by these munitions. In fact, when tested with an unspecified aluminum material as a support, there is reason to believe that certain grades of boron carbide work as well as barriers of aluminum oxide against special projectiles. This is despite the higher hardness of boron carbide. This occurs where double V_{50} velocity is detected (the velocity at which 50% of the projectiles are expected to fully penetrate the target). The disclosures (actions) of double speed V_{50} are usually explained by the transition from penetrating the target with an undamaged projectile to hitting the target with a destroyed projectile at higher speeds. However, the work of the research laboratory of the US Army showed that the impact at a higher speed V_{50} on a composite material lined with boron carbide occurs due to a change in the process of formation of ceramic fragments [7]. Figure 1.5 shows an experimental small-scale helmet made from boron carbide.

Figure 1.5 – A new boron carbide shaping process creates complex curved shapes for use in helmets and other personal protective equipment.

However, the inference from these results means that the boron carbide protection must be thicker than originally expected in order to protect the high velocity projectiles from these dense cores. There is a lot of evidence that boron carbide is a good ceramic material for use against steel armor-piercing projectiles.

Silicon carbide. In recent years, other ceramics have also shown significant promise in providing protection against firearms, but none have been shown to be more effective than silicon carbide specimens. This material is produced under combined heat and pressure to create an incredibly durable product that is proven to provide high penetration resistance by small arms ammunition as well as APFSDS projectiles.

Silicon carbide, microscopic structure of which presented in Figure 1.6, has shown incredible resistance to penetration caused by a phenomenon known as time lag. Simply put, "time lag" is when the projectile appears to literally sit (hence the "lag") on the surface of the ceramic for a while after impact. This phenomenon, which can be seen with high speed photography and X-ray flash, is mainly caused by the fact that the ceramic appears to be stronger than the projectile, and therefore the projectile begins to flow radially over the surface of the ceramic. Although this phenomenon was observed in the early 1990s by US Army laboratories, scientists are still trying to explain the mechanism by which it is supported in ceramics. However, it is known that "long" hold is the key causing this action. One way that this can be achieved is by using a type of hot pressing to encapsulate the ceramic with metal plates. The consequence of this process is the induction of high compressive stresses in the ceramic material through the thermal mismatch of the metal and ceramic layers during cooling. This preload ultimately gives the ceramic an advantage. A second benefit is the metal edging of the ceramic material and the increased ability to withstand multiple hits. This limitation works to keep all the fragments in a single volume and, therefore, increases the erosive ability of the armor with additional shots [7]. The microscopic structure of different ceramic materials is shown on Figure 1.6.

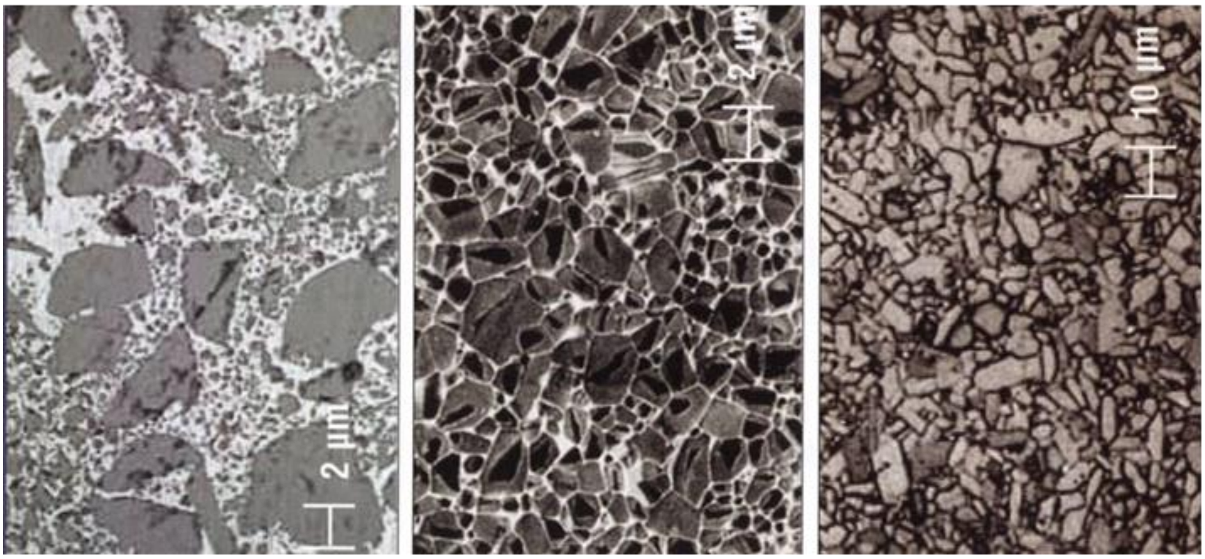


Figure 1.6 – Microscopic structure (left to right): reacted silicon carbide, sintered silicon carbide and boron carbide.

Relatively inexpensive silicon carbide can also be produced through a process known as bonding. This process ensures that the ceramic is accurately sized, whereas other traditional processing methods do not allow this due to high temperatures and pressures. In this case, the chemical reaction is the basis for the production of the ceramic product. The reaction binds the original ceramic materials used for certain types of armor at a low threat. However, by products in the form of "puddles" are often deposited in the ceramic structure, which can form weak points in the ceramic. For silicon carbide obtained by the coupling reaction, they take the form of silicon a relatively soft material. Figure 1.7 shows typical application of this type of armor, Left to right: “Tiger” helicopter seats (BAE Systems Advanced Ceramics Inc.), AH-64 “Apache”, which uses hard pressed boron carbide (Simula Inc.), and MH-60 “Blackhawk” (Ceradyne Inc.).

Figure 1.7 – Typical example of ceramic armor applications in helicopter seats.

Transparent ceramic materials. Modern traditional transparent systems are relatively heavy, especially when required to protect large sections (windows). This causes problems in the design of protection for light vehicles. Traditionally, the glazing systems of such machines consist of several layers of glass, each of which is separated by a polymer layer and held in place by a polycarbonate layer. These types of systems can weigh up to 230 kg / m^2 at a thickness of 100 mm to provide protection level 3 according to the STANAG Level 3 standard (from 7.62 mm bullets) (figure 1.8) [7].

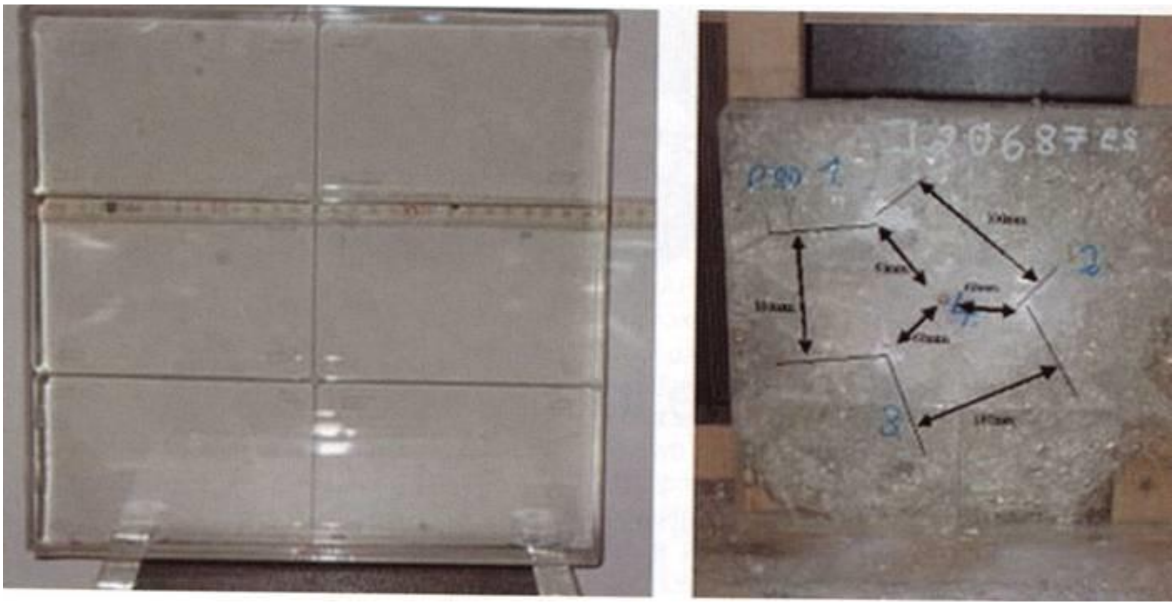


Figure 1.8 – Multiple hits of 7.62 mm by Dragunov bullets in transparent ceramic armor AMAR-T by IBD.

The total mass of the complete system should probably be significant. Transparent ceramic materials provide a tempting alternative to bulletproof glazing systems, as these materials have an inherent hardness that is much higher than that of window glass. This provides shield designers with the ability to reduce weight and thickness. Currently, there are three viable material options for use in transparent security elements, these are aluminum oxynitride (ALON), magnesium alumina spinel or spinel, and single crystal alumina (sapphire). Sapphire has no grain boundaries that cause light diffraction and when grown and polished can provide a solid replacement for systems that use in bullet-resistant glass. The main problem with sapphire is that obtaining a crack-free sample of the required size to provide window protection is quite time consuming and therefore expensive [7]. Typically, to obtain a sample of considerable size, it is necessary to join two or more tiles using the appropriate adhesive.

1.2.3 Active protection system

Is a type of combat vehicle protection used in active mode on aircraft. It is located on an aircraft, and which detects the launching of anti-aircraft missiles and destroying, or at least that greatly weaken the effect of the attacking missile.

The system includes a radar because the modern missile launch detection systems operating in the ultraviolet range (it works in range of the operation of jet engines is clearly distinguishable). The system warns the crew of a launch, the protective systems are automatically deployed, and the automatic curtain-setting system is triggered.

There are varieties according to the principle of action:

Optical-electronic suppression system. The optoelectronic suppression system installed on the aircraft includes searchlights that emit modulated radiation in the optical and infrared ranges, which leads to suppression of the optoelectronic coordinators of anti-aircraft guided missile guidance systems (figure 1.9). The coordinators receive false signals from these searchlights, and the missile receives the wrong commands, causing it to either crash into the ground or fly away.

Infrared homing missiles are among the simplest guided weapons intended to destroy air targets. Pulsating infrared interference is generated with a frequency equal to the operating frequency of the internal guidance elements and a power comparable to the natural thermal radiation of the protected target the interference is introduced into the missile guidance system, leading to deflection of the missile from the protected target.

Figure 1.9 – An example of an ALQ-144 "Hot Brick" pulsed infrared jammer generator on the fuselage of an OV-10D “Bronco” aircraft.

The generator of pulsating infrared interference is a powerful infrared lamp with a rotating reflector, in a casing made of material transparent to infrared radiation, located on the body of the protected object. The probability of disrupting a MANPADS missile attack when using pulsating infrared interference generators is from 0.5 to 0.7-0.8 [9;10].

Systems with fired protective charges (also known as false heat targets). False thermal targets - pyrotechnic devices that emit large amounts of heat when it is burned. That’s why the false infrared field appears which covers the infrared field from engines.

False thermal targets are installed on board the aircraft in special holders (figure 1.10), the so-called false automatic ejection devices.

Figure 1.10 – Holders APP-50 (for shooting 50 mm IR and anti-missile cartridges).

The machines themselves are interfaced with the systems of the on-board defense complex and in some cases their use is automated, depending on the nature of the threat. When such a false target appears in the guidance field, the missile is re-aimed at a more powerful thermal signal [10;11]. It should be noted that some types of missiles (in particular, ultraviolet) can distinguish the spectral characteristics of the emission of false thermal targets and aircraft.

Conclusion to the Part 1

Armor is of great importance for the protection of objects, equipment, people, during the period of wars, exercises (close to combat), testing of new types of weapons. The use of armor increases the survivability of aircraft crew and the army, sharply increases the ability to conduct battles and defense, as it protects people and equipment from death, injury, and failure. At the same time, the armor makes the vehicle heavier, making it a less mobile target, which is under fire longer. To reduce this influence designing military equipment with a supporting armored body, that is, the armor performs both bearing and protective functions, in particular, in aircraft construction, the Il-2 attack aircraft was the first aircraft with a supporting body made of armor.

Another way to solve this problem is to create more durable and at the same time lighter in weight structural materials for armor, which, in turn, allows you to either reduce the weight of combat vehicles without weakening their armor protection, or increase their armor protection without making these same combat vehicles heavier. For quite natural reasons, both methods of solving the problem are combined.

In the modern world, the problem of protecting the crew of various means of destruction is more acute than ever in connection with the emergence of new types of weapons, but the main problem is still light firearms. For aviation, this type of weapon delivers the most problems, since there are no effective protection measures other than the use of armor protection. In this part, different types of protection of aviation equipment were considered, starting with the first experience of the massive use of armor protection in World War II, ending with an overview of modern technologies from new weapons, which differ in their action from the usual light firearms.

For aviation, the main problem is the weight of the entire structure, therefore, a decision was made in favor of using modern composite materials in view of their lower weight to the corresponding protection class relative to traditional rolled homogeneous armor, which allows to reduce the weight of protection. This factor, the weight factor, has the greatest advantage in aircraft construction, despite the high cost of producing composite materials compared to steel protection.

PART 2

ANALYSIS OF AIRCRAFT DANGEROUS ZONES

The most dangerous phases of flight to such zones are take-off and landing. The experience of Western countries shows that the most probable threats to aviation are light small arms, since the enemy can imperceptibly get close to the aircraft and inflict damage to the crew even at a protected airfield. In connection with this threat, the most frequently used weapon will be selected and the calculation of the required protection against it.

This section will analyze the structure of the aircraft for armor resistance in accordance with the general technical requirements of OTT BBC–86 in terms of armor protection. This work is carried out in connection with the increasing demand for cargo transportation to the war zones. The purpose of this work is to determine the armor protection of the crew members (pilots), in accordance with the requirements of OTT BBC–86 “System of general technical requirements for types of weapons and military equipment. Armament and military equipment of the Air Force. General and technical requirements. Onboard and ground radio-electronic complexes (systems) and equipment of aviation technology” (Book 1. Part 2. Section 3 "Requirements for means of increasing the combat survivability of manned aircraft").

This section also overviews documents which regulates the requirements for composite armor in terms of requirements for construction and testing. In accordance with this document, the armor design and protection class will be selected.

2.1 Protection system requirements. Requirements for the lightweight composite armor and choosing the projectiles

The technical requirements for the components of the aviation complex, the armor protection of the aircraft, taking into account the shielding properties of the neighboring aircraft units, should ensure the protection of the crew (pilots) from single hits of 7.62 mm bullets.

Means for increasing combat survivability should provide protection in the following condition of the impact of damaging elements – 7.62 mm bullets weighing 10.4 g at a speed of 830 m/s, approach angles are limited to 45° of the rear part of the lower hemisphere (the upper hemisphere is limited by the geometric parameters of the crew).

The assessment of the armor protection of the crew members is based on the following dimensions: sitting height 98 cm; shoulder width 53 cm; width at the hips while sitting 41 cm; chest thickness 29 cm; head height 26 cm; projection of the distance between the occipital and anterior nasal points (head thickness) 23 cm; head width 18 cm.

Armor protection is assessed in the working position of the crew member. If special clothing is used for crew members, the armor protection is assessed taking into account the size of the special clothing:

1. The size and shape of the armor parts, as well as the design of the armor protection scheme, should be selected taking into account the protective properties of the shielding equipment and aircraft structural elements.
2. To increase the mass recoil, the armor parts used to protect the crew should be easily removable. Their installation and dismantling should be carried out in airfield conditions by the technical staff of aviation units, taking into account the design features of the aircraft.
3. The attachment points of armor parts must withstand without destruction the hit of the striking element into the fixed element of the armor.
4. The installation of armored backs on the seats should not affect the performance of the functional duties of the crew.
5. In the case of the use of armored parts with low tactical survivability, it must be possible to quickly replace them in the field by forces of the technical staff of aviation units [12].

Composite armor requirements according to MIL-PRF-46103E [14]:

The composite armor should be classified into these types and classes according to its ballistic protection limit (ballistic resistance):

For projectiles of Type I 5.56 mm:

- Class 1 – M855 lead ball with steel tip projectile at muzzle velocity 945 m/s.

For projectiles of Type II 7.62 mm (0.30 caliber):

- Class 1 – Lead or mild steel core ball projectile at muzzle velocity 869 m/s.

- Class 2 – Hard steel core armor piercing AP projectile at muzzle velocity 869 m/s.
- Class 3 – Heavy density core SLAP projectile at muzzle velocity 1219 m/s

For projectiles of Type III 12.7 mm (0.50 caliber):

- Class 1A – Mild steel core ball projectile at 1000 meters range 487 m/s.
- Class 1B – Mild steel core ball projectile at 500 meters range 610 m/s
- Class 1C – Mild steel core ball projectile at muzzle velocity 869 m/s.
- Class 2A – Hard steel core AP projectile at 1000 meters range 487 m/s.
- Class 2B – Hard steel core AP projectile at 500 meters range 610 m/s.
- Class 2C – Hard steel core AP projectile at muzzle velocity 869 m/s.
- Class 3 – Heavy density core SLAP projectile at muzzle velocity 1219 m/s.

Type IV 14.5 mm:

- Class 1 – Hard steel core API B32 projectile at muzzle velocity 991 m/s.
- Class 2 – Hard steel core API BS-41 projectile at muzzle velocity 991 m/s. [14].

Requirements:

First article. When specified in the contract or purchase order, a sample shall be subjected to first article inspection.

Materials. Unless otherwise specified the materials are the prerogative of the contractor as long as all the operating, environmental and identification marking requirements are fully met.

Construction. The contractor (the term "contractor" is defined as the organization having a direct contract with the procuring activity) shall select the methodology of construction provided these methods are capable of yielding uniform properties in the completed structure and that all structural interfaces have no unbounded areas.

Molding. If the process of molding is used then the material shall be molded into the required configuration without breaking or damaging the material. Such procedures and methods shall be capable of yielding uniform properties in the completed structure.

Spall cover and edge strip. If a spall cover is used then the spall cover shall be of such a configuration as to cover the entire outer surface. The edge strip shall be cut to go around the entire periphery of the composite armor and extend beyond the inner edges 12.7–19.0 mm. The edges shall not fray before application to the composite armor.

Assembly of components by bonding. All components required to be assembled by bonding shall be thoroughly cleaned of all foreign matter. Surfaces to be bonded shall be properly prepared in a manner which will insure a proper bond capable of meeting the applicable performance requirements. The required adhesive shall be applied uniformly over the entire contact areas of the components to be joined. When bonding components, uniform pressure shall be applied over the entire surface area in order to obtain intimate contact of all components [14].

Operating requirements for armor protection:

V_{50} ballistic limit protection. The V_{50} ballistic limit protection, as defined by MIL-STD-662, shall be the following for the types and classes of armor:

- For Type I, Class 1 – Not less than 945 m/s against 5.56 mm M855 lead ball with steel tip projectiles at zero degrees obliquity.

- For Type II, Class 1 – Not less than 869 m/s against 7.62 mm (0.30 caliber) lead or mild steel core ball projectile at zero degrees obliquity.

- For Type II, Class 2 – Not less than 869 m/s against 7.62 mm (0.30 caliber) hard steel core AP projectile at zero degrees obliquity.

- For Type II, Class 3 – Not less than 1219 m/s against 7.62 mm (0.30 caliber) heavy density core SLAP projectile at zero degrees obliquity.

- For Type III, Class 1A – Not less than 487 m/s against 12.7 mm (0.50 caliber) mild steel core ball projectile at 1000 meters range at zero degrees obliquity.

- For Type III, Class 1B – Not less than 610 m/s against 12.7 mm (0.50 caliber) mild steel core ball projectile at 500 meters range at zero degrees obliquity.

- For Type III, Class 1C – Not less than 869 m/s against 12.7 mm (0.50 caliber) mild steel core ball projectile at zero degrees obliquity.

- For Type III, Class 2A – Not less than 487 m/s against 12.7 mm (0.50 caliber) hard steel core AP projectile at 1000 meters range at zero degrees obliquity.

- For Type III, Class 2B – Not less than 610 m/s against 12.7 mm (0.50 caliber) hard steel core AP projectile at 500 meters range at zero degrees obliquity.

- For Type III, Class 2C – Not less than 869 m/s against 12.7 mm (0.50 caliber) hard steel core armor piercing (AP) projectile at zero degrees obliquity.

- For Type III, Class 3 – Not less than 1219 m/s against 12.7 mm (0.50 caliber) heavy density core SLAP projectile at zero degrees obliquity.

- For Type IV, Class 1 – Not less than 991 m/s against 14.5 mm hard steel core API B32 projectile at zero degrees obliquity.

- For Type IV, Class 2 – Not less than 991 m/s against 14.5 mm hard steel core API BS-41 projectile at zero degrees obliquity[14].

Ballistic deformation. Is the maximum momentary displacement of the back surface of the armor test specimen caused by a fair hit that does not penetrate the armor when the armor is in initial contact with the backing material. Unless otherwise specified in the contract or purchase order the ballistic deformation of the back surface of the armor test specimen shall not exceed 44 mm [14].

Areal density. Is a measure of the weight of armor material per unit area, usually expressed in kilograms per square meter (kg/m^2) of surface area [14].

Environmental requirements for the composite armor:

1. *Vibration*. The composite armor shall withstand expected dynamic vibrational stresses encountered in the service environment.

2. *Temperature*. The composite armor shall be both structurally and ballistically functional within the temperature range -51°C to 71°C. Composite armor intended for use around hot components such as engines and transmissions shall also be functional at temperatures up to 160°C.

3. *Acceleration*. The composite armor shall maintain structural integrity without degradation and shall sustain no physical damage when exposed to acceleration levels up to 12g.

4. *Fluid resistance*. The composite armor shall maintain structural and ballistic integrity after immersion in jet fuel, oil, and water.

5. *Humidity*. The composite armor shall maintain structural integrity without degradation when exposed to 95% relative humidity.

6. *Adhesion of the spall cover*. If a spall cover is to be used there shall be no visible peeling of the tab formed on the spall cover.

7. *Identification marking*. The manufacturer's code (part) number, contract number, serial number, date of manufacture, national stock number, type and class of material, and the number of this specification shall be permanently marked in the location specified by the procuring activity [14].

Operating requirements verification:

1. V_{50} *ballistic limit protection*. The V_{50} ballistic limit protection may be defined as the average of an equal number of highest partial penetration velocities and the lowest complete penetration velocities which occur within a specified velocity spread. The V_{50} ballistic limit protection may be defined as the average of an equal number of highest partial penetration velocities and the lowest complete penetration velocities which occur within a specified velocity spread. The ballistic resistance test shall be conducted in accordance with MIL-STD-662. The contractor shall supply two test samples for each three months of composite armor fabrication for ballistic acceptance testing at a Government approved facility to show conformance to the ballistic requirements. The test samples shall be adequately identified as to contractor, contract number, manufacturer, and date. The testing facility shall report raw data, velocities, penetration observation, thickness, and the ballistic type and class for each test sample.

2. *Ballistic deformation*. Is the maximum momentary displacement of the back surface of the armor test specimen caused by a fair hit that does not penetrate the armor when the armor is in initial contact with the backing material. Examine the armor and the backing material to determine if the projectile made a fair hit and whether penetration occurred. If no penetration occurred and the projectile made a fair hit (a bullet that impacts the armor at an angle of incidence no greater than ±5° from the intended angle of incidence, no closer to the edge of the armor part than 7.6 cm and no closer to a prior hit than 5 cm, at an impact velocity no more than 15 m/s greater than the minimum required test velocity, measure and record the depth of the depression made in the armor backing material to determine compliance with the ballistic deformation requirement. The depth of the depression is the distance from the original undisturbed surface of the backing material to the lowest point of the depression. A projectile that impacts at too high a velocity, but is otherwise a fair hit that meets the ballistic deformation requirement, shall be considered a

fair hit for the determination of deformation. *Complete penetration*. Complete penetration occurs when the impacting projectile, or any fragment thereof, or any fragment of the test specimen perforates the witness plate (a thin sheet located behind and parallel to the ballistic test sample which is used to detect penetrating projectiles or spall), resulting in a crack or hole which permits light passage when a 60 watt, 110 volt bulb is placed proximate to the witness plate. By any fair hit, not meeting the ballistic deformation requirement, or penetration by a projectile at a velocity lower than the minimum required impact velocity, shall constitute failure. *Partial penetration* – any impact which is not a complete penetration may be considered a partial penetration. The testing facility shall report ballistic deformation for each test sample [14].

3. *Areal density*. The areal density shall be reported for each test sample. The areal density in kilograms per square meter (kg/m^2) of the composite armor, shall be calculated from measurements on each component. Each component shall be weighed to the nearest 0.0045 kg. The thickness shall be measured to 0.025 mm at four corner locations on each component. Six measurements shall be made at each corner with the first measurement taken approximately 25 mm from the edge of the corner and the remaining five taken on a straight line toward the center of the armor with the measurements spaced in approximately one inch increments. A deep throat type depth gage shall be used for taking measurements. The average of the 24 readings shall be used in the calculation of the areal density for each component. The average density of each component shall be determined by using ASTM D792, except the immersed weight shall be determined to 0.0045 kg and the liquid used shall be clean tap water, containing a wetting agent if necessary, which shall be changed just prior to examination of each lot [14].

4. *Vibration*. The composite armor shall be tested for vibration in accordance with MIL-STD-810, Method 514.4 for the following vibration environment categories and meet the requirement.

5. *Temperature*. The composite armor shall be tested in accordance with MIL-STD-810, Methods 501.3, 502.3, and 503.3 at the temperature range. The composite armor shall then meet the ballistic requirements.

6. *Acceleration*. The composite armor shall be tested in accordance with MIL-STD-810, Method 513.4 and meet the requirement.

7. *Fluid resistance*. The composite armor shall be immersed in jet fuel in accordance with MIL-PRF-5624, in a gas turbine engine lubricating oil primarily used for aircraft engines, which has a nominal viscosity of 5 centiStokes at 100°C, made with neopentyl polyol ester base stock, and in water for a period of twenty-four hours each at 21° + 5°C. After thoroughly drying, the composite armor shall then meet the ballistic requirements.

8. *Humidity*. The composite armor shall be tested in accordance with MIL-STD-810, Method 507.3 and meet the requirement.

9. *Adhesion of the spall cover*. The sample for this test shall be made from composite armor which has been tested ballistically using an undamaged area, or a small test specimen made identically to the composite armor with respect to surface preparation, adhesion, application and bonding. Make parallel cuts through the spall cover 4 in. (102 mm) long and 25 mm apart. At one end of the cut, make a cut at a right angle so that a 25 mm x 51 mm tab can be peeled from the sample. Attach a 0.9 kg weight to this tab so that the resultant peel force is normal to the plane of the sample. Make gage marks on the sample for the measurement of the amount of peeling during the test. Allow the weight to stand for four hours minimum at room temperature. Any visual peeling of the tab constitutes failure of the test [14].

10. *Identification marking.* Verify the presence of the required markings [14].

Since the decision was made to protect the aircraft from light firearms, it is important to know the characteristics of the weapons used. They are presented in Table 2.1.

The striking elements are both the bullet itself and its fragments.

Bullet hits have a destructive effect on the aircraft structure, bullet fragments hit fuel and oil lines, wiring harnesses and other units. The crew is incapacitated both by the bullet itself and by its fragments, and by secondary fragments generated during the penetration of the skin, equipment, etc.

Table 2.1

Characteristics of selected projectiles

№	Weapon	Bullet description	Mass, g	Velocity, m/s	Bullet type
1	AKM, SKS, RPK	Pointed soft steel core bullet in steel jacket	7,9	730±15	7.62 mm automatic bullet cartridge 57-N-231 mod. 1943
2	SVD, PK (PKM, PKT)	Pointed soft steel core bullet in steel jacket	9,6	850±15	Bullet 7.62 mm rifle cartridge 57-N-323s.
3	AKM, SKS, RPK	A sharp ball with a hardened steel core in a steel jacket	7,4	745±15	Bullet BZ (armor-piercing) 7.62 mm automatic cartridge
4	SVD, PK (PKM, PKT)	A sharp ball with a hardened steel core in a steel jacket	10,4	830±15	Bullet B32 7.62 mm rifle cartridge

The penetration of the structure (armor) is carried out by a bullet that has not lost its integrity, which meets the structure (armor) at small angles (the assumed angle of meeting of the struck element, at which penetration is possible – ≥45˚ to the normal of the armored part). The crew and equipment can be incapacitated by both a solid bullet and its fragments.

2.2 Analysis of the construction of the protected aircraft

The subject of this analysis is a military transport aircraft in terms of airframe design and cockpit equipment. The military transport aircraft is a cantilever monoplane with a high swept wing, single-keel vertical and T-shaped horizontal tail. The aircraft is equipped with two turbojet engines and an auxiliary power unit. The aircraft fuselage is sealed, it is an all-metal semi-monocoque with a longitudinal set of stringers and beams, a transverse set of frames and working skin. The cross-section of the midsection of the fuselage is round. The fuselage is single-deck, conventionally divided in the vertical plane into three parts - nose, middle and tail. The fuselage contains: the cockpit and the cargo compartment. The crew consists of two people – the crew commander and the assistant crew commander. There are also two additional seats for accompanying crew. The cockpit equipment is designed to create the necessary conditions for the crew during the flight, as well as to create the cabin interior. The cockpit equipment includes: The cockpit equipment is designed to create the necessary conditions for the crew during the flight, as well as to create the cabin interior. The cockpit equipment includes: the seat of the crew commander; the seat of the assistant crew commander; an accompanying chair; dashboard; central console; upper control panel; left side panel; right side panel.

The following equipment is installed along the entire cargo compartment: air conditioning system; automatic flight control equipment; communication complex; power supply system; household and rescue equipment; fire equipment; aircraft control system; fuel system; hydraulic system; anti-icing system; landing gear system; lighting and light signaling; oxygen equipment; pneumatic system; water supply and waste disposal system; doors, hatches, sashes; engine control system; aircraft radio equipment; radio equipment for identification and active response; oil system; equipment cooling system; digital computers; onboard means of control and registration of flight data; radar system.

2.3 Determination of parameters of protection material and zones of possible damage

To assess the vulnerability of the cockpit to the weapon, and in particular the need to arm the cockpit, backs and head restraints of pilots' seats, the "Unified Methodology for Assessing the Vulnerability of Discrete Environments of Structural Schemes and Aircraft Assemblies" of shielded obstacles and the total thickness of penetration of sets of obstacles X_{Σ} is calculated. This technique has been confirmed experimentally. To assess the vulnerability of the cockpit to the weapon, and in particular the need to arm the cockpit, backs and head restraints of pilots' seats, the "Unified Methodology for Assessing the Vulnerability of Discrete Environments of Structural Schemes and Aircraft Assemblies" of shielded obstacles and the total thickness of penetration of sets of obstacles X_{Σ} is calculated. This technique has been confirmed experimentally [13].

During the analysis, the following assumptions were made:

1. The design model of the cockpit protection: a shielded scheme with one thin screen (skin), behind which there is a thick barrier.

2. A sheet of D16 with a thickness of 1.5 mm was taken as a screen.

3. The main obstacles were:

- material D16;
- printed circuit boards with microcircuits and radioelements.

The following means of destruction are accepted for the analysis: a single hit by a 7.62 mm bullet:

- V = 730 m / s, m = 7.9 g (type 1);
- V = 850 m / s, m = 9.6 g (type 2).
- V = 745 m / s, m = 7.4 g (type 3)
- V = 830 m / s, m = 10.4 g (type 4).

According to the requirements of OTT BBC-86 and the guidelines for assessing the protective properties and survivability of experimental armor with respect to bullets, shells and fragments, sectors of possible hit multiple of 5° were selected. In accordance with the test requirements, sections of the cockpit were made relative to the seats of the aircraft commander and co-pilot (figure 2.1).

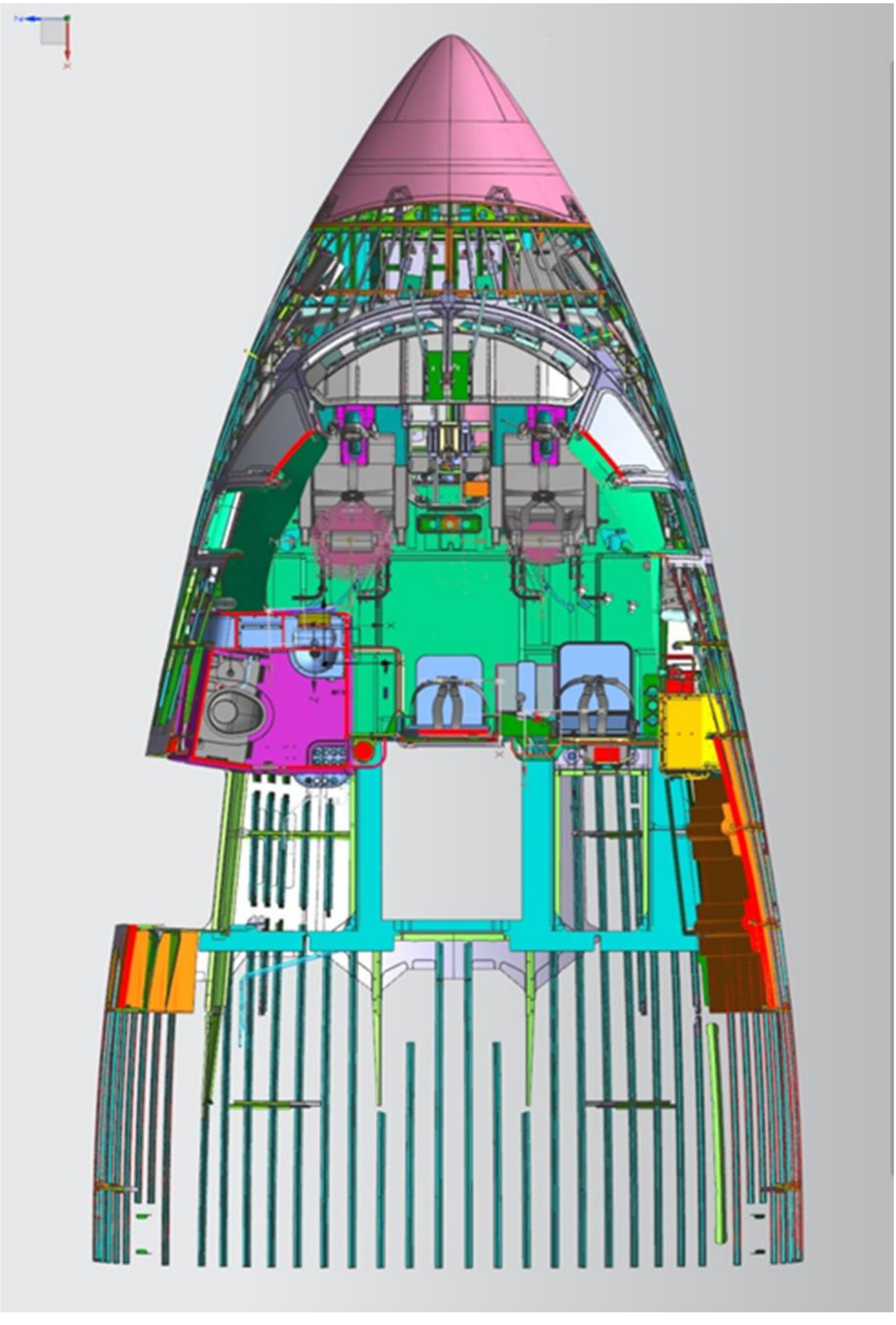


Figure 2.1 – Imaginary lines of cross-sections relative to the seats of the aircraft commander and co-pilot for determination of the possible lesion zones

On the Figure 2.2 shows a graph of the total thickness X_Σ of penetration of an obstacle consisting of one screen and the main obstacle of printed circuit boards with microcircuits and radioelements, depending on the speed of the projectile. Taking into account the air gaps between the panels, the penetration depth is 5 to 8 times greater.

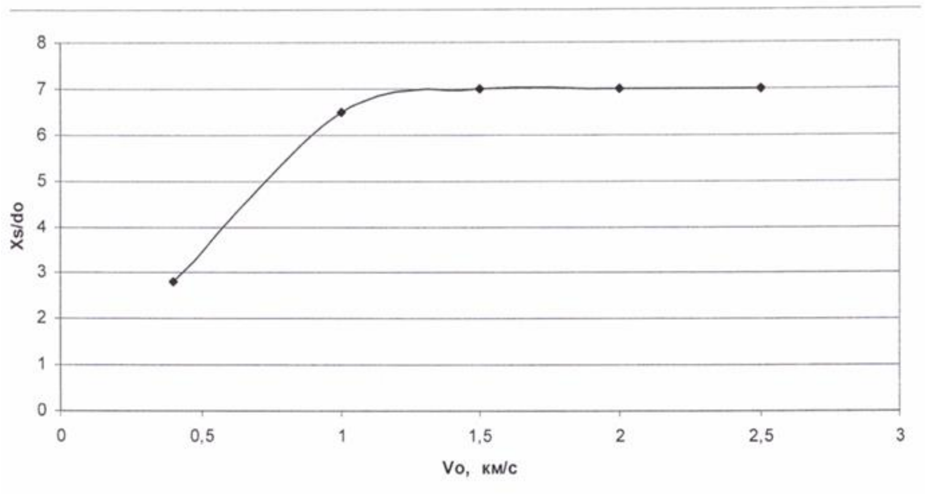


Figure 2.2 – Graph of the dependence of thickness of printed circuit boards with microcircuits and radioelements to speed of projectile

On Figure 2.3 shows a graph of the total thickness X_Σ of penetration of an obstacle consisting of one screen and the main obstacle made of D16 material, depending on the speed of the projectile.

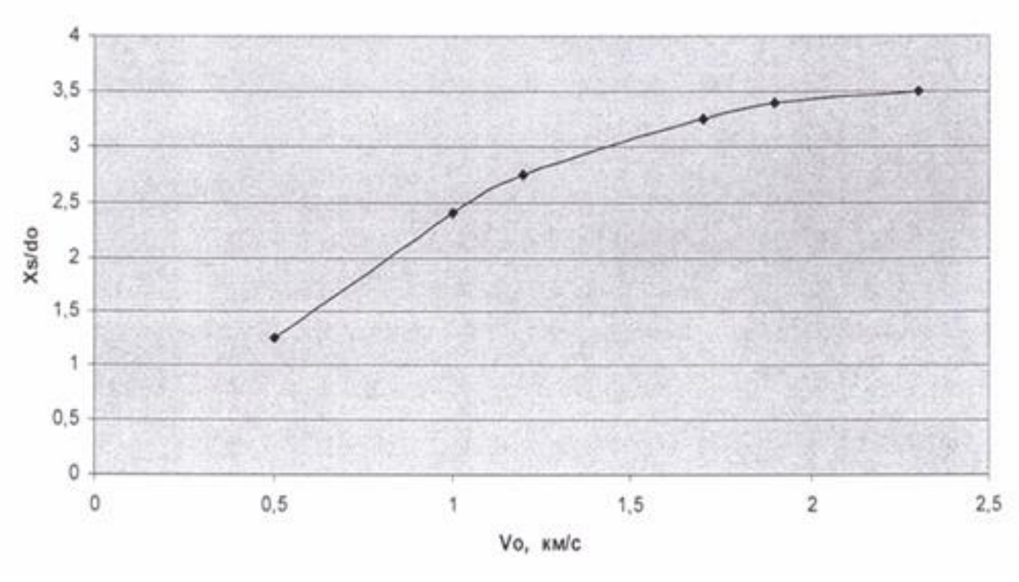


Figure 2.3 – Graph of the dependence of thickness of D16 to speed of projectile

2.4 Calculation of the required thickness of material for guaranteed non-penetration of the projectile

1. Calculation of the required thickness of printed circuit boards with microcircuits and radioelements according to the figure 2.2:

1) Calculation for a type 1 and 3 weapon:

$$\frac{X_s}{d_0} = 5 \tag{2.1}$$

where, $\frac{X_s}{d_0}$ – barrier penetration coefficient; d_0 – diameter of the striking element (take 8mm), mm; X_s – required barrier thickness, mm.

Consequently, the total thickness of the barrier penetration $X_{\sum}$= 0.2 ... 0.32 m.

2) Calculation for a type 2 and 4 weapon:

$$\frac{X_s}{d_0} = 6 \tag{2.2}$$

The total thickness of the barrier penetration is $X_{\sum}$ = 0.24 ... 0.38 m.

2. Calculation of the required material thickness D16 which is determined according to the figure 2.3:

1) Calculation for a type 1 and 3 weapon:

$$\frac{X_s}{d_0} = 1{,}7 \tag{2.3}$$

The total thickness of the barrier penetration is $X_{\sum} = 0{,}014$ m.

2) Calculation for a type 2 and 4 weapon:

$$\frac{X_s}{d_0} = 2{,}2 \tag{2.4}$$

The total thickness of the barrier penetration is $X_{\sum} = 0{,}018$ m.

Conclusion to the part 2

The required thickness of protective elements in all sectors of fire must be at least 7.5 mm equivalent to rolled homogeneous armor with HRC > 60 units (Type II Class 2 according to MIL standard) with the installation of bulletproof glasses of the corresponding protection class. The armor will be made of composite materials, since their use significantly reduces the weight of the entire structure.

According to the results of cross-sections (examples of cross-sections are shown in Appendixes A and B), it can be seen that the design of the cockpit and the equipment installed in it is insufficient to protect the aircraft commander and co-pilot from bullets fired from light small arms.

In the part of the rear (rear low), lower hemispheres, the main obstacles on the way of the means of destruction are the floor of the crew and cargo compartment with a thickness of 1.2 mm and 1.5 mm, respectively, of D16 material, which does not satisfy the design requirements for the thickness of an obstacle made of this material for guaranteed no penetration of types 3 and 4 weapons of destruction. A significant obstacle is the construction of the ladder door; if it hits it, no penetration will occur with a type 1 weapon. When other weapons penetrate, this sector also needs protection. In the lateral and frontal projections (the only significant obstacle in the path of the means of destruction is a hermetic wall with a thickness of 2 mm of D16 material) projections, there are no structural obstacles, therefore this area needs full protection of the crew member. The upper part of the bow in the area from the pressurized wall to the glazing also needs full protection, since there are many zones not covered by equipment. Glazing is also required to enhance its protective properties.

Since the aircraft is high-speed, the use of an external armor arrangement is a problem. External armor creates additional resistance to the flow, in addition to the already increased mass of the entire aircraft. Armor protection will be installed inside the cockpit using the overhead armor method. The conditional mandatory zones which should be protected are shown in Appendix C.

PART 3

LOADS DETERMINATION AND STRENGTH CALCULATION OF ASSEMBLY UNIT

In the last part of this work, the areas in which the crew protection is required were identified and recommendations for the installation of protection were issued. For a more detailed consideration of the issue of the required armoring, a zone of 15°–30° of the rear hemisphere (Appendixes A and B) was chosen relative to the place of the crew commander and limited by the dimensions of the pilot in the working position, which is 1.4 meters from the cockpit floor. In this zone, the cladding panels of the cockpit are located, which allow the protection process to be performed by installing an invoice protection elements.

Protection elements will be made of modern composite material – silicon carbide or boron carbide. The advantage of using these materials is that the weight of the armor element is about 1.5 times less than that of rolled steel armor, which is a key requirement in aviation use, since the balance of the aircraft and the payload for transporting something depend on the weight of all protection. According to data from open sources, the weight of a modern combined composite protection element is 3.8–4.0 kg/dm^2, and the area of required protection elements in the cockpit is 2 m^2, from which it can be concluded that the weight of the required armor parts will be approximately 80 kg/m^2 ... The calculation takes into account not only the total weight of the armor, but also the weight of the cladding panels of the cabin.

The purpose of this part is to determine the loads acting on the cladding panels in the cockpit with the hinged armor installed on them. The main point is in the answer to the question whether the standard attachment unit will withstand the additional loads that will undoubtedly appear with the installation of additional weight. Based on the results of the calculation, it will be seen whether the strength characteristics of the cladding panel attachment point, which is used in production aircraft, are sufficient and whether additional conditions are required for the use of the modernized aircraft. Calculations will be done in NX Nastran computer complex.

3.1 Brief description of the software

NX Nastran is a general purpose finite element analysis computer program that lets solve a wide range of engineering problems. NX Nastran is written primarily in FORTRAN software and is optimized to run efficiently and provide identical results on a wide variety of computers and operating systems**.** NX Nastran contains the following analysis capabilities: linear statics (including inertia relief); normal modes and buckling; heat transfer (steady-state and transient); transient response; frequency response; response spectrum and random response; geometric and material nonlinear static and transient response; design optimization and sensitivity (including dynamic and shape optimization); composite materials; acoustic response; aeroelasticity; superelements; complex eigenanalysis; axisymmetric analysis; cyclic symmetry. The NX Nastran software is composed of a large number of building blocks called modules. Each module is a collection of FORTRAN subroutines which is designed to perform a specific task, such as processing model geometry, assembling matrices, applying constraints, solving matrix problems, and calculating output quantities. Within NX Nastran, the modules are controlled by an internal language called the Direct Matrix Abstraction Program (DMAP), which is a high-level programming language with its own compiler and grammatical rules. A DMAP statement is like a subroutine call statement within FORTRAN, with both input and output information. Each type of analysis available in NX Nastran is called a “solution sequence.” Each solution sequence is a pre-defined collection of hundreds or thousands of DMAP commands. Once you select a solution sequence, its particular set of DMAP commands sends instructions to the modules that are needed to perform the requested solution. NX Nastran also includes DMAP (Direct Matrix Abstraction Programming), a high-level programming language that allows you to build custom solution sequences or modify existing ones [15].

3.2 Determination of loads acting on cladding panels with armor hung on them

The calculation to determine the load on the bracket is carried out on the basis of the finite element method using the "NASTRAN" computer complex.

Description of the cladding panels model in the cockpit are shown on Figure 3.1.

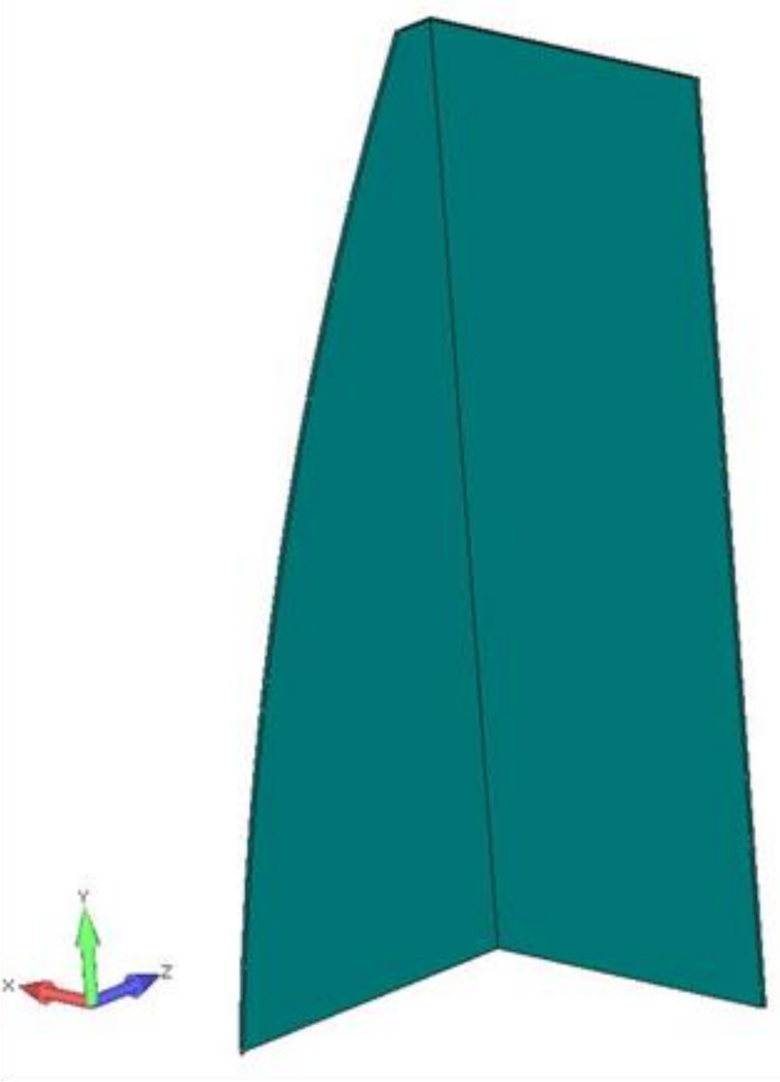
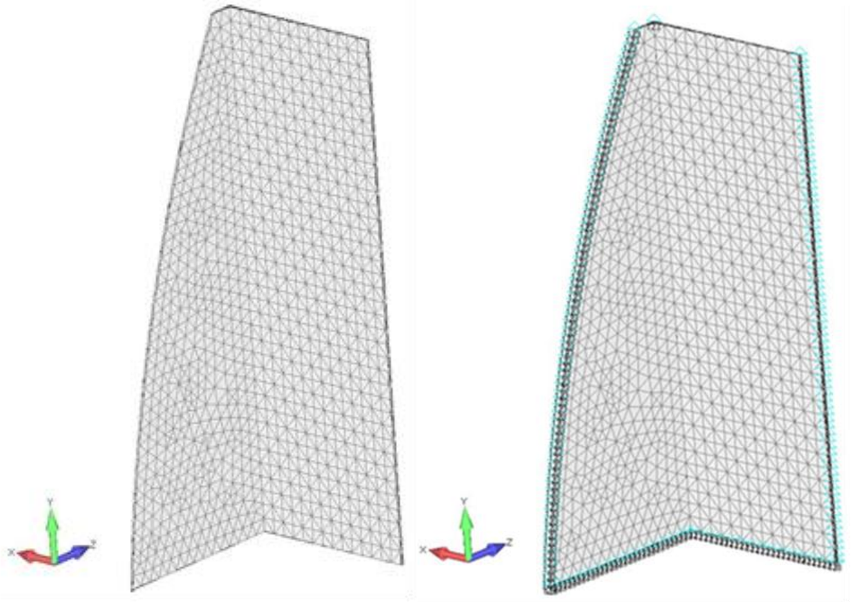


Figure 3.1 – Design model of the cockpit panels

A finite element model was created to determine the load acting on the bracket connecting the facing wall to the aircraft load-bearing structure (frame) (figure 3.2).

To simplify the model, let's consider two walls on which the armor is attached. The facing walls of the cockpit are set by plates 10 mm thick. The characteristics of the material used correspond to the characteristics of the material used in the facing walls of the cockpit - polymerosotoplast. The panels are cutted down into finite elements, fixed like the real construction (figure 3.2) and chose the point of fixing (figure 3.3).



a) b)

Figure 3.2 – Division into finite elements (a) and fixation according to real structure (b)

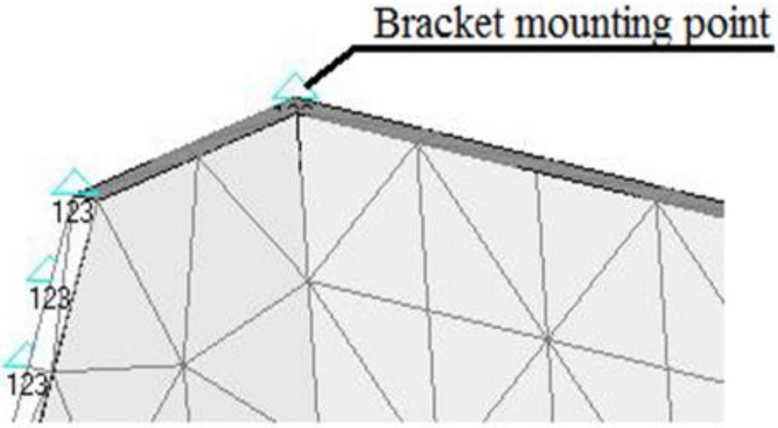


Figure 3.3 – The point that simulates the bracket of the attachment unit

Loads are applied to the planes of the walls during take-off / landing cycles, since in these modes, significant loads act on the structure, based on the mass of the attached armor and inertial overloads acting on the aircraft:

$$\eta_X^p = +2.05$$

$$\eta_Y^p = -2.55$$

The protection element of the longitudinal cladding panel has an area of 1 m^2, therefore, the mass of the protection will be approximately 40 kilograms (a larger value is assumed for the calculation than it may actually be).

Knowing the values of the acting overloads, the loads applied in the model to one panel can be found:

$$P_X^p = m_{ar} \cdot \eta_X^p \tag{3.1}$$

$$P_Y^p = m_{ar} \cdot \eta_Y^p \tag{3.2}$$

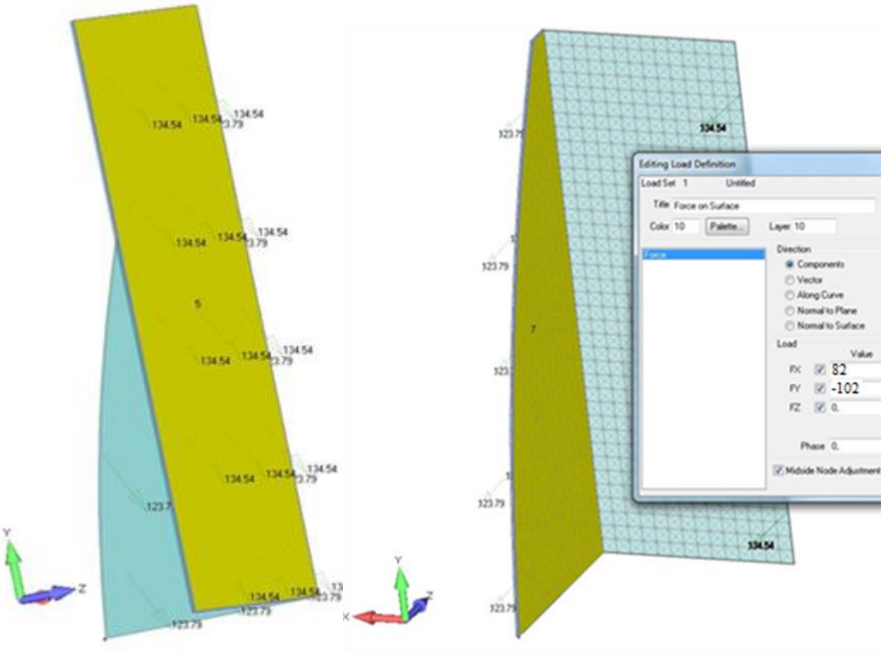
where, η_Y^p – inertial overloads acting on the aircraft; m_{ar} – mass of the protection element.

Therefore, the values of panel loads will be:

$$P_X^p = 40 \cdot 2.05 = 82\ (kgf)$$

$$P_Y^p = 40 \cdot (-2.55) = -102\ (kgf)$$

These values are entered into the program to calculate the actual loads on the panel (figure 3.4).



Editing Load Definition
Load Set 1 Untitled
Title Force on Surface
Color 10 Palette... Layer 10
Force
Direction
● Components
○ Vector
○ Along Curve
○ Normal to Plane
○ Normal to Surface
Load Value
FX ☑ 82
FY ☑ -102
FZ ☑ 0.
Phase 0.
☑ Midside Node Adjustmen

a) b)

Figure 3.4 – Calculation of loads acting on longitudinal (a) and transverse (b) cladding panels

For the both cladding panels, the load values are the same, because the area of the protective elements is also 1 m^2 on each panel.

Based on the results of the calculation, the loads were obtained acting on the bracket (figure 3.5) connecting the cladding panel with the structural structure of the aircraft.

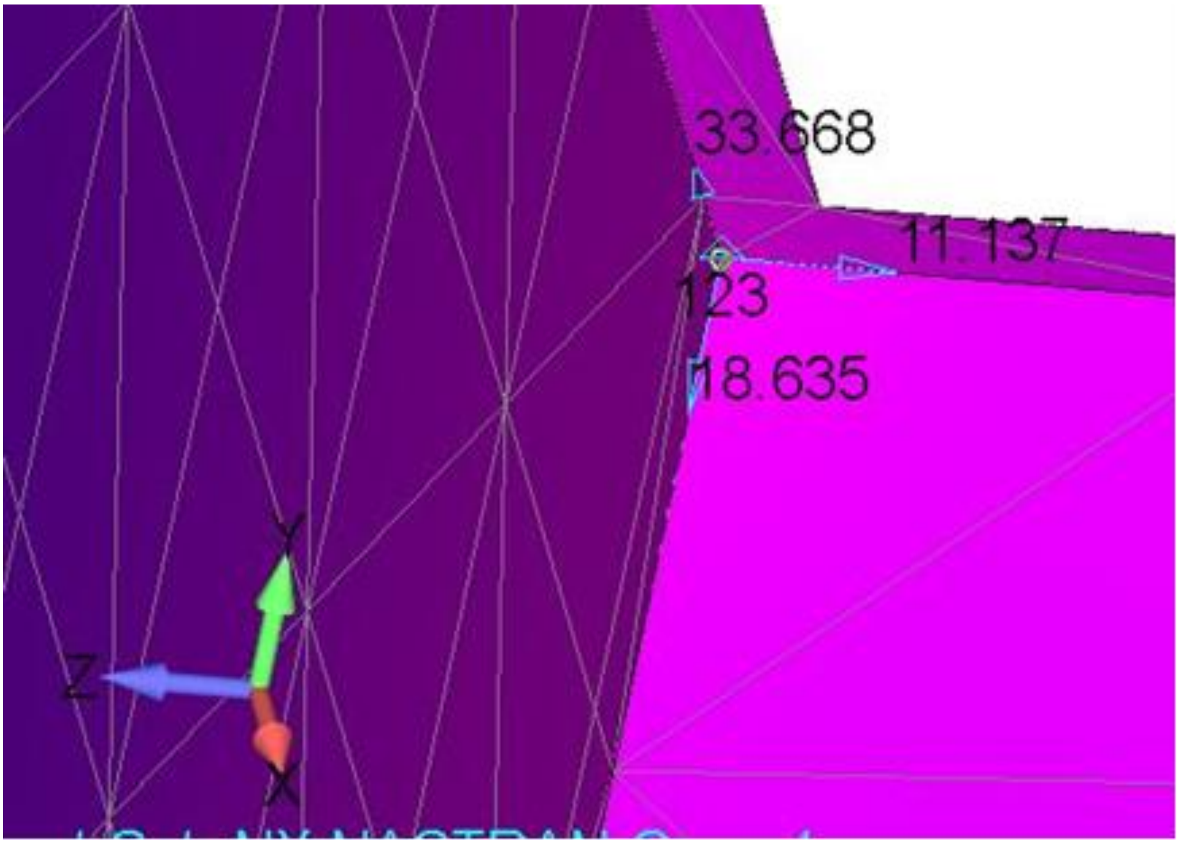


Figure 3.5 – Loads acting on the attachment unit

Values of loads acting on the attachment unit:

$$P_X^P = 34\ (kgf)$$

$$P_Y^P = 19\ (kgf)$$

$$P_Z^P = 11\ (kgf)$$

3.3 Calculation of the stress-strain state of the assembly of the cladding panels of the cockpit to the power structure of the aircraft

Consider the place of attachment according to the general view (figure 3.6) of the bracket to the panel:

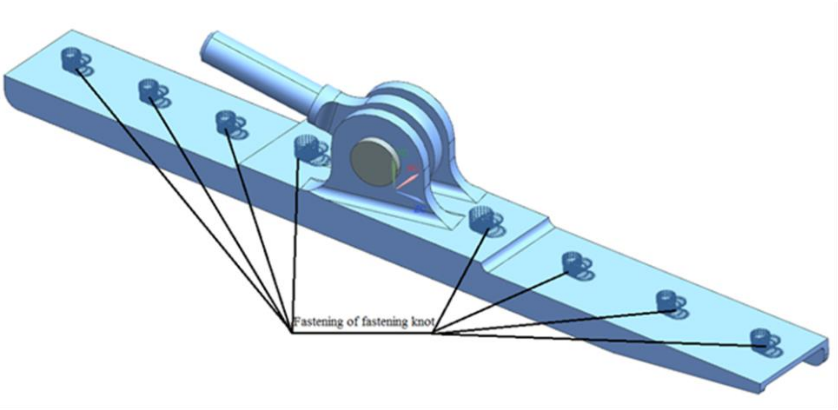


Figure 3.6 – General view of the mounting assembly

The calculation of the stress-strain state (SSS) is performed using the module "NX Advanced Simulation".

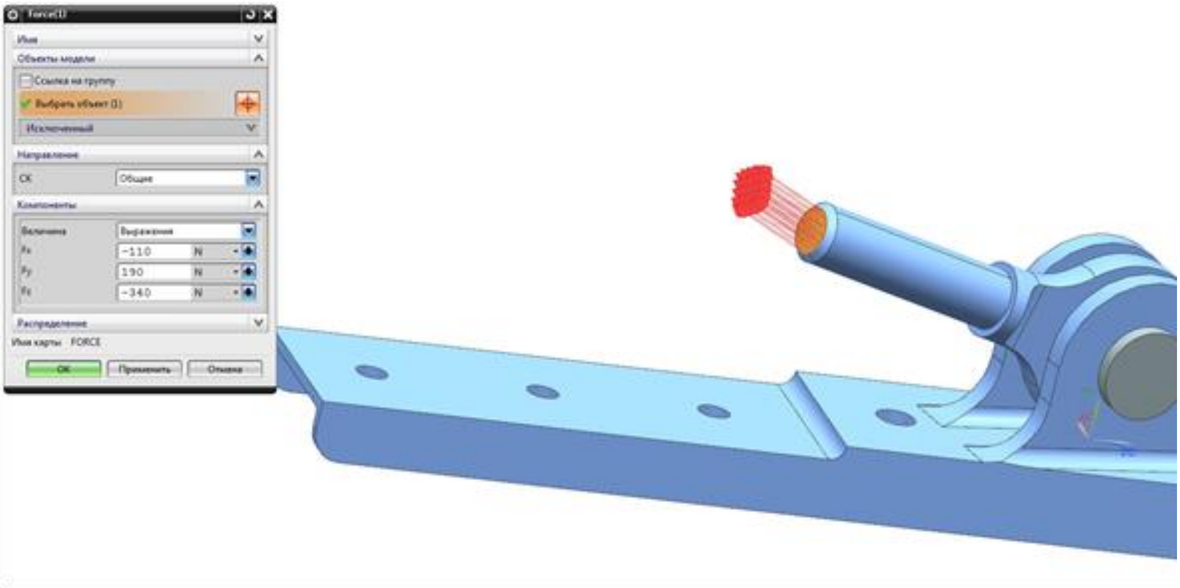
Fixing the model in space. The bracket is fixed rigidly on the ends of apertures, in places of its fastening to a wall. Contact surfaces are created between all parts, through which the load is transmitted.

The load is applied to the tip (figure 3.7):

$$P_X^P = 340\ (H)$$

$$P_Y^P = 190\ (H)$$

$$P_Z^P = 110\ (H)$$



СК: Общие

Величина: Выражение

Fx: -110 N

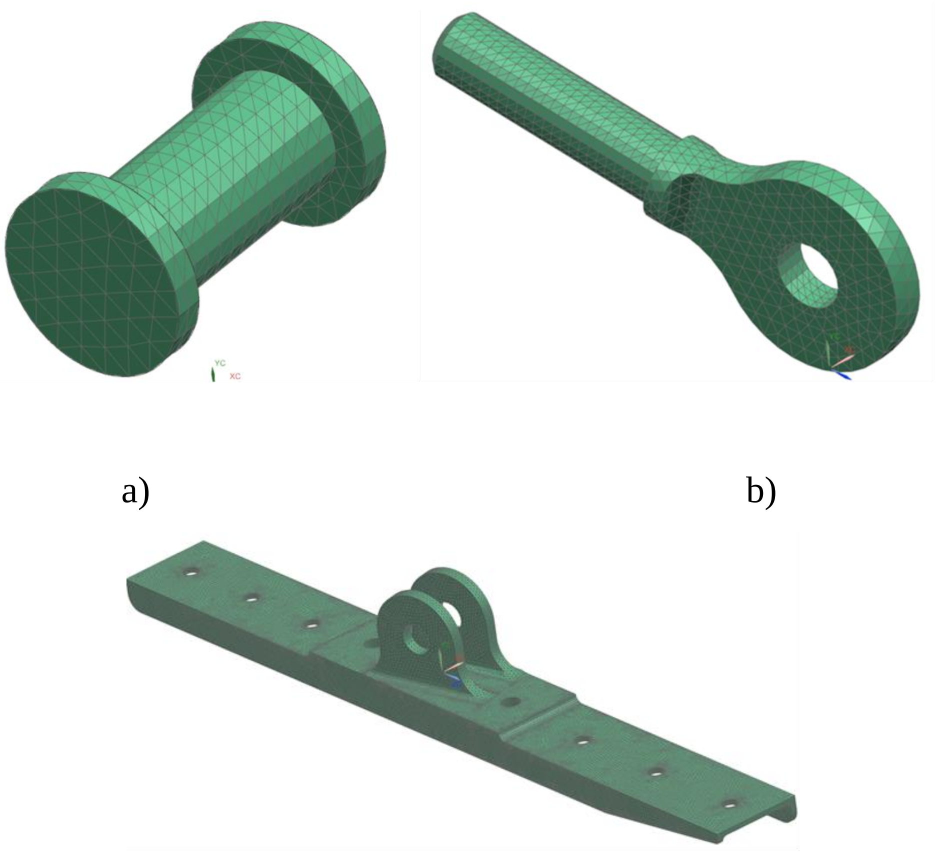
Fy: 190 N

Fz: -340 N

Имя карты: FORCE

Figure 3.7 – The direction of the applied load

When creating a finite element model (figure 3.8) the properties of materials are set. The smaller the size of the finite elements, the more accurate the results of the calculation.



a) b)

c)

Figure 3.8 – Elements of the assembly unit: bolt (a), tip (b), bracket (c)

As a result of the calculation, the stress-strain state of the model (figure 3.9) is obtained.

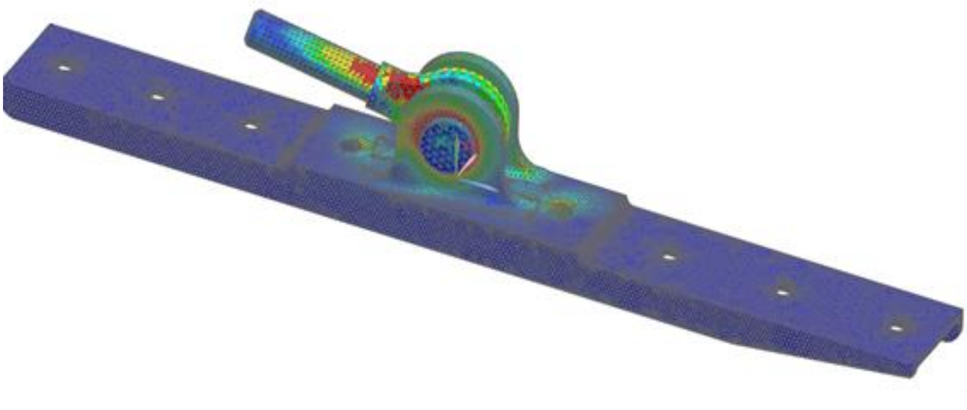


Figure 3.9 – Stress-strain state of a mounting unit

Next, let's look at the stress-strain state in more detailed:

$$\eta = \frac{\sigma_b}{\sigma_{eq}^p} \tag{3.3}$$

where, σ_b – permissible normal stress; σ_{eq}^p – maximum equivalent stresses occurring in the bracket.

1. Bracket:

Material D-16;

$$\sigma_b = 4100\ (\frac{kgf}{cm^2})$$

$$\sigma_{eq}^p = 1060\ (\frac{kgf}{cm^2})$$

So it is possible to determine the coefficient of strength:

$$\eta = \frac{4100}{1060} = 3.9$$

2. Tip:

Material: 30 HGSA;

$$\sigma_b = 11000\ (\frac{kgf}{cm^2})$$

$$\sigma_{eq}^p = 1790\ (\frac{kgf}{cm^2})$$

So it is possible to determine the coefficient of strength:

$$\eta = \frac{11000}{1790} = 6.14$$

Conclusion to the part 3

In this part of the thesis, the elements and conditions were selected for calculating the loads acting on the attachment point of the cockpit facing panels with mounted protection elements installed on them. The calculation data showed that the calculated attachment point has a sufficient safety margin, or rather: the bracket – by 3.9 times, and the tip – by more than 6 times. These data allow us to conclude that the strength characteristics of the materials used in the production aircraft allow for its modernization without significant changes in the design.

This complies with the requirements of OTT BBC-86 “In order to increase the mass return of military transport aircraft and helicopters in peacetime and when used on internal routes in wartime, the armor parts used to protect the crew must be removable. Installation and dismantling of them must be carried out in the airfield conditions by the technical staff of the aviation units [12]. Consequently, it can be concluded that in the selected for consideration zone of approach of the weapon, it is possible to upgrade the aircraft in accordance with the requirements, since the revision will not affect the basic structural elements, which does not contribute to a radical change in the aircraft design.

PART 4

OCCUPATIONAL SAFETY

The task of this thesis is to protect the crew members from the means of destruction of small arms, and the key role of this task is the work of the design engineer.

The modern method of designing aircraft components is the use of computer technologies (information and communication), and this factor directly affects the human body in a negative way, since the workplace is located in close proximity to the computer. But it should be noted that the use of computer technologies in the field of design opens up a wide scope for the creativity of engineers, expands its capabilities in solving professional problems.

Each workplace must comply with generally accepted sanitary standards, which regulate standards for the workplace, lighting, ventilation.

4.1 Requirements for the area of the workplace

According to requirements of ДСанПІН 3.3.2.007-98 “State sanitary rules and norms of work with visual display terminals of electronic computers” the design of the desktop must meet modern ergonomic requirements and ensure optimal placement on the working surface of the equipment used (display, keyboard, printer) and documents. The work table should have legroom at least 0.6 m high, at least 0.5 m wide, at least 0.45 m deep (at knee level) and at least 0.65 m at the level of outstretched legs. The working chair should be lift-and-swivel, adjustable in height, with the angle and inclination of the seat and backrest and the distance from the backrest to the front edge of the seat, the seat surface should be flat, the front edge - rounded. adjustment for each of the parameters should be carried out independently, easily and reliably fixed. The step of adjusting the elements of the chair should be: for linear dimensions - 15 – 20 mm, for corner dimensions 2 – 5 degrees. The adjustment forces should exceed 20 N. The height of the seat surface should be adjusted within the range of 0.4 – 0.5 m, and the width and depth should be at least 0.4 m. The seat tilt angle – up to 15 degrees forward and up to 5 degrees. back. The surface of the seat and back of the chair should be semi-soft with a non-slip, airtight coating, easy to clean and not electrified. The screen of the video display terminal (VDT) should be located at an optimal distance from the user's eyes, 0.6 – 0.7 m, but not closer than 0.6 m, taking into account the size of the alphanumeric characters and signs. The location of the VDT screen should ensure the convenience of visual observation in the vertical plane at an angle of +30 degrees to the worker's normal line of sight. The keyboard should be placed on the table surface at a distance of 0.1 – 0.3 m from the edge facing the user. The design of the keyboard should provide for a support device (made of material with a high coefficient of friction, prevents its displacement), which allows you to change the angle of inclination of the keyboard surface within 5–15 degrees. The height of the middle row of keys should not exceed 30 mm. The surface of the keyboard has a matte finish with a reflection coefficient of 0.4. The location of the information input - output device should ensure good visibility of the VDT screen, convenience of manual control within the reach of the motor field and in height - 0.9–1.3 m, in width 0.4–0.5 m [17].

The dimensions of the office where the design work is carried out: length 10 m; width 6 m; height 3.5 m.

Based on these dimensions, the area of the room is 60 m^2, and the volume is 210 m^3. 7 people work in the office at the same time, which meets the requirements for the working space. The area of one workplace, equipped with a personal computer, should be at least 6 square meters, and the volume 20 cubic meters.

4.2 Harmful and hazardous production factors

During the performance of work, the following harmful and hazardous production factors can affect the body of the design engineer according to ГОСТ 12.0.003-74:

1. Physical harmful factors:

- increased level of electromagnetic radiation (when working at a personal computer);

- increased voltage in the electrical circuit, the short circuit of which can occur through the human body (when working at a personal computer);

- increased level of static electricity (when working at a personal computer);

- increased level of electromagnetic radiation (when working at a personal computer);

- increased electric field strength (when working at a personal computer);

- lack or absence of natural light (when working at a personal computer);
- insufficient lighting of the working area (when working at a personal computer);
- increased brightness of light (when working at a personal computer);
- increased levels of infrared radiation [16].

2. Biological harmful factor:

- pathogenic microorganisms (bacteria, viruses, spirochetes, fungi, protozoa) and products of their vital activity [16].

For example, one employee who comes to work with signs of illness will be dangerous to the other workers around him.

3. Psychophysiological harmful factors:

- physical overload;
- neuropsychiatric overload (mental strain, emotional overload) [16].

In my opinion, the most dangerous factor affecting the work of a design engineer is the lack of lighting. Insufficient illumination affects the functioning of the visual apparatus, that is, it determines visual performance, the human psyche, his emotional state, causes fatigue of the central nervous system, which arises as a result of efforts made to recognize clear or dubious signals.

Lighting of workplaces is of great importance to optimize working conditions. The tasks of organizing the illumination of workplaces are as follows: ensuring the distinguishability of the objects under consideration, reducing tension and fatigue of the organs of vision. Industrial lighting should be uniform and stable, have the correct direction of the luminous flux, exclude glare and the formation of harsh shadows.

4.3 Measures to reduce the impact of harmful and dangerous production factors

Natural light requirements. Natural lighting should be provided through skylights, oriented mainly to the north or northeast and provide a coefficient of natural illumination (CNI) of at least 1.5%. Calculated by CNI according to the method described in ДБН В.2.5-28-2018 [18].

Natural lighting is subdivided into side, top and combined (top and side):

- lateral natural lighting – natural lighting of the room through skylights in the outer walls;

- upper natural lighting – natural lighting of the room through lanterns, light openings in the walls (in places where the heights of the building differ);

- combined natural lighting – a combination of top and side natural lighting.

In industrial premises with a depth of up to 6 meters with one-sided side lighting, the minimum value of CNI is normalized at the point located at the intersection of the vertical plane of the characteristic section of the room and the conditional working surface at a distance of 1 meter from the wall or the line of maximum deepening of the zone farthest from the light openings [18].

With top or combined natural lighting of premises for any purpose, the average value of CNI is normalized at the points located at the intersection of the vertical plane of the characteristic section of the room and the conditional working surface (or floor). The first and last points are taken at a distance of 1 meter from the surface of the walls (partitions) or the axis of the columns.

In industrial premises with visual work of I-III categories, combined lighting should be taken. It is allowed to use overhead natural lighting in large-span assembly shops, where work is performed in a significant part of the volume of the room at different levels of the floor and on differently oriented work surfaces in space. In this case, the normalized values of CNI are taken for categories I, II, III, respectively 10; 7.5% [18].

Calculation of natural light. The work of a design engineer is closely related to the quality of working conditions. Under the wrong conditions, the possibility of getting occupational diseases increases sharply, as well as the productivity of his work decreases. Based on the requirements of ДБН В.2.5.28-2018, the work of an engineer corresponds to the 4th level of visual work. For this level, the intensity of natural light should not be lower than 200 lux. Also, this calculation will help to make the right choice when designing the working place with artificial lighting [18].

A preliminary calculation of the area of light openings for side lighting is carried out according to the formula 4.1:

$$S_s = \frac{D_n}{100m} \cdot \frac{K_s \cdot \eta_l \cdot K_b}{\tau_0 \cdot r_1} \tag{4.1}$$

where, S_s – area of light slots in side lighting; D_n – normalized value of CNI, %; K_s – stock ratio, which is taken according to the table; m – the coefficient of the light climate of the aperture, which is taken according to the table and equals 1.05; η_l – light characteristics of the windows, which is determined according to the table; K_b – a factor that takes into account the shading of windows by opposite houses which is determined according to the table; τ_0 – total light transmission coefficient; r_1 – coefficient that takes into account the increase in CNI in side lighting due to the light reflected from the surfaces of the room and the underlying layer adjacent to the house and which is taken from the table.

Based on the data in the tables, the values of the coefficients should be as follows:

The area of the room S_f is 60 m^2, the normalized value of CNI (D_n) is taken as 1.5, the safety factor (K_s) is 1.5. The ratio of the length of the room to its depth is 1.66 (we take the value of the coefficient 1.5 for calculation), and the value of the light characteristic with the ratio of the depth of the room to its height from the level of the conditional working surface to the top of the window (η_l) is 12 (the most suitable number, based on the table, will be 13). The coefficient of shading of windows by opposite houses (K_b) is taken as 1.1. The coefficient that increases the CNI level, due to the reflection from the surfaces of the room and the underlying layer (r_1), is taken as 1.05.

The total light transmittance (τ_0) is calculated using the formula 4.2:

$$\tau_0 = \tau_1 \cdot \tau_2 \cdot \tau_3 \cdot \tau_4 \cdot \tau_5 \tag{4.2}$$

where, τ_1 – the light transmittance of the material, which is determined by the table; τ_2 – a factor that takes into account the loss of light in the frames of the aperture, which is determined by the table; τ_3 – coefficient that takes into account the losses in the load-bearing structures and which is determined according to the table (with side lighting

τ_3 = 1); τ_4 – coefficient that takes into account the loss of light in sunscreens and which is determined according to the table; τ_5 – a factor that takes into account the loss of light in the protective grid, which is installed under the lights, which is taken equal to 0.9.

The data of the coefficients for the calculation are taken from the tables of ДБН В.2.5-28-2006 and will have the following values: τ_1 = 0.8 (for a window that has 2 layers of sheet glass); τ_2 = 0.75 (steel frame, single, which opens); τ_4 = 1 (adjustable folding blinds and curtains) [18].

Based on the known parameters, you can find the overall light transmission coefficient (τ_0):

$$\tau_0 = 0.8 \cdot 0.75 \cdot 1 \cdot 1 \cdot 0.9 = 0.54$$

After finding the value of the total light transmission coefficient and transforming the formula 4.1, the value of the required area of light openings under side illumination (S_s) can be found:

$$S_s = \frac{1.5 \cdot 1.5 \cdot 13 \cdot 1.1}{100 \cdot 1.05 \cdot 0.54 \cdot 1.05} = 0.54\, m^2$$

4.4 Occupational Safety Instruction

General safety requirements. To work as a design engineer are allowed persons who have a higher professional (technical) education in a specialized specialty with or without presentation of requirements for work experience, depending on the category, and also have no medical contraindications.

The design engineer informs his immediate supervisor about any situation that threatens the life and health of people, about every accident that occurs at work, about the deterioration of his health, including the manifestation of signs of an acute illness.

A design engineer must undergo training in labor protection in the form of: introductory briefing, special training in labor protection in the scope of job duties upon admission to work during the first month, then as needed, but at least once every three years. A design engineer who has not timely passed the appropriate instruction on labor protection, an annual examination of knowledge on labor protection, a periodic medical examination, is not allowed to work [19].

*Safety Requirements before starting work***.** Every engineer should follow the following rules before starting work:

1. Arrive at work in advance to avoid haste and, as a result, falls and injuries.
2. Inspect the workplace and equipment. Remove all unnecessary items.
3. Adjust the seat height. Check the height of the equipment.
4. Check the availability of fire-fighting equipment, first aid kit (its complete set).
5. Check by visual inspection: absence of cracks and chips on the cases of sockets and switches, as well as the absence of bare contacts; reliability of closing all current-carrying devices of the equipment; presence and reliability of grounding connections (absence of breaks, strength of contact between metal non-current-carrying parts of the equipment and the grounding wire); the integrity of the insulation of electrical wires and power cords of electrical appliances, the serviceability of safety devices; sufficiency of lighting of the workplace; absence of foreign objects around the equipment [19].

*Safety Requirements during operation***.** Upon detection of faulty equipment, fixtures, etc., other violations of labor protection requirements that cannot be eliminated on their own, as well as a threat to health, personal or collective safety, the design engineer should inform the employee responsible for eliminating the violations , or to a superior leader.

When working with a PC, an engineer observe the rules for their operation in accordance with the instructions for labor protection:

1. The screen should be 5 degrees below eye level, and be located in a straight plane or tilted towards the operator (15 degrees).
2. The distance from the eyes to the screen should be within 60–80 cm.
3. The local light source in relation to the workplace should be located so as to exclude direct light from entering the eyes, and should provide uniform illumination on a surface of 40 x 40 cm, not create blinding glare on the keyboard and other parts of the console, as well as on the video terminal screen in direction of the eyes.
4. To reduce visual and general fatigue, after each hour of working at the screen, you should use regulated breaks of 5 minutes, during which you can rest.

5. During a work shift, the display screen must be cleaned of dust at least once [19].

When performing work, the design engineer is prohibited from:

1. Touch the rear panel of the system unit (processor) when the power is on.

2. Switch connectors of interface cables of peripheral devices when the power is on.

3. To turn off the power during the execution of an active task.

4. Allow moisture to get on the surface of the system unit (processor), monitor, working surface of the keyboard, disk drives.

5. Perform self-opening and repair of equipment [19].

Safety Requirements after work. Labor protection requirements for the design engineer at the end of work: Inspect the workplace, put things in order. Remove equipment, documentation, etc. to the designated places. When working with electrical equipment, disconnect it from the network [19].

Safety Requirements at emergency situations:

1. Upon detection of malfunctions of equipment, instruments and apparatus, as well as in the event of other conditions that threaten the life and health of workers, the design engineer should stop work and report them to his immediate supervisor and the employee responsible for the implementation of production control.

2. When a fire source appears, the design engineer must: stop working; turn off electrical equipment; organize the evacuation of people; start extinguishing the fire immediately (when electrical equipment catches fire, use only carbon dioxide or dry powder fire extinguishers).

3. If it is impossible to carry out extinguishing on his own, the design engineer should, in accordance with the established procedure, call the fire brigade and inform the immediate supervisor about it.

4. In the event of injury or deterioration of health, the design engineer must stop work, notify the management and seek medical attention.

5. In the event of injury or deterioration in the health of a subordinate employee, remove him from work and send him to the first-aid post, and, if necessary, call the city ambulance [19].

Conclusion to the part 4

In this part of the thesis, the main regulatory documents were considered, the data of which must be taken into account in the design and arrangement of the workplace. This is very important, since a person spends a lot of time in an environment that must meet standards, otherwise it will adversely affect his health and, accordingly, his productivity.

Since my workplace is located on the side, where it is sunny almost all day, I took into account the amount of daylight required in the workroom and this parameter is from the state building codes. As a result of calculating the parameters of the room and the environment, it was found that the amount of daylight supplied to the working room is sufficient to organize the working space in accordance with the standard norms.

But one cannot ignore the requirements of safety at the workplace, so this part would not be complete without listing these requirements. Since the risk of injury when working with computer equipment is very high, and it is important to know how to start work correctly, how to end the work day and how to act in emergency situations. The latter is especially important, since the overall safety of the team, and sometimes even life, depends on the correct sequence of actions.

PART 5

INFLUENCE OF AIR TRANSPORT ON ENVIRONMENT

The rapid development of air transport and the increasing in its role in human life could not have a hazardous impact on the environment. The main environmental impacts of aviation are acoustic pollution because the high sound has dangerous impact on human’s ears. In the another hand we have a problem of air pollution because the release of gases from the engines into the atmosphere leads to the main problem of modern society such as climate change.

The main advantage of air transport over its other types is the saving of a great part of time due to the high flight speed for transportation of a person, cargo etc. from one point to another. The main advantages also include lower fixed costs compared to many other kinds of transport. The construction of airports requires very large open spaces and, as a rule, air transport is not integrated into a single system with other types of transport and this fact provides the interjacent transporting to the place of departure or arrival.

Air transport is used to transport a wide variety of products, primarily in cases of emergency or when the another type of transportation is not available due to high cost or the transportation is carried out to hard-to-reach places for another type of transport. The main function of this transportation by air is passenger transportation. According to them, it takes the third place among the other kinds of transportation. Aircraft are also used in the building of pipelines, bridges, communication lines, in some agricultural work, in geological prospecting due to its mobility and ability to transport a lot of goods in one flight.

Influence of different types of pollution on the environment

The air transport is the main source of acoustic, electromagnetic, air and water pollution. Let’s describe this four harmful factors more closely:

1. *Acoustic pollution*. Noise (acoustic) pollution is an irritating noise of anthropogenic origin that disrupts the vital activity of living organisms and humans. Irritating noises also exist in nature (abiotic and biotic), but it is incorrect to consider them as pollution, since living organisms have adapted to them in the process of evolution [20].

Noise pollution has a negative impact on the natural balance in ecosystem. Noise pollution can lead to disorientation in space, communication etc. In this regard, some animals begin to emit louder sounds, which is why they themselves will become secondary sound pollutants, further disturbing the balance in the ecosystem. One of the most famous cases of damage caused by noise pollution to nature is the numerous cases when dolphins and whales were thrown on the beech, losing orientation due to the loud sounds of military sonars that impacts on the animal’s biological locator.

Noise is caused by aircraft engines, auxiliary power units of aircraft, special vehicles for various purposes, cars made on the basis of aircraft engines with thermal and wind turbines that have expired flight life, equipment of stationary objects of the airport infrastructure where maintenance and repair of aircraft is carried out.

Under certain conditions, noise can have a significant impact on human health and behavior. Noise can cause irritation and aggression, hypertension (high blood pressure), tinnitus and hearing loss. The greatest irritation is caused by noise in the frequency range of 3000-5000 Hz. Chronic exposure to noise levels greater than 90 dB can lead to hearing loss. At a noise level of more than 110 dB, a person develops sound intoxication, which in subjective sensations is similar to alcohol or narcotic. At a noise level of 145 dB, a person's eardrums rupture. Women are less resistant to loud noise than men. In addition, the susceptibility to noise also depends on age, temperament, health status, environmental conditions, etc. [20;21].

Bad feeling may be caused not only by acoustic pollution, but also by the complete absence of sounds. Moreover, some sounds of a certain heavy increase efficiency and stimulate the process of thinking (especially the counting process) and, conversely, in the complete absence of noise, a person loses his ability to work and feel stress. The most optimal for the human ear are natural noises: rustle of leaves, murmur of water, singing of birds. Industrial noises of any power do not improve well-being. Road traffic noise can cause headaches and other problems with health.

2. *Electromagnetic pollution*. Electromagnetic pollution is a combination of electromagnetic fields of various frequencies that negatively affect on the human organism. Some researchers call the electromagnetic smog that has arisen, one of the most

powerful factors that negatively affect on the human organism at the moment. This is due to its virtually every day whole day exposure and rapid growth.

Electromagnetic pollution depends mainly on the power and frequency of the emitted signal. It is caused by a radar and radio navigation equipment of airports and aircraft, which is necessary to monitor aircraft flights and meteorological conditions for increasing the safety of flights. Radar devices emit streams of electromagnetic energy into the environment. They can create high-intensity electromagnetic fields that appear a real problem to people.

At civil aviation airports, the electromagnetic environment is mainly determined by the radiation of powerful radar stations. These primarily include ground surveillance radar stations operating in the ultra-high and ultra-high frequency ranges. The effect of the electromagnetic field on a person in the areas where these stations are located is intermittent, which is due to the period of rotation of the electromagnetic radiation. Studies have confirmed the possibility of using calculation methods for a preliminary assessment of the electromagnetic environment around radar stations. There are also national and international hygienic standards for the levels of electromagnetic radiation, depending on the range, for the residential area and at workplaces. Being in an area with elevated levels of the electromagnetic field for a certain time leads to a number of adverse consequences: fatigue, nausea, and headache are observed. If the standards are significantly exceeded, damage to the heart, brain, and central nervous system is possible. Radiation can affect the human psyche, irritability appears, it is difficult for a person to control himself. Perhaps the development of diseases that are difficult to treat, up to cancer [21].

3. *Air pollution*. The greatest environmental pollution occurs in the airport area during aircraft landing and take-off, as well as during warming up of their engines. It is estimated that with several hundred takeoffs and landings of large airliners per day, the emission of harmful substances into the atmosphere is not evenly distributed, but depending on the schedule of the airport. When the engines are operating during take-off and landing, the largest amount of harmful compounds such as carbon monoxide and hydrocarbon enters the environment, and the maximum amount of nitrogen oxides is released during flight.

The concentration of harmful components of the exhaust gases of aircraft engines in the air and the rate of their propagation through the airport territory largely depends on the meteorological conditions. In this case, the influence of the direction and speed of the wind is most clearly traced. Other factors such as air temperature and humidity, solar radiation although affect on the concentration of pollutants, but this influence is less pronounced and has a more complex relationship.

At emergency situations, aircraft are forced to drain excess fuel in the air to reduce the landing weight. The amount of fuel discharged by an airplane at a time ranges from 1 - 2 thousand to 50 thousand liters. The evaporated part of the fuel is dispersed in the atmosphere without hazardous consequences, however, the non-evaporated part reaches the surface of the earth and water bodies and can cause strong local pollution. The proportion of non-evaporated fuel reaching the ground in the form of droplets depends on the air temperature and the height of the drain. But something else is more dangerous. When flying in the lower stratosphere, the engines of supersonic aircraft release nitrogen oxides, which leads to ozone oxidation. In the stratosphere, there is an intense interaction of sunlight with oxygen molecules. As a result, the molecules disintegrate into individual atoms, and those, joining the remaining oxygen molecules, form ozone. The area of increased ozone concentration, the so-called ozonosphere, which falls at altitudes of 20-25 km, plays a very important role for the Earth. Air pollution by vehicles with rocket propulsion systems occurs mainly during their operation before launch, during take-off and landing, during ground tests during their production and after repair, during storage and transportation of fuel, as well as when refueling aircraft [21].

4. *Water pollution*. Groundwater pollution by oil products occurs near the airports, mainly due to leakage of fuel when refueling aircraft, oil from oil tanks as well as due to technical errors during its transportation and storage of the aircraft. During emergencies, spilled oil products and contaminated soil are removed from the earth's surface. When oil products enter the aquifers, the polluted water is usually pumped out and then purified through appropriate filters. A mixture of dust, fuel combustion products, particles of washable tires and other materials accumulates on the surfaces of airports. Together with rain streams, all this falls into water bodies [21].

Conclusion to the part 5

Over the past hundred years, environmental pollution has increased with various emissions. Due to its technological specificity, harmful emissions produced by aircraft in the atmosphere much faster and spread in it, therefore, protecting the environment from the negative impact of air transport is actual for all people over the world.

A significant amount of impurities at the airport is also thrown out by ground vehicles, vehicles approaching and leaving. The largest share of emissions falls on emissions of volatile organic substances – 82%, carbon monoxide – 14%. To reduce harmful emissions from engine operation, the airline uses the following methods:

- use of fuel additives, water injection, etc .;
- fuel atomization;
- enriched mixtures in the combustion zone;
- reduced engine running time on the ground;
- reduction of the number of operating engines during taxiing (waste emission is reduced by 3-8 times) [20].

To reduce the specific content of toxic substances in the exhaust gases, along with the improvement of the types of gas turbine engines in operation, new gas turbine engines are being created with new designs of the combustion chamber, injection systems of the fuel-air mixture, compressors that provide the most favorable ratio in the fuel-air mixture, better atomization and mixing of the mixture supplied into the chamber, and its more complete combustion. New two-zone chambers are being created, where fuel is burned in two stages in different places of the chamber, and one of these zones ensures the best fuel combustion in the low-thrust mode, for example, taxiing (in this case, no fuel is supplied to the second zone), and the second zone, together with the first allows to optimize the combustion process in take-off, climb and cruise flight modes. In the latter case, the combustion process in the second zone proceeds at a lower temperature, which makes it possible to reduce the release of nitrogen oxides [20].

GENERAL CONCLUSION

Over the period of numerous conflicts, aviation engineers came to the conclusion that the use of aircraft as military aviation requires equipping with additional crew protection systems. First of all, this not only increases the chances of a successful return of the aircraft from a combat mission, but also helps to protect the crew from possible hitting by various means of destruction. For the first time, this task was embodied in the massive use of armored structural elements (armored seat back, armored glazing of the cockpit) during the Second World War, which made it possible to reduce human losses, first of all – this factor is the main factor in the design of protection. With the development of technologies, both new protection materials and new means of destruction appeared, which were briefly described in this work. Ceramic materials of various thicknesses began to enter mass use, which made it possible to create combined protection elements. As a rule, the first layer of such elements is ceramic filler, which has a much higher hardness in comparison with the materials of bullets, and accordingly its destruction occurs. And the second layer is a material that is designed to catch fragments of a bullet and a ceramic element, not allowing them to go outside the protective element, thereby causing damage to the crew.

The main task of this work was the modernization of an existing aircraft in terms of protecting the crew using the armoring method. To carry out this work, a mandatory requirement was compliance with regulatory documents that describe the main requirements for the developer. A detailed analysis of the design and internal layout of the aircraft equipment showed that the crew needs protection from all possible sectors of fire, and the required thicknesses of materials were calculated, which were taken into account. For a more detailed consideration, sectors 15 °–30 ° of the rear hemisphere relative to the aircraft commander were taken. The calculation of the required thickness of the material of the structure showed that this thickness is not enough for guaranteed protection of the crew. Based on this, it was decided to install armored elements without changing the basic structure of the aircraft, which meets the existing requirements.

In accordance with the requirements for the ease of removal of armored elements and the previous analysis of the structure with the choice of the likely sector of fire, the elements of the cockpit environment were selected, on which the installation of protective elements should be carried out. The problem was whether the standard fastening of the cockpit inner lining panels would withstand the weight of the installed protection. Based on the results of computer modeling and calculations, it was found that the standard mount has a margin of safety more than 3 times for the bracket and more than 6 times for the tip. The result showed that changes in the basic design are not required, which makes it possible to modernize any of the existing aircraft without reworking the design, and this meets one of the main requirements of the OTT BBC-86.

Since all work is performed at the workplace as a design engineer, working conditions must comply with established standards. In the part on labor protection, regulatory documents were examined that regulate the parameters for the workplace and the general harmful factors that an engineer may be exposed to in the process of performing work tasks. Also, the required amount of natural light was calculated, which corresponds to the actual working conditions. In terms of environmental protection, the types of environmental pollution and their impact on living organisms were considered. At the end of the part, examples of work that are being carried out to improve the environmental situation are given.

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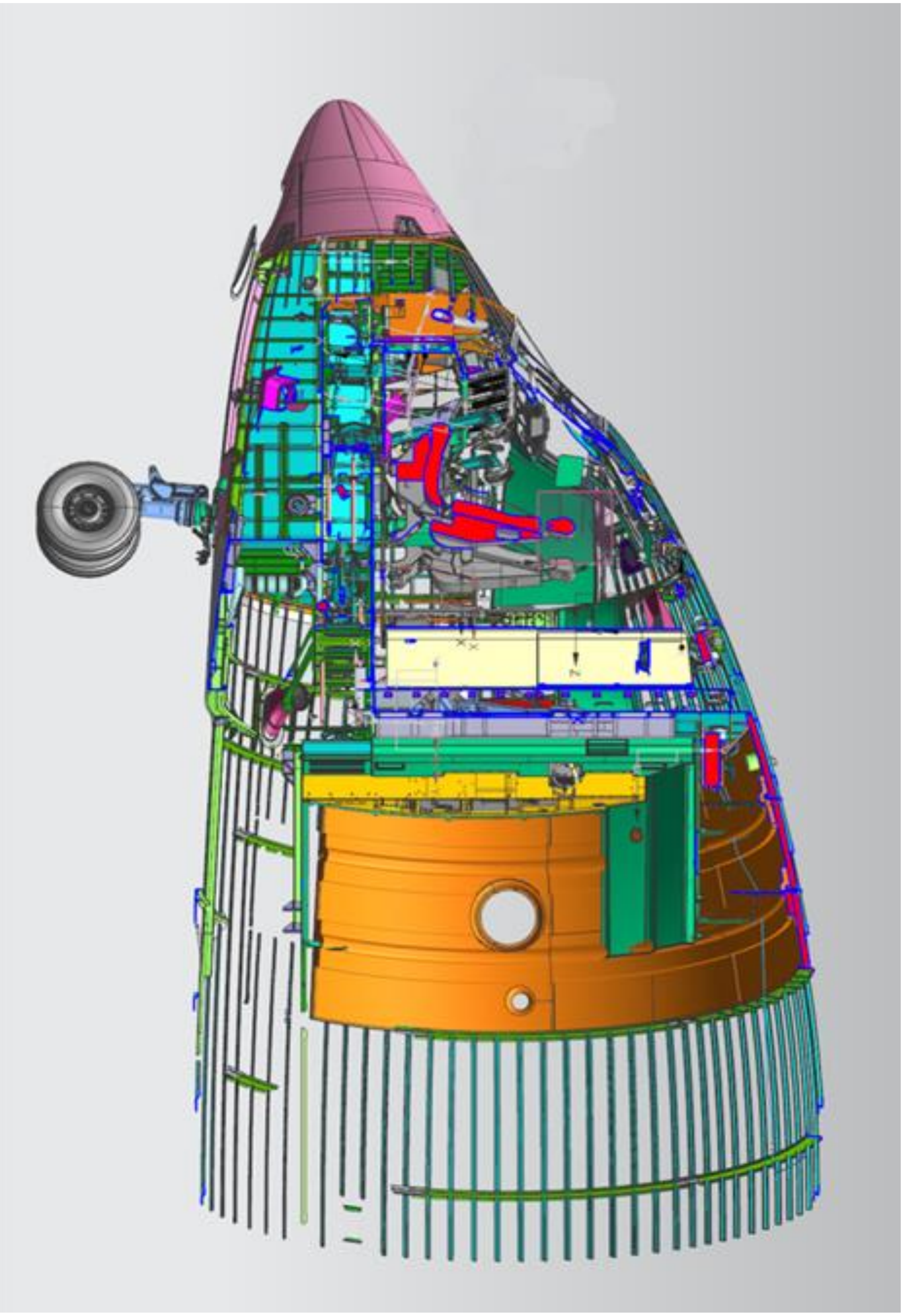
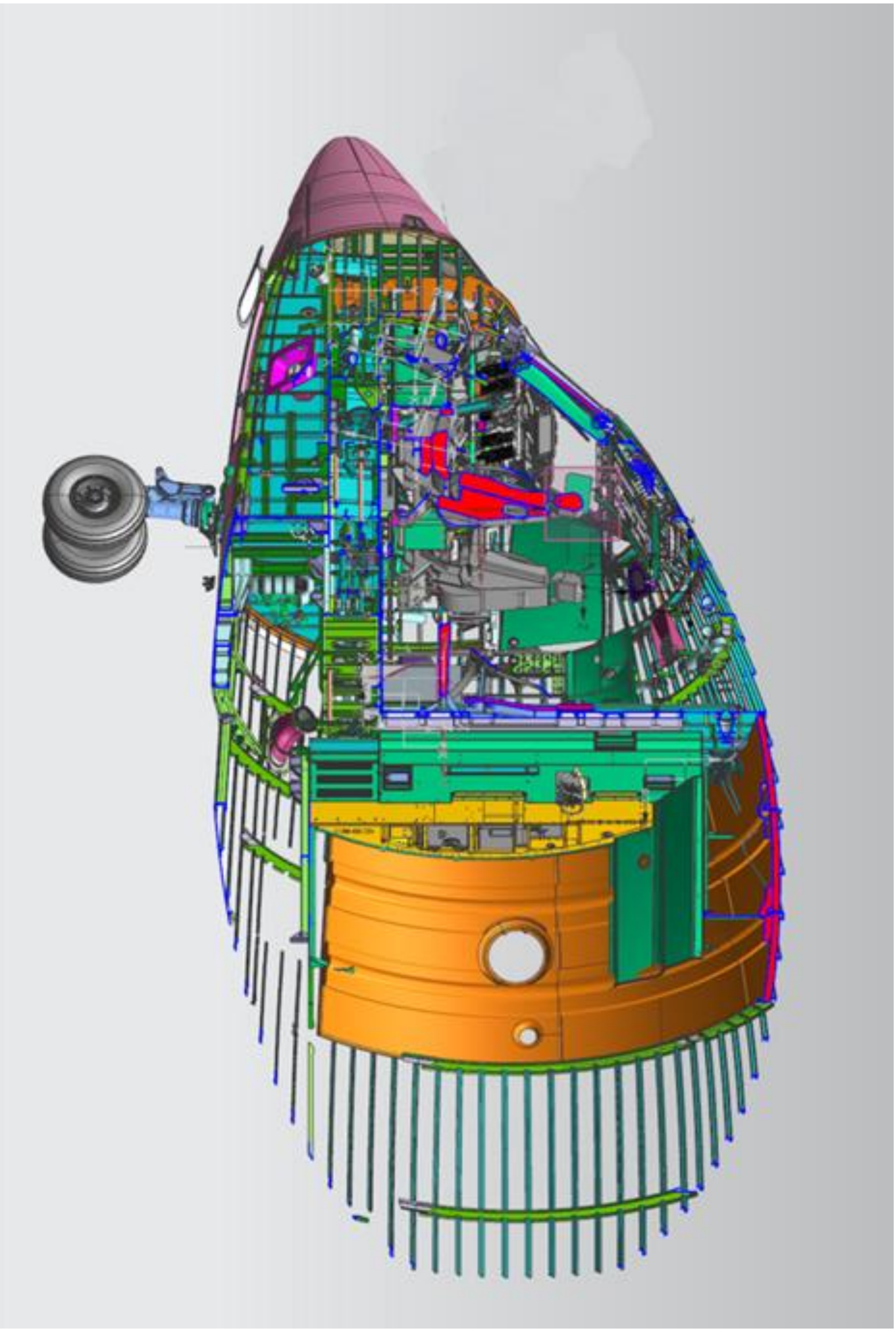
APPENDIX A

Fuselage cross-section 15° relative to the aircraft commander's seat



APPENDIX B

Fuselage cross-section 30° relative to the aircraft commander's seat



APPENDIX C

The conditional mandatory zones which should be protected