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ANALYSIS OF LONGITUDINAL AND ROTATIONAL ACCELEARATIONS FOR DIFFERENT SETUPS USING AMERICAN FOOTBAL HELMET AND HEAD MODEL

Abstract: The article presents simulations of the professional model of an American football helmet with a head-neck model. The aim of the research is the analysis of longitudinal and rotational accelerations acting on the head. Presented are two setups, each with two different aspects of velocities. Investigated parameters are angular and longitudinal accelerations acting on the head during a collision. Finite Element discrete model was prepared and explicit format of the simulation was performed. Presented results include graphs of longitudinal and rotational accelerations measured with respect to head's center of gravity and HIC analysis.

Keywords: American football, helmet, Finite Element Method, facemask, brain, brain injury

1. INTRODUCTION

Every American football game is full of spectacular tackles (Figure 1). Sadly, each tackle brings a risk of injury. Despite this fact, the will to play the game wins in players' heads. Each athlete is acquainted with the possibility that he may be carted off the field, still decides to compete on the highest possible level. It has been often recently mentioned about former NFL players suffering various brain dysfunctions such as memory loss, slurred speech, paralysis, seizures, personality changes. In some cases, the injuries lead to a subdural hematoma, diffuse brain edema, arteriovenous malformation, and diffuse brain edema [1]–[3].

Figure 1. One of the authors captured by Rafał Seifert during the game

This topic was mentioned in "Concussion" (2015), the movie directed by Peter Landesman and explained chronic traumatic encephalopathy, which is brain degeneration that players suffered after frequent head to head collisions. Moreover, in the series "Ballers" (5th season, 2019) players safety and post-career medical care were mentioned [4], [5]. Discovering this problem among one of the authors' experiences as a player leads to an investigation of the mechanical aspect of the collision. The aim of the research is the analysis of longitudinal and rotational accelerations acting on the head and estimation of HIC (Head injury criterion) values measured with respect to head's center of gravity.

The Finite Element model of the helmet together with the head and neck model of a dummy is utilized in this study. As it has been discussed about doubts in the HIC as it covers only longitudinal accelerations, it was decided to analyze both, longitudinal and rotational accelerations acting on the head in two different setups [6]–[9]. The rotational acceleration is associated with strain response while longitudinal with transient intracranial pressure gradient [10]. One setup is a head to head collision and the second setup is a collision with 150mm offset (Figure 2). Each setup is modeled into two variations. First with one helmet with an initial velocity and the second helmet set as stationary and second with initial velocities set to both helmets. The velocity is equal to 5m/s in the x-axis of the global coordinate system.

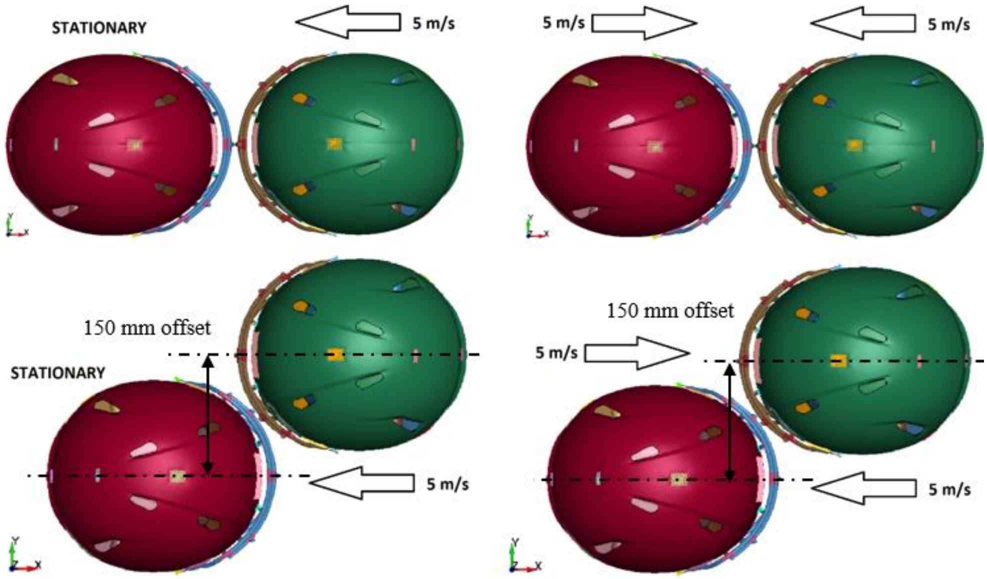

Figure 2. Impact configurations

2. MATERIALS AND METHODS

2.1 Model discretization

Both head and helmet structures are meshed with respect to the geometry. Each element is modeled individually, thanks to this it is possible to minimize computational time with fine mesh. The simulations are performed in the LS-DYNA (explicit solver, LSTC corporation) environment with the fulfillment of Courant-Friedrichs-Lewy condition as the simulation is in an explicit format. The discretization is displayed in Figure 3 [11].

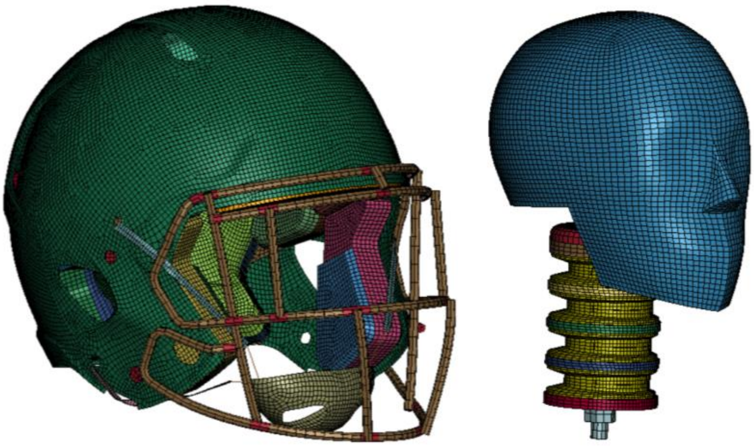

Figure 3. Discrete model of helmet and head

The used head model is an HIII Head Neck model. Figure 3 shows that the model is composed of: head skin, head skull, neck and selected coordinate systems.

The coordinate systems enable to retrieve specific data such as longitudinal and rotational accelerations acting on the head and location and orientation of upper and lower neck mountings. In use with neck mount, it is possible to obtain neck forces in connection to the head and body [12].

2.2 Material description

The material used to manufacture the shell is polycarbonate, the material used to manufacture the facemask is titanium alloy (Table 1).

Table 1. Mechanical properties of used materials

PART	*FACEMASK*	*SHELL*	*PADDING (FRONT)*	*PADDING (TOP, SIDES)*	*PADDING (BACK)*
DENSITY $[g/cm^3]$	8.546	1.095	0.1705	0.07 0.095	0.07 0.1
YOUNG'S MODULUS [GPa]	210	1.565	0.003	0.02	0.02 0.2
POISSON'S RATIO	0.3	0.3	-	-	-

2.3 Simulation description

The aim of the study is to analyze accelerations and velocities acting on the dummy during the collision. Moreover, it is possible to establish the crashworthiness of the helmet structure. Prepared models contain a professional helmet model with a head and neck model of the dummy. There are four simulations in two different setups. Firstly the helmets are oriented head to head (Figure 4). In first setup there two simulations: one with initial velocity set to one helmet impacting the other, second with initial velocities set to both helmets. The velocities are equal to 5 m/s in the x-axis of the global coordinate system.

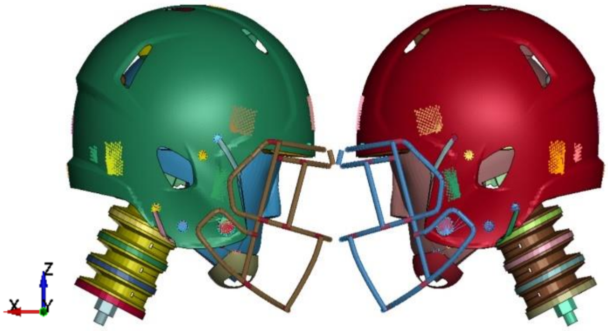

Figure 4. First simulation setup with the global coordinate system

Secondly, the helmets are offset by 150mm (Figure 5). Respectively, in the first setup, one helmet is set with an initial velocity. In the second setup, both helmets are set with a velocity equal to 5 m/s in the x-axis of the global coordinate system.

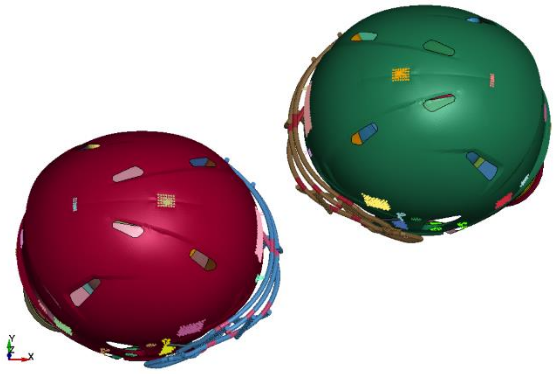

Figure 5. Second simulation setup with the global coordinate system

Displayed below graphs show how the longitudinal and rotational acceleration varies with respect to different setups and velocities. The data was collected from the head's center of gravity. The number of frames for the acceleration and HIC data is set as 10 000 and calculated for 23 ms. Displayed is 12 ms simulation course. The data was filtered by 1 000 Hz SAE filter.

3. RESULTS

While analyzing head impacts it is important to analyse both, longitudinal and rotational accelerations measured with respect to head's center of gravity. The rotational acceleration is associated with strain response while longitudinal with transient intracranial pressure gradient.

The graphs presented picture longitudinal and rotational accelerations during the collision (12ms). The helmet models are oriented close to each other, this is the reason why the accelerations peak is in the first millisecond. Morover, another small peak is observed. The reason is the so called secondary injury which is present in head collions. Firstly, the head is in contact wih the front padding in the helmet, then head bounces and is in contact with the rear padding.

In Figure 6 and Figure 8, where one of the helmets was stationary it is observed that the accelerations for 2nd helmet are significantly lower. In Figure 7 and Figure 9, where both helmets had set initial velocity, it is observed that accelerations are at the same level.

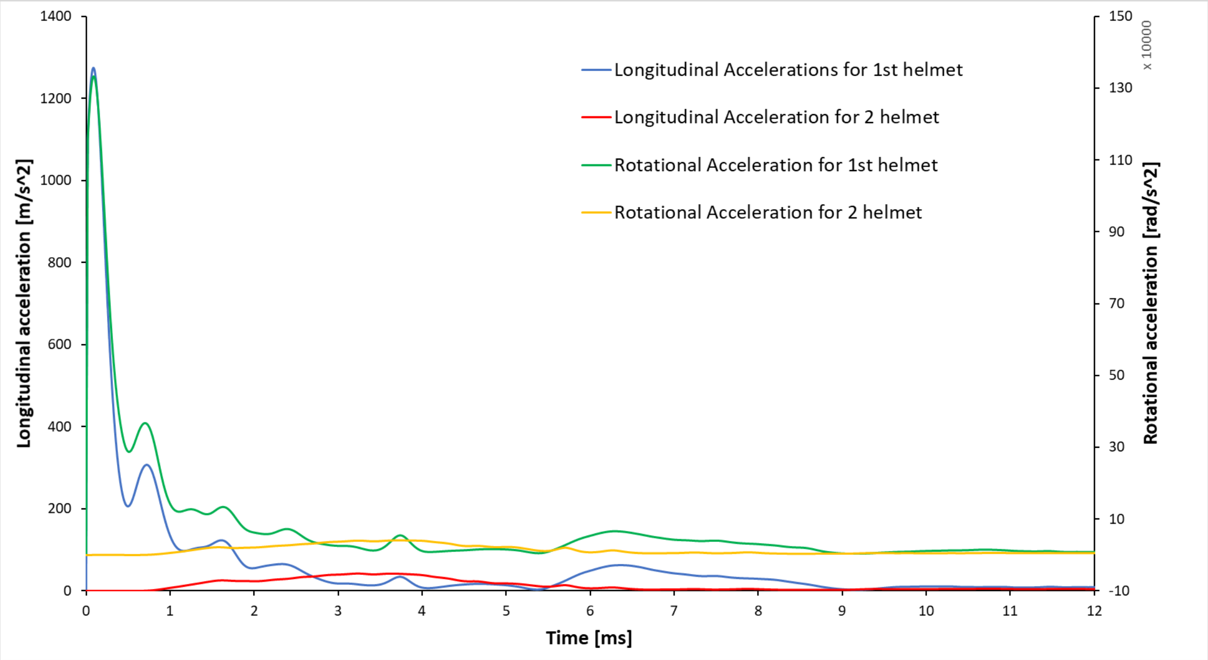

Figure 6. Resultant accelerations graph in head to head setup with one stationary helmet and one moving helmet

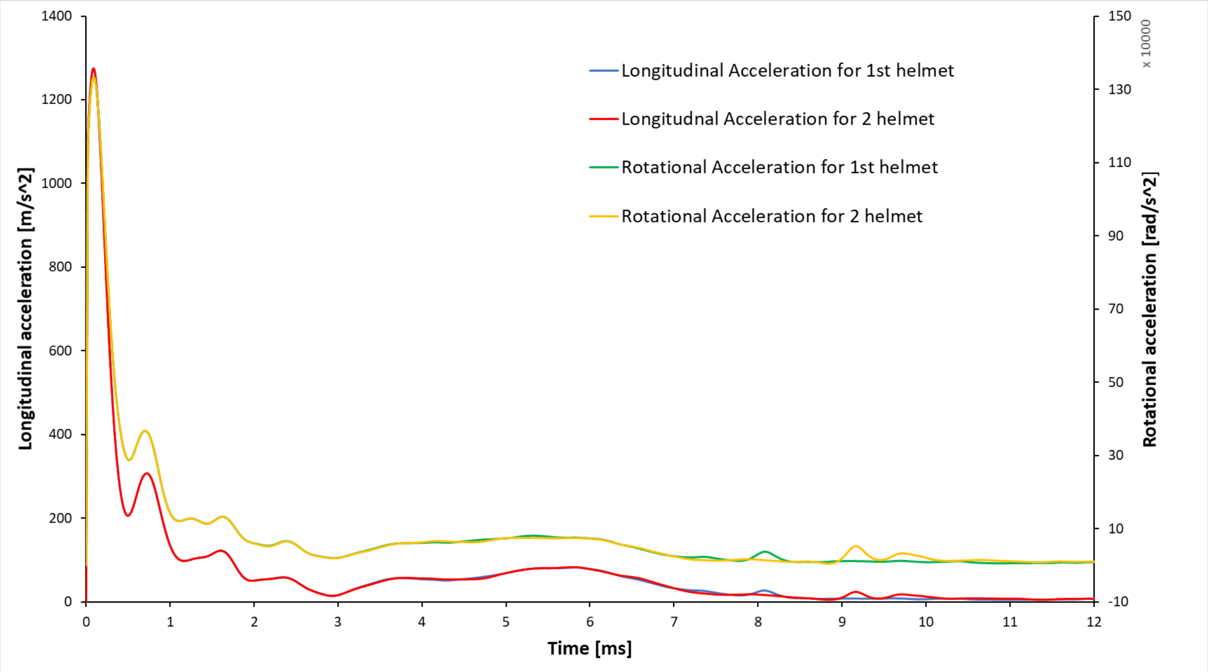

Figure 7. Resultant accelerations graph in head to head setup with both moving helmets

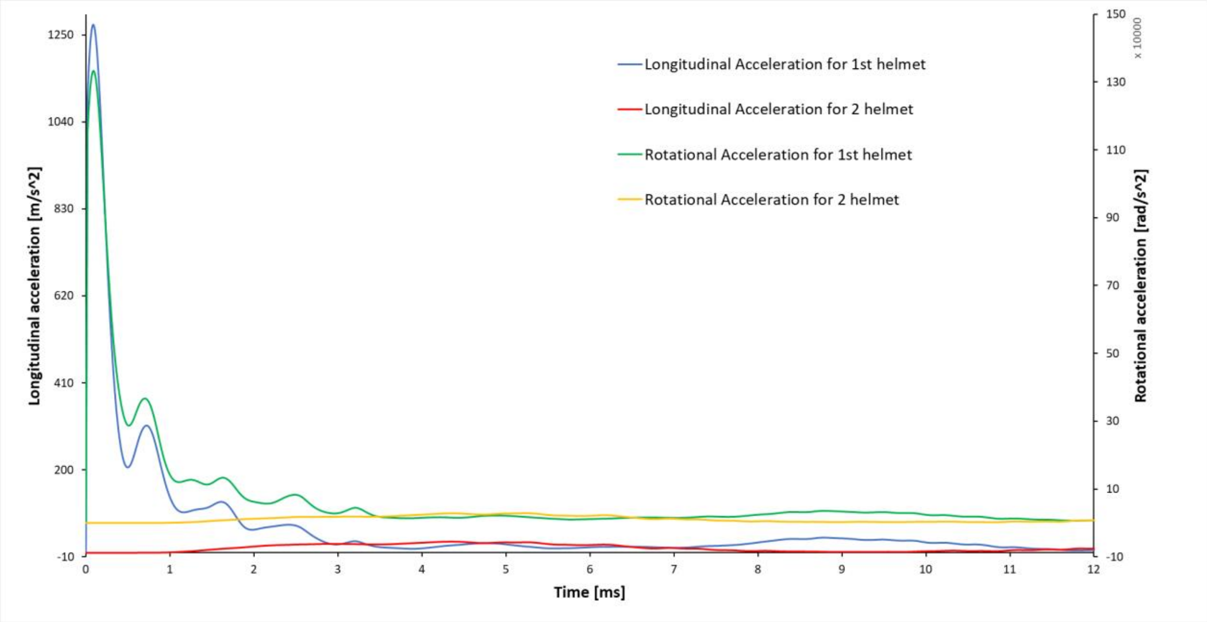

Figure 8. Resultant accelerations graph in offset setup with one stationary helmet and one moving helmet

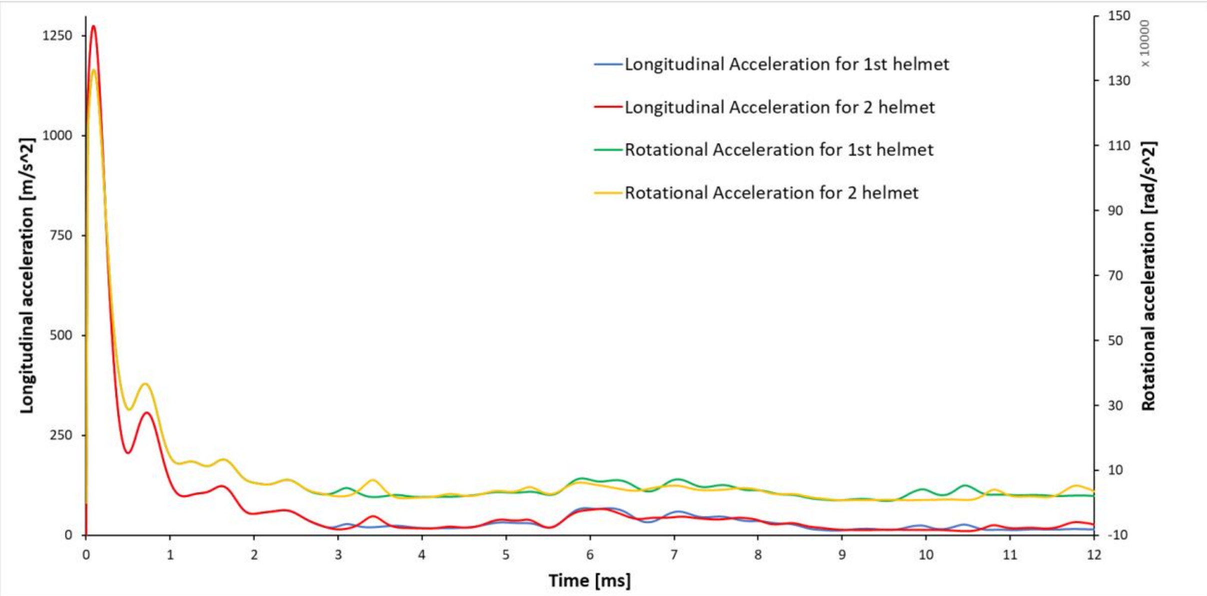

Figure 9. Resultant accelerations graph in offset setup with both moving helmets

HIC analysis is displayed in Table 2.

Table 2 HIC analysis

	Head – to – head setup		Offset setup	
	Double velocities	One velocity	Double velocities	One velocity
Highest HIC value	1728	1728	1728	1728

Head injury criterion analysis (Table 2) points out that even thoug the setups were different, the maximum values are identical. This is due to the fact that HIC is calculated using longitudinal acceleration only.

4. DISCUSSION

The simulation proved the initial assumptions about the differences in accelerations for different setups. It is clearly visible that the head to head setup is much more dangerous in terms of accelerations than the offset setup. Moreover, the readings from stationary helmets are significantly lower. Analyzing the accelerations in terms of overload, it is observed that for selected setups overload exceeds 100G in duration up to 1.5ms. In Comparison, Robert Kubica was subjected to 75G in a car accident in 2007. Additionally, taking into consideration head injury criterium (Table 2), it can be noticed that such collisions can result in fatal injury (5% probability) or critical injury (30% probability). This study pointed out how important rotational acceleration is. The maximum HIC values are the same for each simulation no matter the setup. Basing the assessment only on HIC is not sufficient in order to minimize injuries in sports, urban accidents, and motorsports.
What has to be pointed out are the values of rotational acceleration acting on the head. Bearing in mind the fact that skull bones are much more vulnerable for side impacts than for longitudinal impacts, this can have significant matter. [12] Rotational acceleration is as significant as longitudinal acceleration while computing the probability of concussion. The rotational acceleration is associated with strain response while longitudinal with transient intracranial pressure gradient [10]. At this stage of research, it is considered to suggest a new head injury criterium that will include both longitudinal and rotational acceleration with respect to brain injury probability. Moreover, it is can be said, that helmet structure remained undamaged in all configurations. Considering mechanical injuries of the head – none occurred. Basing on this additional criterium, it can be said that athletes' body parts such as eyes, nose, mouth or ears are completely safe.

5. CONCLUSIONS

The knowledge acquired in this study proved that further research definitely should be conducted not only on American football helmets but also on motorbike, race car, lacrosse or hockey helmets. The NOSCAE organization validates as well industrial safety and fire and emergency equipment [13]. Firefighters' helmets may also be analyzed on their protection on brain tissues. Basing on this research it is advised to proceed with an actual head – brain model to investigate displacement of the brain inside the skull and intracranial pressure. Morover HIC parameter is not sufficient criterion in consideration of head impacts. With that being researched, it will be possible to design new absorbing technology that will help to minimalize the probability of head injury.

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ANALIZA WZDŁUŻNYCH I KĄTOWYCH PRZYSPIESZEŃ DLA RÓŻNYCH USTAWIEŃ PRZY UŻYCIU MODELU KASKU DO FUTBOLU AMERYKANSKIEGO ORAZ MODELU GŁOWY

Streszczenie: Artykuł ma na celu zaprezentowanie symulacji zderzenia kasków do futbolu amerykańskiego z użyciem modelu głowy. Celem pracy jest analiza przyspieszeń wzdłużnych i kątowych oddziałujących na głowe. Zaprezentowano dwa ustawienia kasków, każde ustawienie jest podzielone na dwie symulacje przedstawiające różne wariacje prędkości. Nacisk w tej pracy jest położony na zbadanie wartości przyspieszeń wzdłużnych oraz kątowych podczas prezentowanych zderzeń. W tym celu został stworzony model dyskretny (obliczeniowy) kasku oraz głowy. Zaprezentowane rezultaty pokazują wykresy przyspieszeń wzdłużnych i kątowych odziałującyh na środek ciężkości głowy oraza analizę parametru HIC.

Słowa kluczowe: Futbol Amerykański, kask, Metoda Elementów Skończonych, zderzenie, mózg, urazy mózgu