Research on the Pressure Comfort of Pilot Helmets

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Abstract

With the advancement of technology, the functions of pilot helmets are constantly being upgraded. The highly integrated helmets with display, positioning, sensing, night vision and camera are the future development trends. Although the multifunctional and highly integrated design enhances the combat maneuverability, the add-on components will result in local tenderness as the weight gain and center of gravity change, which seriously affects the pilot's wearing comfort, especially in high-speed overload conditions. These factors have become potential factors affecting flight safety. At present, experience-based methods are no longer suitable for new product development. Therefore, it is urgent to establish a simulation model on the pressure comfort of "helmet-head", the finite element method is used for simulation calculation. This paper studies different conditions of the center of gravity, and using the standard head shape, ball shape and real head shape as a control, to analyze the center of gravity, the difference of the head shape, and the influence of overload loading on the pressure distribution. By comparing with the actual flight situation, the simulation results are consistent with the actual situation, which proves that the simulation model has good credibility.

Keywords: pressure comfort, helmet, center of gravity, local tenderness

1. General Introduction

Head-mounted display system (HMDS), as important personal protective life-saving equipment for pilots, the wearing comfort of HMDS directly affects the combat effectiveness of pilots. With the advancement of science and technology, the carrying functions of pilot helmets are constantly upgraded, and pilot helmets equipped with helmet-mounted displays have become the future development trend [1]. Although the helmet display increases the maneuverability of the aircraft, while the comfort of wearing the helmet is decreasing [2] due to the weight gain and center of gravity change. According to the pilot's personal experience during the high-overload flight of the fighter, the head part (top of the head, forehead, etc.) tenderness of the helmet in the overload environment is particularly obvious, which seriously affects the pilot's flight safety.

In response to this phenomenon, a simulation test of the pressure distribution after wearing the helmet was carried out. The influencing factors of pressure distribution including the center of gravity, the head shape and the overload are studied.

2. Simulation model

At present, the research on helmets is mainly focused on the helmet's bullet-proof penetration performance, simulating the biological response of the head under different impact loads, but there is no complete system for the analysis of the pressure distribution on the head after wearing the helmet. A simulation model is established on the current HMDS, in order to study the influencing factors of pressure comfort, including the center of gravity, head shape and overload.

A simulation method that is closest to the actual wearing situation are established after many explorations in model simplification, meshing, boundary conditions, definition of contact and load application method.

2.1 Model simplification

The helmet is worn on the head, and its structural hierarchy can be simplified as: helmet-Thermoplastic liner(TPL)-fabric padding-human head. The weight of the helmet and the position of the center of gravity remain unchanged. According to the actual structure and working environment of the helmet and human head, the following principles are followed in the modeling:

a) The integrity of the main structure of the helmet and the human head;

b) Ensure that the force transmission route does not change;

c) The node constraint should be consistent with the actual connection form.

The finite element model of the helmet and human head is established according to the drawing including the helmet shell, hard liner, soft liner and human head, the small parts that have little influence on the force transmission route were deleted.

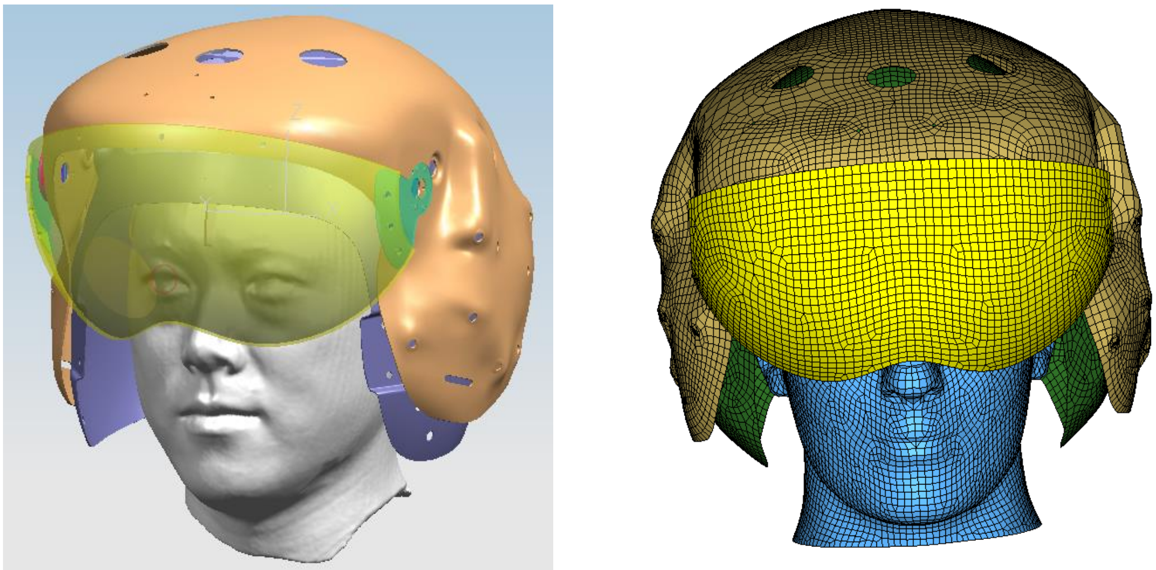


Figure 1 – Schematic diagram of wearing and finite element model

2.2 Material parameters

The human head model is based on the 50th percentile pilot head model established by GJB4856-2003[3]. The overall material parameters given to the bone are the elastic modulus of 20Gpa and the Poisson's ratio of 0.3[4].

The helmet shell material is carbon fiber, the elastic modulus is 210GPa, and the Poisson's ratio is 0.307; the elastic modulus of the TPL liner is 3GPa and the Poisson's ratio is 0.32; the elastic modulus of the fabric padding is 50MPa and the Poisson's ratio is 0.38.

2.3 Meshing

The helmet shell is meshed with quadrilateral shell elements as the shell is a thin-walled carbon fiber piece, the TPL cushion liner and the fabric padding are meshed with hexahedral elements; the pilot's head model also uses quadrilateral shell elements to divide the mesh, as shown in Figure 2.

Headform helmet TPL cushion Liner

Figure 2 – Schematic diagram of finite element mesh

2.4 Boundary conditions

The helmet finite element model is fixed the restraint at the bottom (neck) of the head mold to avoid rotation, as shown in Figure 3. Considering that the helmet body, the TPL liner and the fabric padding are connected to each other by bonding, the interface between the shell and the TPL liner is defined as a surface-to-surface displacement coupling.

In order to improve the efficiency of the solution, the grid is set to one-to-one correspondence between nodes (that is, common node processing) at the interface between the TPL liner and the fabric padding.

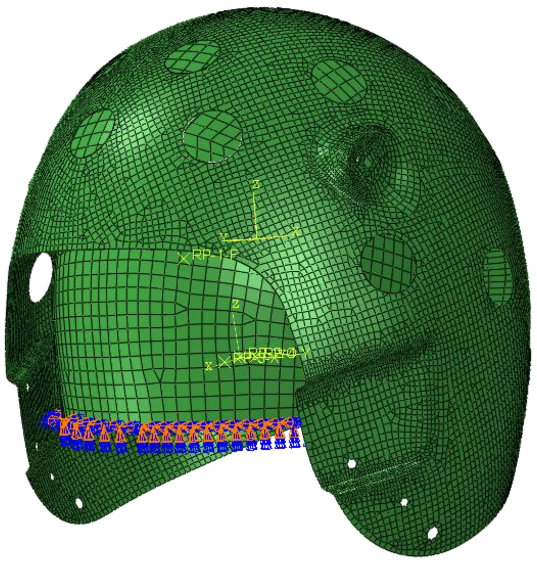


Figure 3-Schematic diagram of structural displacement constraints

2.5 Definition of contact

A three-dimensional surface-to-surface contact pair is defined in the area where the fabric padding and the head mold may come into contact.

2.6 Load application method

According to the helmet mass and overload acceleration, the inertial force on the helmet is calculated, and then the inertial force is applied to the center of mass of the helmet. The direction of the inertial force is determined according to the physiological coordinate system. In the coordinate system shown by the red line in Figure 4, the inertial force load is applied in the negative direction of the Z axis. The inertial force loading point is coupled with the helmet model to ensure that the overload is transmitted to the helmet [5].

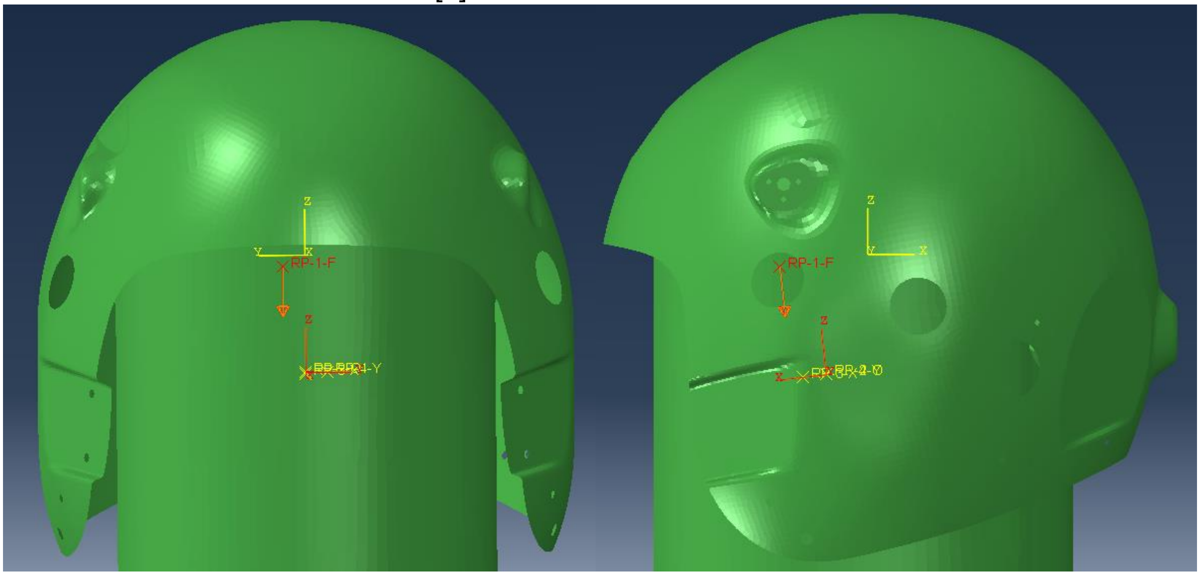


Figure 4-Schematic diagram of inertial force loading

3. Simulation condition

Based on the foregoing analysis, the simulation model are determined. Six sets of center of gravity are set, as shown in Table 1. The weight is uniformly set to 1.92 kg.

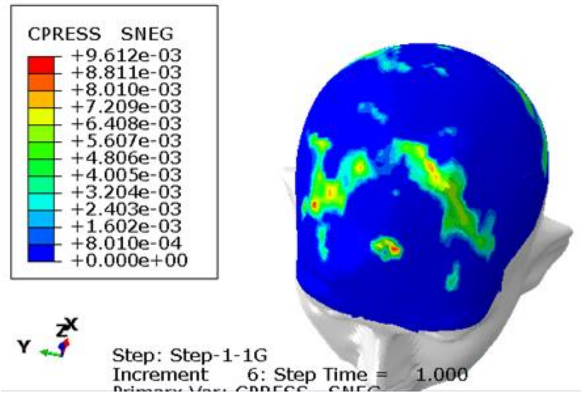
Since the center of gravity of the current helmet is forward on the X axis, it is the main cause of rotation of the helmet when sitting in a horizontal position. According to the comparison of the simulation results of the previous working condition 6 and working condition 1, the pressure distribution are basically the same, indicating that the change of the Z-direction center of gravity has little effect on the head pressure. Therefore, the change of the center of gravity in the X direction is an important factor influencing the helmet displacement and pressure distribution.

Table 1 Center of gravity

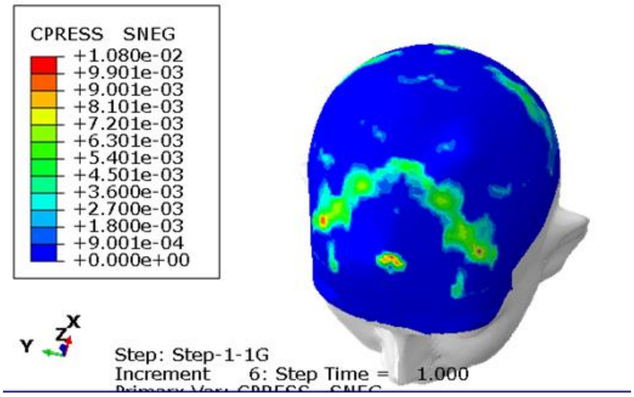
	X（mm）	Y（mm）	Z（mm）
Working condition 1	4.7	-12	43.2
Working condition 2	7.7	-12	62.8
Working condition 3	9.7	-12	43.2
Working condition 4	15	-10	49
Working condition 5	25	-2.7	45
Working condition 6	7.7	-1.4	62.8

4. Simulation result analysis

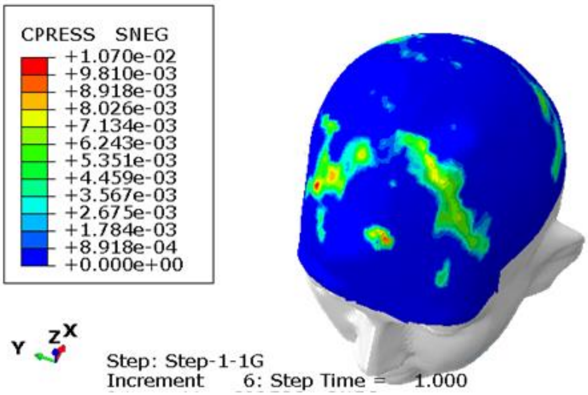
4.1 The influence of X-center of gravity



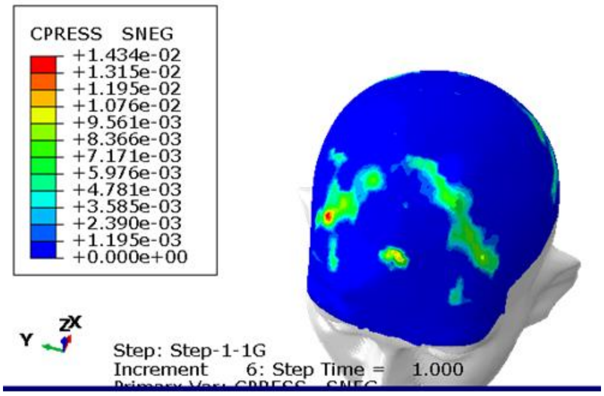
Condition 1（X=4.7mm）/ CPRESS（KPa）



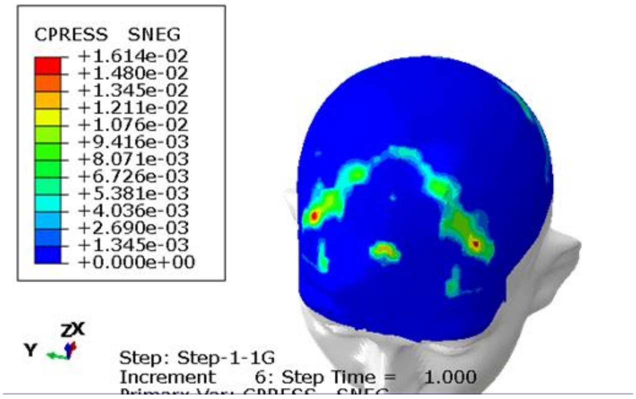
Condition 2（X=7.7mm）/ CPRESS（KPa）



Condition 3（X=9.7mm）/ CPRESS（KPa）



Condition 4（X=15mm）/ CPRESS（KPa）



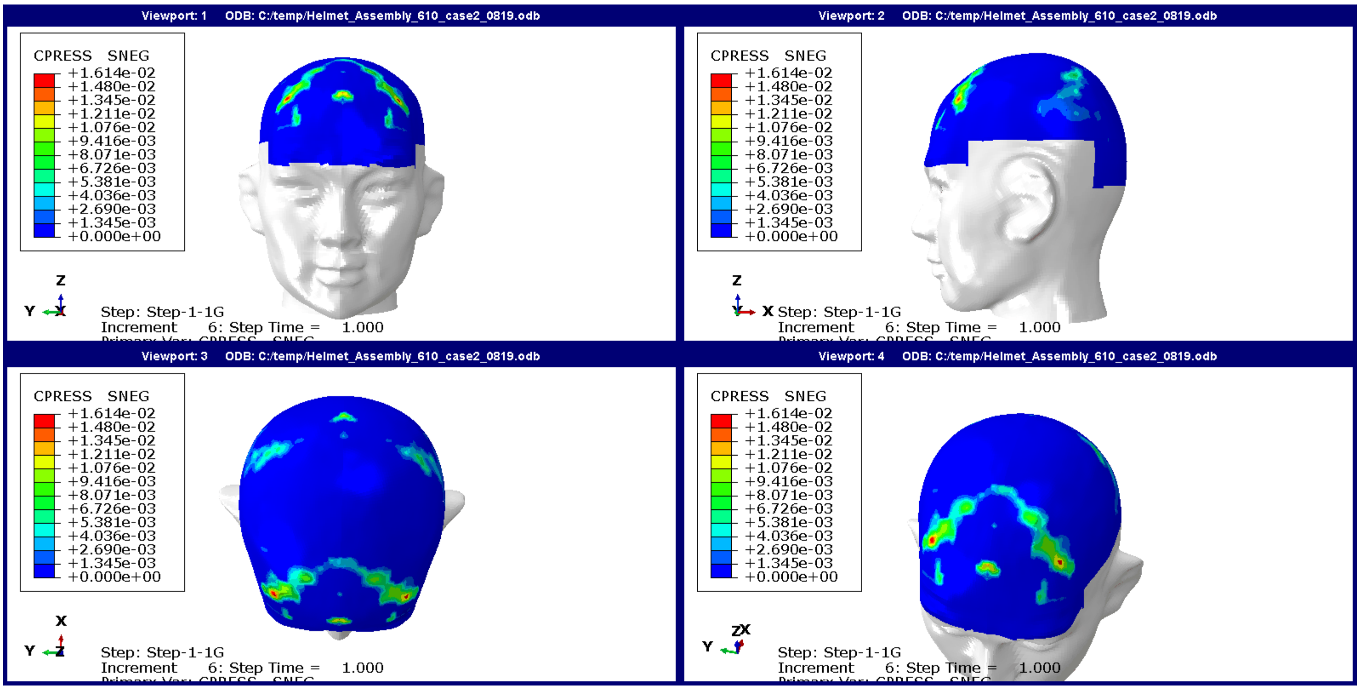
Condition 5（X=25mm）/ CPRESS（KPa）

Figure 5-Schematic diagrams of simulation results

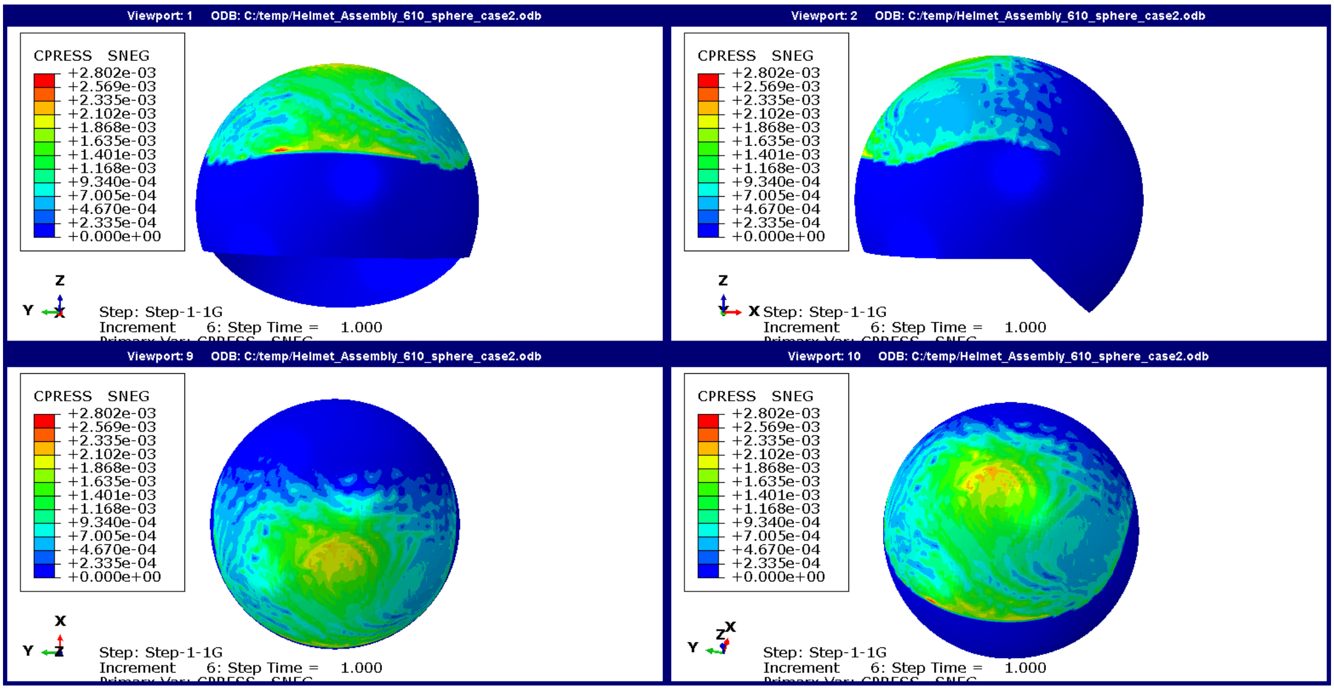
From the pressure distribution diagram, it can be clearly found that the area of the force-bearing area is decreasing as the center of gravity moves forward, and the pressure gradually shifts from the top to the front. It can be found that the forehead pressure continues to rise as the center of gravity moves forward.

4.2 The influence of head shape

Comparative analysis with standard head type and spherical head type, the force distribution of the standard head type and the ball type is shown in Figure 6. The overall force distribution trend is basically the same.



(a) head pressure of the standard head/ CPRESS（KPa）



(b) head pressure of the spherical head/ CPRESS（KPa）

Figure 6 - Analysis of the head pressure of the standard head type and the spherical head type

It can be found that the most obvious difference between the force distribution of the ball type and the standard head type is that the force surface is continuous, rather than the block-type distribution of the standard head type, especially the pressure distribution on the forehead. The forehead pressure of the ball type is linearly distributed at the forehead, while the forehead pressure of the standard head type is basically concentrated in the middle area of the forehead.

The reason is: the standard head and the fabric padding are not completely consistent, there are many block-shaped contact areas, as shown in Figure 7, According to the calculation method of this simulation, deformation is caused by contact, and there are many uncontacted areas in the final equilibrium stage. Therefore, the force distribution is discrete.

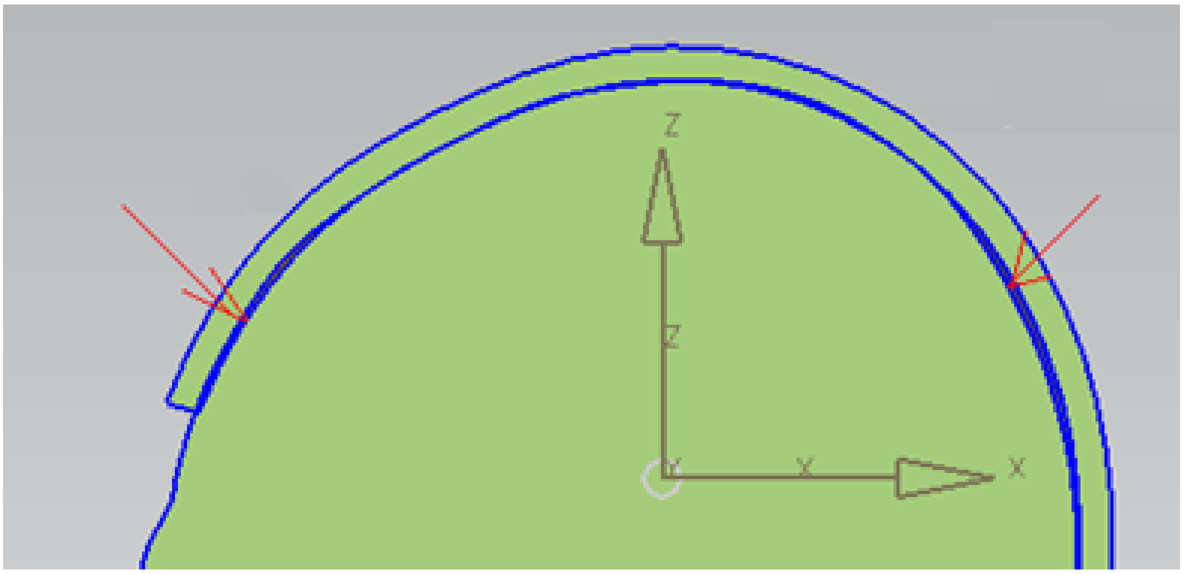
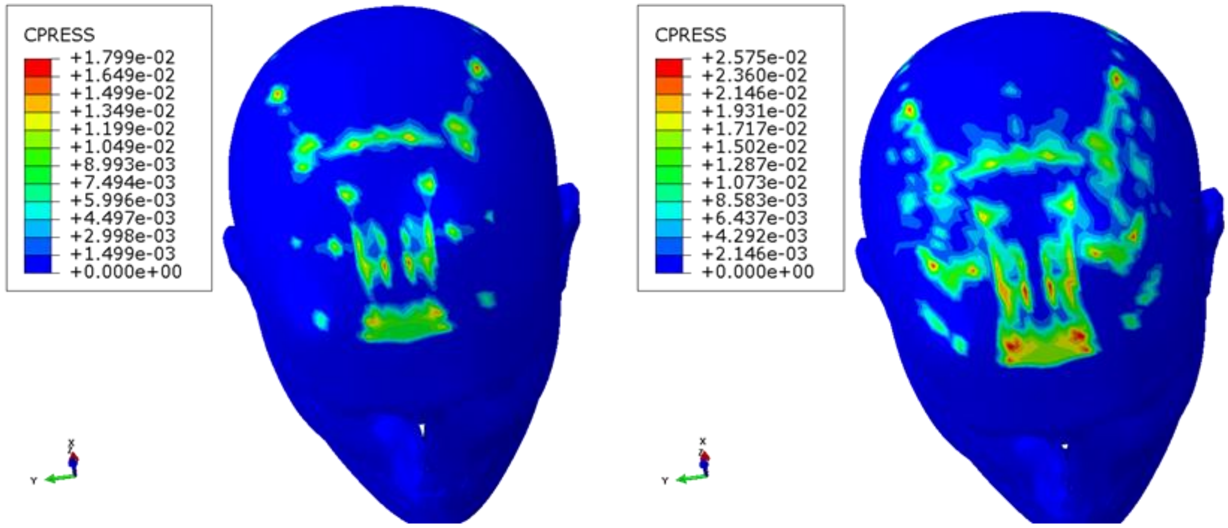


Figure 7 A slight gap between the standard head and the fabric padding

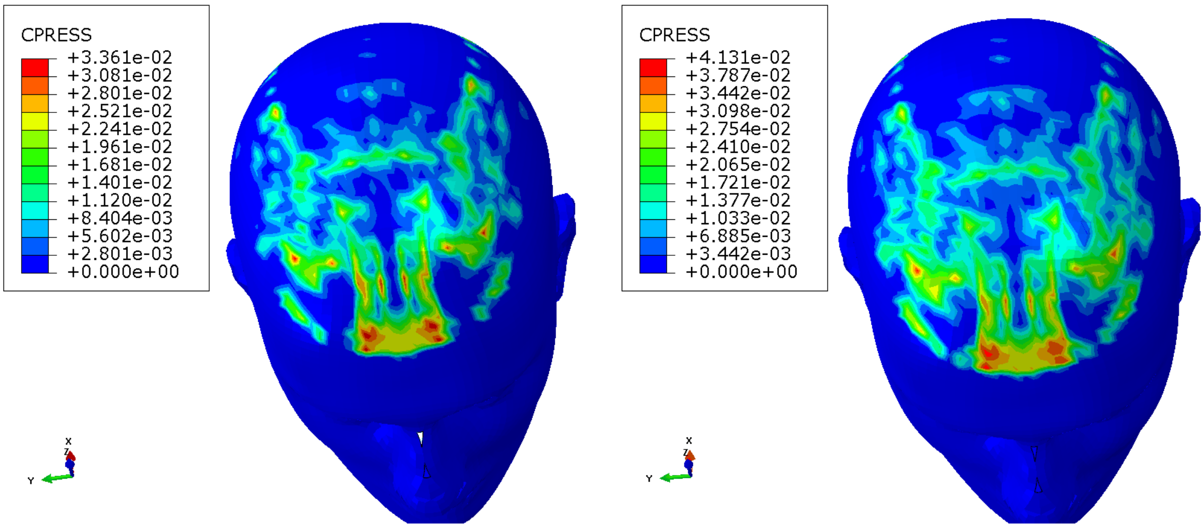
The ball shape and the fabric padding are completely fit, so the force distribution is continuous. The pressure is still concentrated on the front side of the head. There is basically no force on the back of the top and the back of the brain, the increase in weight moves the center of gravity of the helmet forward, causing pressure to concentrate on the forehead

4.3 Pressure distribution for different overloads

The comparison diagram of the head pressure on the helmet under different overloads are shown in Figure 8. The maximum pressure on the head under each working condition is shown in Table 2.



1G 3G



5G 7G

Figure 8 Head pressure distribution diagram for different overloads/ CPRESS（KPa）

Table 2 Maximum pressure on the head under different overloads

Overloads	1G	3G	5G	7G
Maximum pressure（KPa）	17.99	25.75	33.61	41.31

It can be seen from the figure that as the overload increases, the pressure on the pilot's head gradually increases, and the peak pressure gradually moves to the forehead, this is also consistent with the actual flight that severe tenderness on the top of the head and forehead.

5. Conclusion

This paper established a simulation model for comprehensively displaying the pressure of the helmet system in the wearing state, discussed the simplification of the model, the finite element meshing method and the setting of boundary conditions, and the factors that may affect the pilot's head pressure, including X-direction center of gravity, head shape, and overload pressure, etc. are analyzed.

The simulation results are basically consistent with the actual pressure distribution of the pilot's wearing condition. The addition of the display system makes the overall center of gravity of the helmet move forward, so that the pressure on the head is concentrated on the forehead, especially under the effect of large overload. The local pressure is very likely to exceed the human body's physiological tolerance value, bringing great hidden dangers to flight safety. A series of simulation and experiment studies will be carried out in the follow-up to explore ways to improve the pressure comfort of pilot's helmets.

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7. Copyright Statement

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