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A Finite Element Model of the Hybrid III Ribcage

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ABSTRACT

Recent tests conducted at Wayne State University by Cavanaugh et al. have demonstrated that while a given downward force on the sternum of a supine cadaver will produce a significantly smaller deflection than the same force on a rib at 2.8 inches to the side, the same test on a Hybrid III dummy will display the opposite effect, producing a sternal deflection up to 1.68 times that of the rib at the off-center location.

In order to study the possibility of bringing the side-to-sternum stiffness ratio of the Hybrid III more in line with the measured values from the actual cadaver, a finite-element model (FEM) of the Hybrid III ribcage was created. Modifications to the material types and element thicknesses as well as small changes in geometry were made in order to find whether it would be possible to achieve this goal without the addition of stiffeners between the sternum and spine. It was concluded that reaching the goal without the stiffeners was not possible. The development of a dynamic model using the same geometry was then begun, and is currently in progress.

METHODOLOGY

The finite-element model of the Hybrid III rib was created on NISA II, a PC-based finite element analysis program marketed by Engineering Mechanics Research Corporation of Troy, Michigan. General 3-D shell elements, with four nodes per element, were used. The model consisted of six steel ribs and an aluminum sternum connected to the rib ends by a sheet of plastic on each side, 0.25 in. thick, and having an elastic modulus of 10,000 psi. The geometry of the ribs was taken from Drawing No. 78051-33 of the General Motors specifications for the Hybrid III. The steel rib is 0.080 in. thick and 0.75 in. wide.

The damping material that partially lines the inner surface of each rib was represented by a slight increase in the elastic modulus of these portions of the ribs from 30×10^6 psi to 34.5×10^6 psi. This value was found to give the best agreement with the measured test deflections.

It is important to note that the FEM, when originally created, was substantially too stiff. In order to make the ribcage more compliant, the elastic modulus of the plastic was decreased until a value was found which would cause the FEM to produce more desireable results. The value which was arrived at is quite low: 10,000 psi. It is also perhaps worth noting that in the current development of the dynamic model such a low modulus for the plastic has not been necessary so far.

The cadavers tested by Cavanaugh et al. were loaded at six locations: three on the sternum and three on the ribs on the right side. These same six locations were used to load the FEM. The FEM was loaded at each location with the same magnitude of force that Cavanaugh found was necessary to cause one inch of deflection at that site. These force magnitudes are presented in Table 1.

Table 1.

Force Applied in Each Case
for One Inch Deflection

SIDE		STERNUM	
Case	**Force** (lb.)	**Case**	**Force** (lb.)
UR	181.1	US	165.3
MR	320.8	MS	196.5
LR	252.8	LS	150.2

The deflection measurements from the physical model and from the FEM are presented in Table 2. At this point, modifications to the original FEM were begun, in order to determine whether the goal of developing a Hybrid III that would be stiffer at the sternum than at the side locations without the use of stiffeners between the spine and sternum was indeed possible. Modifications evaluated included substituting materials, changing element thicknesses, and making small changes in the geometry, such as the removal of parts of the connective plastic.

CONCLUSION

Based on evaluation of the effects of the many modifications made to the original FEM, it was concluded that it is not possible to obtain a greater stiffness at the sternum than at the side locations on the Hybrid III without the addition of stiffening elements between the spine and sternum.

DYNAMIC MODEL

Upon completion of the static model, development of a dynamic model was begun using the same geometry. The original objective was to simulate a frontal impact by a pendulum to the thorax of the dummy, using data recorded in the Biomechanics database for verification. NISA, like almost all other finite elements analysis codes for the PC, does not feature a contact impact algorithm. It is therefore necessary to represent the impact of the pendulum using force-time histories applied to the various nodes in the area which would be impacted. This work is currently in progress.

Future plans for the dynamic model involve simulations of a belt test and an airbag test, both of which are also recorded in the Biomechanics database.

Table 2.

Deflection Results
Cavanaugh Test vs. FEM

KEY: Test
FEM

All measurements are in inches.

Right Ribs	Sternum	Left Ribs	Right Ribs	Sternum	Left Ribs
	UR			US	
1.0	.52	.31	.58	1.0	.60
.87	**.82**	**.29**	**.66**	**1.13**	**.66**
.50		.19	.44		.48
.59		**.15**	**.44**		**.44**
.33	.32	.09	.32	.52	.34
.35	**.21**	**.02**	**.16**	**.19**	**.16**
	MR			MS	
.80	.67	.29	.56		.58
.99	**.96**	**.29**	**.49**		**.49**
1.0		.24	.54	1.0	.55
1.02		**.22**	**.50**	**.79**	**.50**
.74	.68	.25	.53		.59
.74	**.66**	**.14**	**.62**		**.62**
	LR			LS	
.43	.33	.10	.27	.41	.31
.37	**.21**	**.03**	**.16**	**.19**	**.16**
.56		.15	.34		.38
.68		**.16**	**.35**		**.35**
1.0	.67	.26	.47	1.0	.53
1.21	**1.12**	**.399**	**.60**	**1.03**	**.60**

DISCUSSION

PAPER: A FINITE ELEMENT MODEL OF THE HYBRID III RIBCAGE

SPEAKER: Cam Riviere, ASG/DOT

Question: King-Hay Yang, Wayne State University, Bioengineering Center

I noticed that you did not model damping material in the rib cage, would you comment on that?

Answer: We didn't model damping material in the static model. Obviously, in the static model any damping that goes on is irrelevant for static matters. However, we did sort of a parameter study of adding slight amounts to the Young's modulus of the steel in the area of the ribs where the damping was in order to simulate the static behavior, the stiffness that would be added by the damping material. What we ended up with was raising up the Young's modulus of those areas to 34.5×10^6 psi rather than 30×10^6. We experimented with this but really got better results with leaving the steel at 30,000.

Question: Guy Nusholtz, Chrysler

What kind of material models were you using?

A: We were using . . . as far as what sort of elements? The mathematical basis?

Q. Like elastic? plastic?

A. We were using a linear elastic model.

Q. Did you use nonlinear geometry?

A. No, we didn't.

Q. One other small comment. Normally, when you are running a direct code, you can decrease the amount of computer time by remeshing it and going to slightly larger elements in certain areas. One reason for that is your time step is normally dictated by your smallest element.