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THE DESIGN OF AN EJECTION SEAT FOR MILITARY AIRCRAFT

Abstract: *This paper addresses issues that may arise when implementing the new proposed electromagnet head lock system. It also introduces new elements to protect the upper limbs during ejection, but also modeling and simulating the flight trajectory of the seat according to the flight speed of the aircraft, made with the help of MATLAB-Simulink software. Last but not least, a simulation of the air flow around the structure made in the Ansys Fluent program is exposed..*

Key words: *ejection seat, electromagnet, aircraft, military, simulation, trajectory*

1. INTRODUCTION

In the event of damage to an aircraft, the rescue of the pilot is hampered by the action of the air resistance force acting on the body, especially at low altitudes and high flight speeds. This problem arose with the development of propulsion systems, which led to increased flight speed. Therefore, it is necessary to catapult the pilot and the seat with a force large enough to ensure rapid detachment and movement at a certain distance from the aircraft. With the help of the calculation of the elements of the flight path of the seat, the collision of the seat - pilot assembly can be prevented by the vertical tail or other parts of the aircraft [1].

Moreover, the duration and action of the forces on the pilot's body during the ejection process must be such as not to endanger the person's health or affect his ability to work.

The overloads acting on the human body after the ejection is triggered are determined by an overload factor. Its average value is 18, ie an inertial force of about 1500 daN acts on the pilot.

The correct position on the ejection seat is very important because it helps the person to be able to withstand overloads without consequences on the body, due to the short ejection duration. The pilot must maintain a straight posture, ensuring a neutral shape of the spine and reducing the large overloads caused by the inertial force of the upper body.

In order to reduce the influence of forces on the spine, especially in the cervical area, it has been proposed to introduce at the level of the helmet and the headrest of the seat, a mechanism for locking the head with an electromagnet. The advantage of this system is that during normal flight operations, the pilot's head is not constrained and can move freely. When the ejection handle is fired, the electromagnet is supplied with electric current, and the force produced keeps the pilot's head and helmet attached to the head restraint until the seat is detached.

2. IMPLEMENTATION OF THE ELECTROMAGNET MECHANISM

One of the problems that occurs in the implementation of the head lock mechanism is the change in the weight of the headset. If initially the helmets were made of soft lined leather, then for a higher hardness they were made of steel, today new materials with superior properties and low weight are used [6]. Most of the helmets that can be found on the market today have a construction made of carbon fiber and kevlar [7]. Carbon fiber is a material often used in aerospace industry due to its special mechanical properties, and kevlar is a synthetic fiber that stands out for its high strength-to-weight ratio.

During ejection, the pilot feels a much greater force than the weight of the helmet due to the appearance of the overload factor, their mass is an essential factor in the manufacture of helmets. Normally, a helmet made of carbon fiber and kevlar weighs about 1-2 kg, without an oxygen mask.

Next, we will study the change of the weight of a helmet after the implementation of the electromagnet locking system. It is considered a helmet made of light materials, with a mass of 1.5 kg. A metal plate with an area of 150 cm^2 and a thickness of 5 mm will be integrated in its structure (Figure 1). The material from which the plate is made is steel and will have a mass of 259.5 g.

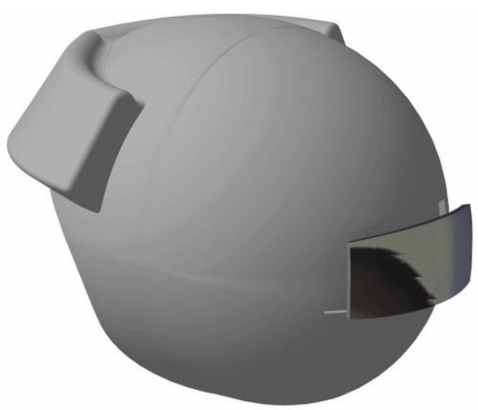

Figure 1 Pilot helmet with metal plate

To attach the metal plate, a cut will be made in the back area of the helmet. The cutout will have the dimensions of the plate and will have a depth of 4 mm. This will make it easier to remove the plate in order to replace it. After cutting the area and integrating the plate, as shown in Figure 1, the final weight of the helmet reaches about 1.75 kg.

There is an increase in mass by 250 g which in case of an ejection with an overload factor of 10 G leads to the appearance of an inertia force 2.5 kg higher than the initial version. However, the advantage of keeping the head stable in the continuation of the spine makes this overload much easier to bear. In this way, the risk of fracture of the spine in the cervical area can be eliminated due to the impact produced when hitting the chest with the chin.

On the other hand, the position of the electromagnet in the seat headrest is also essential. It must be mounted at an appropriate height to keep the column in an upright position so that no compression moment occurs.

The MIL-STD-1472 standard provides anthropological data in the range of the 5th percentile female to the 95th percentile male, covering 90% of the individuals concerned. These sizes are recommended and have the role of providing general design guidance. According to them, the size from the seat of the chair to the eye line is recommended to be 86.1 cm for men and 80.2 cm for women, for most of the people.

Taking this into account, it can be said that the optimal size for positioning the electromagnet is 84 cm from the seat of the seat. However, human bodies are extremely different and can have various sizes that do not correspond to the optimal size. In such cases, the height of the seat cushion can also be adjusted.

3. HAND PROTECTION ELEMENTS

During the process of ejecting the pilot together with the seat, the position of the hands may endanger the health and safety of the pilot. It is essential that both the lower and upper limbs of the person on board are kept close to or inside the seat. The moment of exit from the aircraft and the meeting of the structure with the air flow is a very strong shock. Therefore, the limbs must be very well protected because they can be easily torn by this current.

Many manufacturers of ejection seats include in their configuration leg retraction systems using two straps that are pulled when starting the system. On the other hand, those for the arms are still being developed to identify the best solution.

The seat produced in Romania benefits from a hand retraction mechanism that is based on the same principle of operation as that of the lower limbs. It consists of two cables connected at one end with the retraction mechanism, and at the other, mounted on the antigravity suit. In addition, in order to increase the protection of the feet against the air current, it is observed the implementation of two defenders with the role of preventing the lower part from coming out of the seat [2].

With this in mind, it is proposed to introduce two such devices in the upper part of the seat as well. Because during normal flight operations, the pilot must be able to move his arms without hitting these protections, it was proposed to introduce retractable structures. Normally, these will be overdue, not exceeding the seat line. When the ejection phase begins, the mechanism behind these devices will push the moving part out, keeping the body inside the structure. Figures 2 and 3 show the two states (retracted and extruded) of the two structures configured for the ejection seat SC.HV-0.

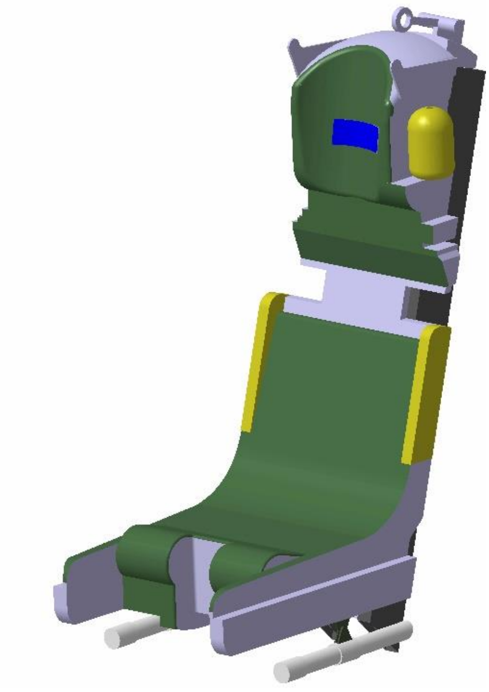

Figure 2 Withdrawn protection elements

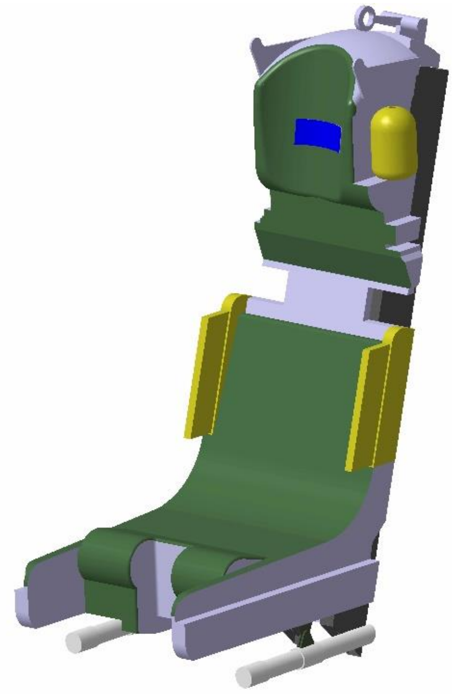

Figure 3 Extended protection elements

The material from which they will be made is carbon fiber [8]. This material was chosen due to its excellent mechanical properties and especially its high strength. The mechanism behind them consists of a set of pistons which, when actuated, push out the sliding component.

4. CALCULATION OF TRACK ELEMENTS DEPENDING ON FLIGHT SPEED

For the calculation of the elements of the ejection trajectory, the ejection hypothesis from an aircraft that is in horizontal flight will be taken into account [3], [4]. The pilot-seat assembly will be analyzed as a solid body and will be represented in the absolute XOY coordinate system, neglecting the rolling moment of the aircraft. The aircraft moves at a constant speed, V_p and at a constant flight altitude H.

The coordinate systems that will be used in this calculation are:

- XOY – the absolute coordinate system, with the origin in the center of gravity of the seat at the moment of leaving the aircraft and with the OX in the direction of V_p;
- $X_1O_1Y_1$ – the relative coordinate system, connected to the aircraft, with the OX_1 axis in the direction of the projection of V_0 on V_p;
- $X_vO_vY_v$ – the relative coordinate system, connected to the seat which has the axis OX_v on the direction of the speed of the seat V;
- $X_2O_2Y_2$ – the relative coordinate system, connected to the seat, with the OX_2 axis in the direction of the "back-chest" overload.

When the ejection phase starts, by pulling the ejection handle, the seat begins to move on the guide rails, inclined at an angle χ to the vertical, with a relative initial speed, V_0.

Figure 4 shows the trajectory of the ejection seat together with the speeds and angles involved in this process.

The body leaves the rails with the absolute initial velocity, VH at an initial angle of inclination of the trajectory, θ_H.

The aerodynamic forces acting on the body, as shown in Figure 5, are the lifting force acting on the perpendicular direction of air flow, the drag force opposing the movement, the weight of the assembly, perpendicular to the horizontal plane and the aerodynamic moment [9], [10].

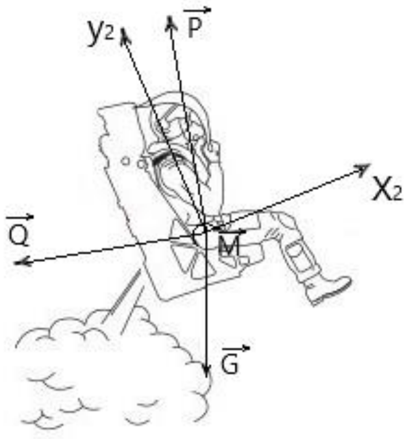

Figure 5 Aerodynamic forces acting on the pilot

The expressions of the forces acting on the trajectory on the ejection seat are:

$$P = \frac{1}{2}\rho S C_x V^2 \quad (1)$$

$$Q = \frac{1}{2}\rho S C_y V^2 \quad (2)$$

$$M = \frac{1}{2}\rho S l C_m V^2 \quad (3)$$

where C_x, C_y, C_m represent the aerodynamic coefficients, S the calculation surface of the pilot's seat, ρ the air density, V the speed of the seat per trajectory and l the characteristic linear dimension.

The problem is to determine the components of the

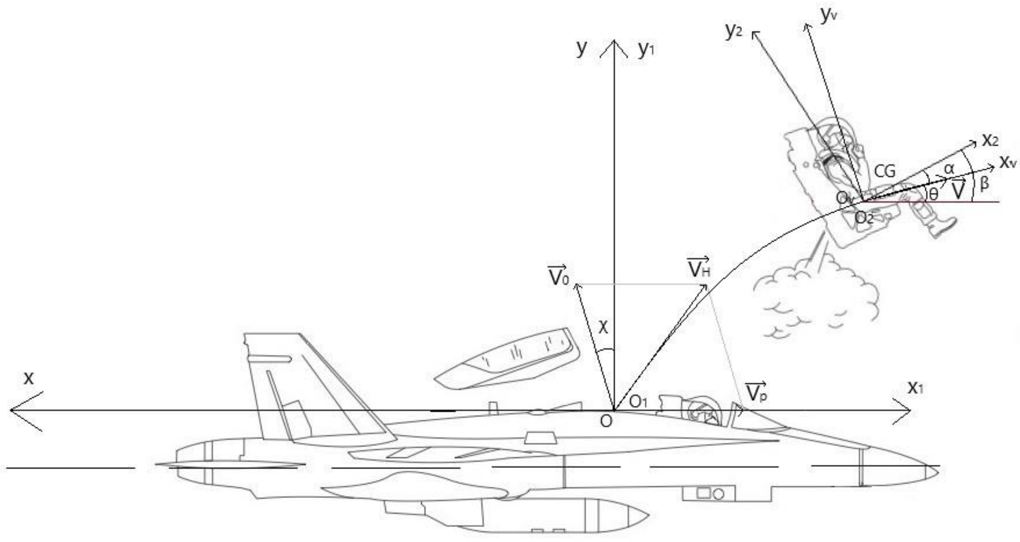

Figure 4 Flight trajectory

trajectory so that the body does not collide with the tail of the plane. For this, the ejection seat SC.HV-0 equipped on the Romanian military aircraft, IAR 99 Șoim, will be studied.

This is a school and training aircraft manufactured in Romania, at Avioane Craiova SA. It can carry out reconnaissance missions as well as ground attack missions. The general characteristics of this aircraft are:

- Length (without Pitot tube) — 11.01 m
- Wingspan — 10.16 m
- Height — 3.898 m
- Parking angle — 1.30
- The mass of the empty equipped plane — 3320 kg
- Maximum take-off weight — 5850 kg.

By drawing a straight line from the seat position to the height of the tail, the minimum vertical and horizontal distances that the seat must cover in order for the airplane to pass under it without colliding can be determined. In the case of the IAR 99 aircraft, the distance from the seat to the end of the tail is approximately 8.5 m and the height is 1.9 m [2].

The initial speed of the seat after leaving the guide rails in the absolute coordinate system is:

$$V_H = \sqrt{(V_p - V_0 sin\chi)^2 + V_0^2 cos^2\chi} \qquad (4)$$

with an initial angle of inclination:

$$\theta_H = \arcsin\left(\frac{V_0 cos\chi}{V_H}\right) \qquad (5)$$

Using them, the equations of motion of the pilot seat assembly are determined:

$$\begin{cases} m\dfrac{dV}{dt} = -Q - Gsin\theta \\ mV\dfrac{d\theta}{dt} = P - Gcos\theta \\ \dfrac{dx}{dt} = Vcos\theta \\ \dfrac{dy}{dt} = Vsin\theta \end{cases} \qquad (6)$$

This system is solved by the numerical integration method using the MATLAB-Simulink program for three different flight speeds of the aircraft.

After determining the equations, the model presented in Figure 6 was made in the form of a block diagram. For this calculation, the mass of a human-seat assembly of 179 kg, a constant flight altitude of 3000 m and three flight speeds of the aircraft: 250 km / h, 450 km / h, 750 km / h were taken into account. To run the program it is necessary to enter the initial data and set the simulation time.

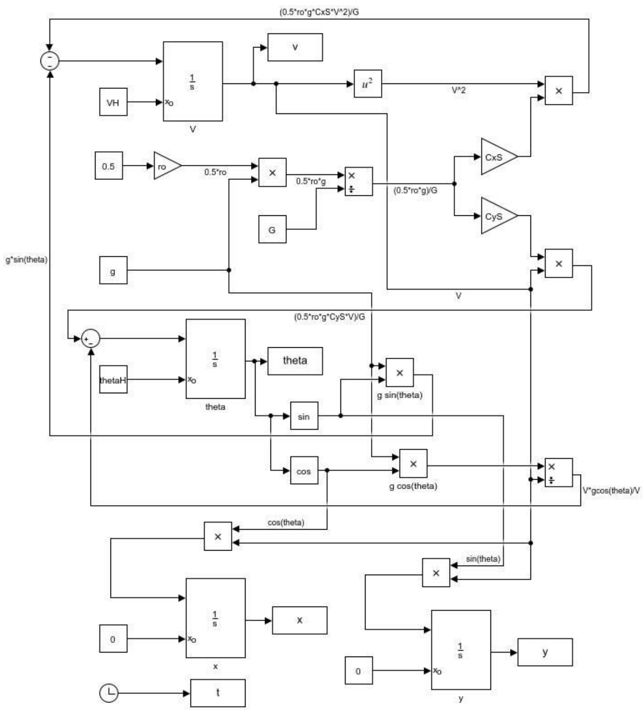

Figure 4 Block diagram

Because the ejection is performed very quickly, 2 s was chosen as the simulation time. The model then automatically calculates the flight speed, the angle of inclination of the trajectory, as well as the coordinates of the seat position at each time point. These results will be shown below in the form of graphs.

The graph in Figure 7 shows the coordinates of the ejection seat depending on the flight speed of the aircraft. It can be seen that as the speed increases, the ejection height of the seat decreases.

In the case of the IAR 99 aircraft and the SC.HV-0 ejection seat, the speed required to avoid a collision with the tail of the airplane is 350-450 km / h. Thus, it is ensured that at time t = 1s, the assembly is in a safe position with respect to the vertical tail of the aircraft [5].

In Figure 8, the variation in time of the inclination angle of the trajectory can be observed. As the object advances, the angle of inclination decreases due to changes in the slope of the flight path. It is also noted that the range of variation of the angle increases with the decrease of the flight speed of the aircraft because the slope is steeper.

The variation in the speed of the object over time can be seen in Figure 9. As can be seen, the speed decreases with increasing time due to the collision of the body with the air flow. Moreover, the speed of the seat decreases more sharply as the speed of the aircraft increases as the impact with the air is greater.

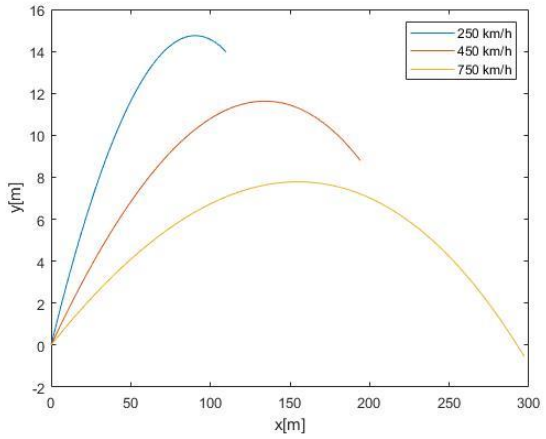

Figure 5 Flight trajectories depending on the speed of the aircraft

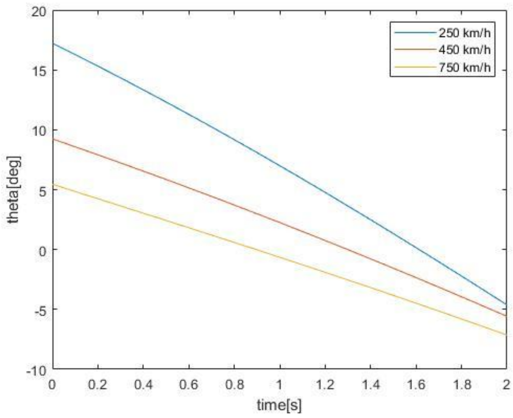

Figure 6 Variation of the angle of inclination of the trajectory in time

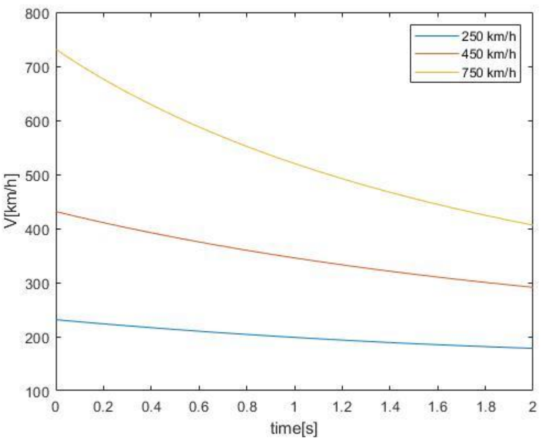

Figure 7 Seat speed variation over time

5. FLOW CURRENT SIMULATION AROUND THE SEAT CONFIGURATION

To study the air flow around the seat during ejection, a CFD simulation was performed using the Ansys Fluent program. This program is intended to calculate fluid dynamics and to determine the impact of fluid flow on a product from the design stage [11].

Initially, it is necessary to generate the fluid flow area around the ejection seat and to introduce the inlet and opening conditions, as shown in Figure 10. Thus, as inlet type conditions, the speed (350 km / h), the air temperature (15°C) and the atmospheric pressure (0.6 bar) was introduced, and at the opening conditions the absolute pressure of the range was determined.

The K-epsilon turbulence method was used as the calculation model [12]. This is one of the most used models of turbulence for fluid flow because it leads to the smallest calculation errors. The model comprises two transport equations that provide an overview of turbulence. The first transported variable is k which represents the turbulent kinetic energy, and the second is ε, the rate of dissipation of the turbulent kinetic energy.

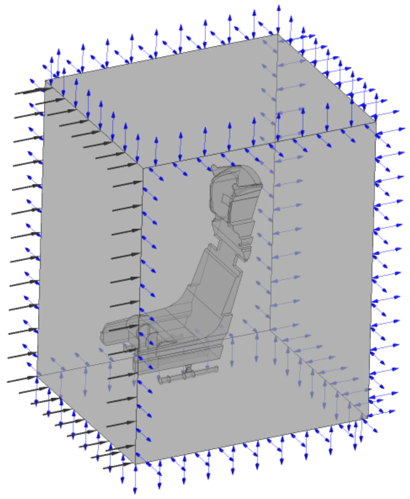

Figure 8 Flow range

Figure 11 shows the unstructured numeric grid comprising 190693 nodes and 1043429 elements. This represents the calculation points on the entire domain for 300 iterations and with residues of the order of 10^{-6}.

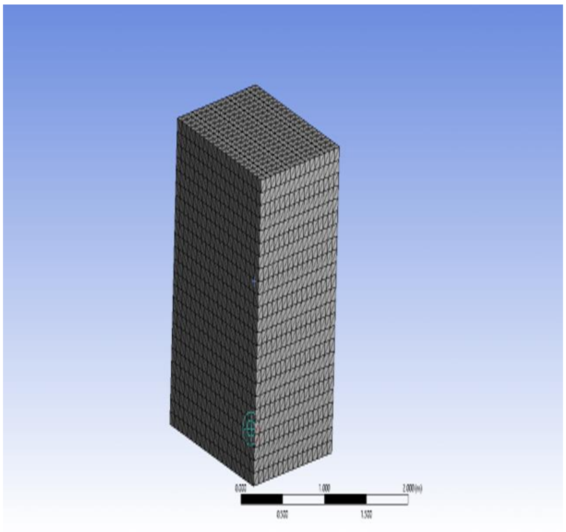

Figure 9 Value grid

Figure 12 shows the air flow currents around the ejection seat. As the body opposes the direction of air flow, a deceleration of the fluid velocity and a decrease in the flow behind the seat can be observed. This is due to the collision of currents with the surfaces of the seat, the working fluid losing its energy. In the upper left part is presented the grid of wind speed variation with different colors from red to blue. The blue current lines present in the simulation mark a decrease in the working fluid speed by 0.451 m / s.

The local pressure map for a reference pressure of 0.6 bar can be seen in figure 13. As in the previous figure, on the left side of the image is represented a color grid that represents the pressure variation during the flow of fluid around the seat. Areas marked in dark orange mark the appearance of an increase in pressure by approximately 650 Pa. This is due to the collision of air currents with the front surfaces of the seat, ie in the area of the backrest and seat headrest, but also in the space intended for the placement of the legs. Areas marked in yellow and green show a smaller increase in pressure because on those surfaces, the air flow bypasses the configuration, not causing a violent collision.

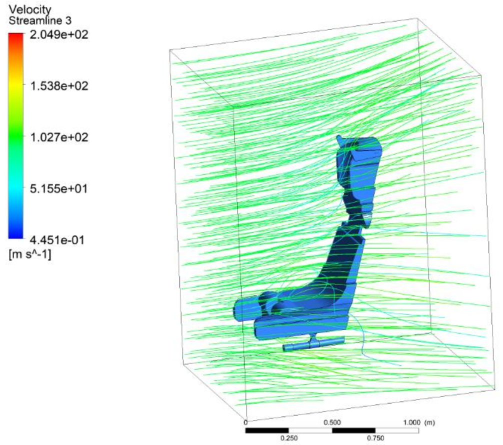

Figure 10 Simulation of air flow around the seat

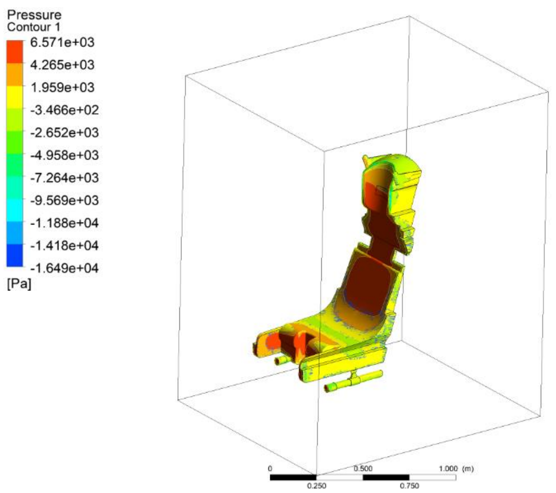

Figure 11 Pressure map

6. CONCLUSIONS

Despite technological advances, the ejection seat remains a developing system. The paper addressed some of the issues faced by the producers of this mechanism. The proposed changes are intended to increase the safety of the crew in the event of an emergency ejection, but lead to additional costs and changes in the weight of the assembly. It has also been shown that a calculation of the trajectory and a simulation of the air flow around the seat are essential elements in the manufacture of these devices.

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