Hockey Stick Swing Analysis Using Finite Element Methods

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Abstract: This paper is related to using Finite Element Analysis to analyze the motion of a hockey stick hitting a puck. The end result is a determination of the optimal position to hit the puck during the stick swing on the stationary puck as well as the optimal swing pattern. The puck's exit velocity and direction is obtained after the impact with the stick. The results will not only show the direction the ball will travel, but how far it will travel as well. The stresses on the hockey stick are also determined for each impact. For simulation purposes the puck was designed to have material properties similar to that of the official puck used in National Hockey League. The stick was also designed to have two rigid grips, to mimic two hands. The primary goal of this research was to show the advantages of utilizing finite element analysis applications in sports. The results will show that accurate results can be attained if the simulations mimic that of the real case. In this manner, guidance can be provided to players on the optimal swing pattern to apply for different shooting direction of the puck. All simulations are run using Abaqus/Explicit and three different materials are analyzed for the stick. These are wood, aluminum, and composites.

Keywords: Abaqus/Explicit, Hockey, Exit Velocity, Carbon-Fiber, Finite Element Analysis

1. Introduction

Argued one of the best sports to see live and play; ice hockey has long been considered a favorite winter sport by many. National Hockey League (NHL) is North America's highest level of play, where players can be seen every winter competing for a spot at the coveted Stanley Cup, in which one team will be crowned the best for that year. The major premise behind the game is to score points. Hitting the puck in the proper part of the stick is the key to a great hit.

The three most common materials that hockey sticks are made of are wood [Green et Al, 2015], aluminum and carbon fiber composites. The first hockey sticks were made of wood, but nowadays the most common used material is carbon fiber composite. The evolution from wood sticks to carbon fiber composite sticks shows how important the technology has been to improve performance in sports and, at the same time, brings more comfort and safety to players.

The use of computer simulation to develop new sports suits and sports equipment is essential for all the stakeholders: the industry wants to be more accurate and innovative; the companies want to be competitive and increase their market share; the athletes want to have the best available equipment to maximize performance.

In this research, dynamic finite element simulations are used in order to analyze, where on the base of the stick the puck should be hit, to provide the puck with the highest exit velocity and the lowest stress levels in the stick. We are searching for a "sweet spot".

Three situations with various impact positions of the puck were considered and simulated. In this case, a typical swing angular velocity is applied, but this can be varied further to determine the effect of different swing parameters as well. Abaqus/Explicit lends itself very well in allowing these types of simulations to be run, given its versatility in applying prescribed rotation angle over time functions to the stick. This is normally data that can be measured experimentally, allowing to further use this work in conjunction with experimentation on players themselves. [Jin et Al, 2015]

2. Methods

2.1 Material and Mesh

Finite element models of the carbon fiber, wood, and aluminum sticks and rubber puck were built. For the wood and aluminum sticks, the models were mostly solid, but for the carbon fiber stick, the mesh consisted of shell meshes due to the thin tubular structure for those sticks. Similar to the one used in NHL, the puck is composed of the rubber as shown in Figure 1. The carbon stick has a core structure, which is made of graphite at the base (blade) of the stick, while the long stick part is modeled as a composite shell structure. Details of the meshes are shown in the coming figures.

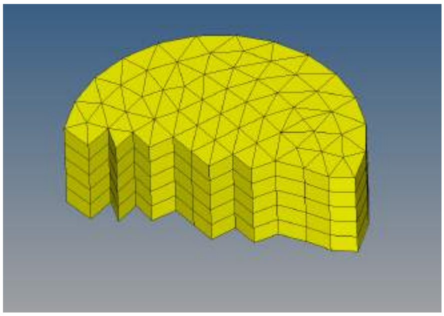

Figure 1. Puck material layers.

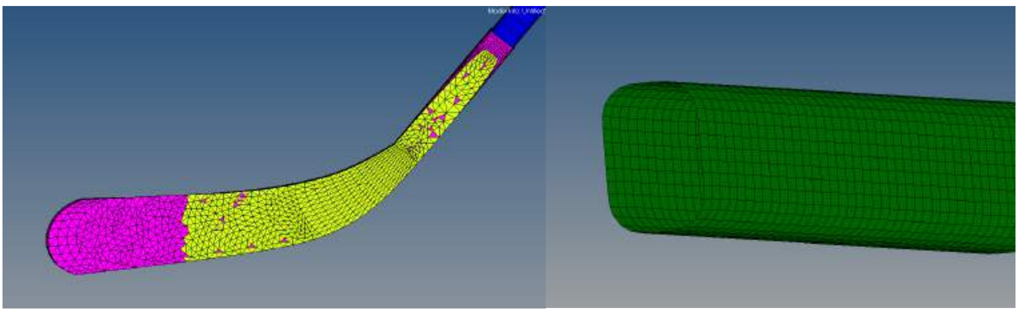

Figure 2. Stick material layers.

Before the model could be used for impact simulation, the material properties of the stick and puck were obtained to not only ensure accurate results from the analysis but to ensure the FE simulation closely represented that of actual stick swing. The material properties for the stick and puck [Deann-Shinbrot, 2013] are shown in Tables 1 and 2 respectively.

In addition, rigid handles are modeled at the area of the stick that is typically held by the players. The rigid handles are controlled through a reference node on each handle at which rotational speed and translational speed profiles can be applied to mimic the actual player's impact. These can be easily modified to further optimize hits and then players can be trained to hit based on these findings, rather than intuition and practice alone.

Table 1. Puck material property.

Material	Density (g/mm^3)	Young's Modulus (MPa)	Poisson's Ratio
Rubber	9.5e-4	40000	0.49

Table 2. Hockey stick material properties.

Material	Density (g/mm^3)	Young's Modulus (MPa)	Poisson's Ratio	E2	G12	G13	G23	Temp
HM400	1.63e-9	233967	0.032	14778	10191	5777	5634	0
T800	1.63-9	177000	0.21	14920	5700	5700	5630	0
Graphite	2.49e-3	2760000	0.23					

2.2 Impact Simulation Results

The results of the hockey shot scenarios are shown in the Fig. 1 - Fig. 4. In this case, we present the results for the wood and aluminum sticks hitting the puck at the center of the blade and the edge of the blade. Velocities of the puck and the stick are shown as well as the stresses in the sticks, based on the angular rotational velocities of the sticks as applied by the rigid handles.

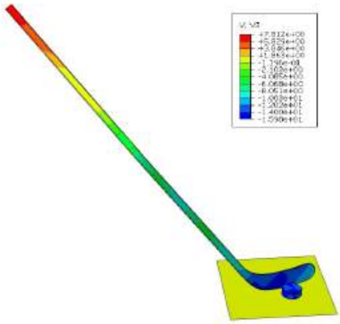

Figure 3 – Wood stick: shot in the middle of the stick's blade.

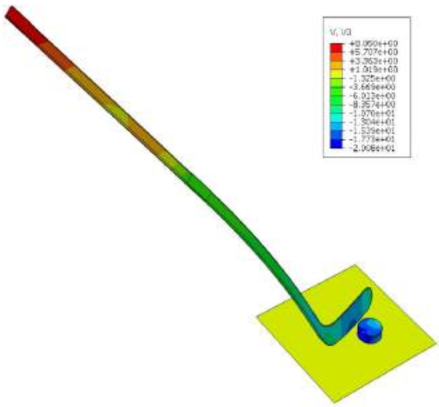

Figure 4 – Aluminum stick: shot in the middle of the stick's blade.

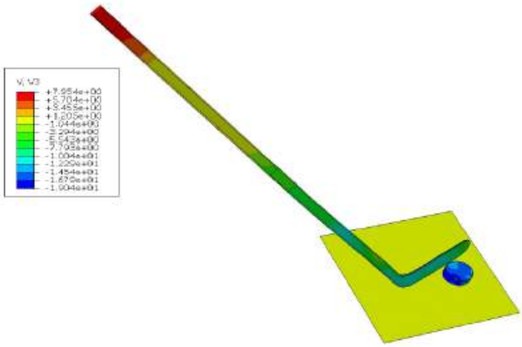

Figure 5 – Wood stick: shot on the edge of the stick's blade.

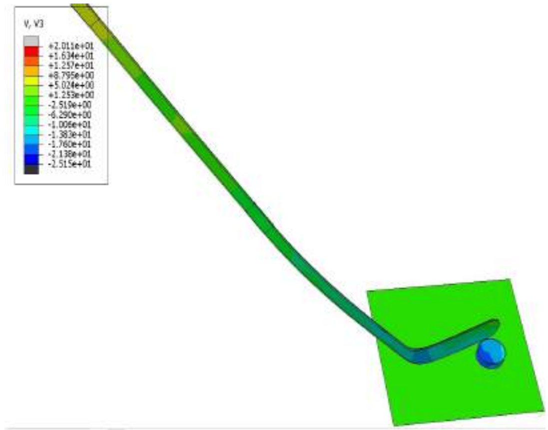

Figure 6 – Aluminum stick: shot on the edge of the stick's blade.

Table 3 –Average velocity of the puck when hit at different locations on the blade and different stick materials.

	Middle	Edge
Wood	12.4 m/s	15.2 m/s
Aluminum	15.5 m/s	17.2 m/s

Further analysis is completed for the composite stick, which requires more detailed modeling to capture the composite layers and the solid construction of the blade.[Pederson J, 2003], [High Performance Composites] As shown in Figure 7, three random hitting positions were simulated, where the puck was stationary toward the stick moving at 3.0 mm/s. The swing motion was analyzed over a 3s time frame around the moment of impact. The entire motion was idealized by simplifying the swing pattern from a 3D motion to a rotational motion to reduce computational time.

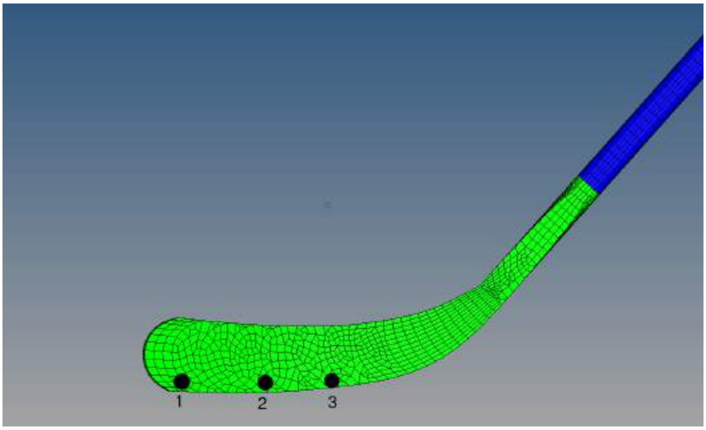

Figure 8. Impact positions.

Table 4 shows the coordinates of the impact positions with respect to the edge of the blade as shown Figure 8. The dimensions in the x direction are measured from the left bottom end point. The dimensions in the y and z coordinates are considered as zero.

Table 4. Impact position on the stick.

Impact	Position 1	Position 2	Position 3
X coordinate	1.5cm	9cm	16.5cm

Table 5 shows the magnitude of the ball's exit speed at each position.

Table 5. Puck exit speed.

Position	Position 1	Position 2	Position 3
Exit Speed	86cm/s	104.6cm/s	94.38cm/s

Due to the swing motion, the velocity of the puck was considered as a 3 dimensional vector to understand the actual movement of the puck. Table 6 depicts the speed in each direction right after the impact. It can be clearly seen that the speed in the x-direction is the fastest, while other velocities in y and z are also present. The data in Table 6 suggests that for positions 1, 2, and 3, the puck does not move directly parallel to the ground; it has some 3D directional movement, which is reasonable to expect.

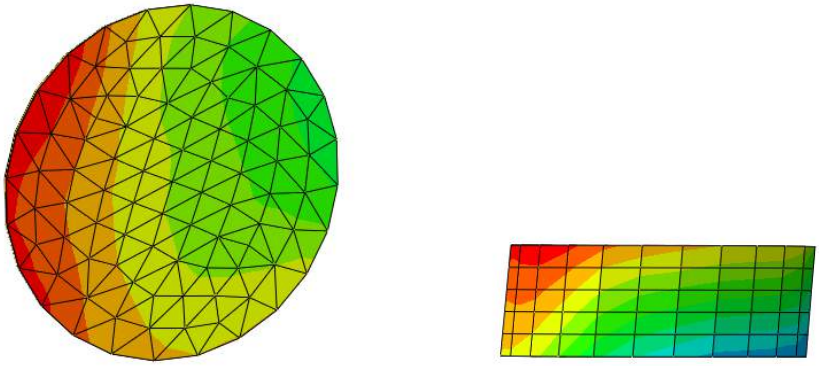

Figure 9. Puck Speed distribution after impact

Table 6. Puck directional exit speed.

Position	Speed [cm/s]		
	x	y	z
1	-55.37	-23.87	-14.77
2	-83.13	-6.818	-2.189
3	-45.64	-1.801	-12.1

Table 7 depicts the maximum stress of the stick right after the impact moment. The middle point shows the smallest maximum stress value on the stick head, while the position 3, closest to the pivot point, shows the biggest maximum stress value on the model.

Table 7. Maximum Stress on the solid head after the Impact Moment.

Position	Max Stress [MPa]
1	10.81
2	10.21
3	11.44

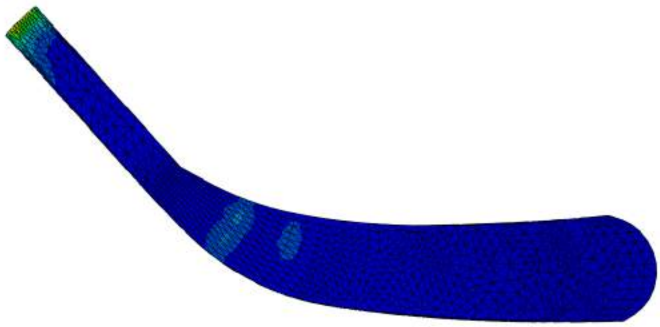

Figure 10. Stress distribution on the back side of the stick blade portion

3. Analysis and Discussion

The exit velocity shows that the difference of position could affect the velocity of the puck. Generally, position 2 has faster exit speed but point 1 and 3 show more z-directional motion, which is necessary for the hockey player to aim at the top point of the goal to score. This is expected because the center of the puck is hit along the center of the hockey stick head at these positions, thus minimum energy is lost during impact with no directional change for the hitting point 2. Position 3 show more 3D reaction of the puck to fly the puck in the air, then the player can aim the top point of the goal to score by avoiding a gate keeper's defense and other player's defense.

The swing simulation shown in figures 3 correlates previous findings, further confirming when the puck collides with the stick, some energy is stored in the stick because of the material property of the carbon-fiber as it deforms due to impact. From this it can be concluded that the amount of energy stored in the stick and how it is transferred back to the rubber puck contributes to the exit velocity of the ball.

Compared with the stationary motion analysis, this dynamic swing motion analysis can show the entire motion of the hockey stick and the puck before and after the hitting point. Also, it is able to estimate a flying direction. With proper computational power and the inclusion of gravity effects, it is possible to allow the puck to actually travel in space and observe its full trajectory. Our team did not have much computational power and the runs were completed on a laptop computer.

4. **Conclusion**

This research has proven a Finite Element Model can simulate a real sports event. Abaqus/Explicit was critical in solving this problem. The model can estimate the puck's exit velocity, and where the puck is directed towards the goal, when hit at various positions on a stick. In regards to the swing motion, the results show that 7.5cm can cause a big difference in the puck's movement. It also shows how the energy stored in the stick from impact is transferred to the puck. The Finite Element Model provides an excellent alternative to investigating not only material properties of the stick, but determining the best stick swinging techniques for different situation with different material.

5. References

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