

8

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Development of Methodology to Measure Airbag Contact Load

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This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

ABSTRACT

A methodology for measuring airbag-dummy surface contact load was explored. The TekScan surface thin film individual FlexiForce sensors were used. These individual sensors allow the flexibility of distributing the sensors over a wide surface area. A 24-channel data conditioning system was constructed to collect data at 10 kHz per sensor. The sensors were calibrated individually before use. A rigid disc is used to provide backing for the sensor when mounted on a compliant surface. The best mounting disc was identified based on extensive evaluation tests. A set of 14 sensors was mounted on the small Hybrid-III dummy for airbag tests at close proximity. The summed sensor load shows fair repeatability and agrees with the airbag pressure data trend. Variability of the sensor load at individual locations was observed and could be caused by the variable airbag fabric unwrapping and shearing effects. Recommendations were given for further validation of the sensor performance under various loading and compliant surface conditions.

INTRODUCTION

Basic research in understanding airbag loads on occupants requires accurate contact load data. Such knowledge can advance research in minimizing airbag risks to small occupants, while retaining the crash protection effectiveness for large occupants. Some recent work includes Bass, et al., (1999), Chan, et al., (2004) and Lu, et al (2004). Airbag-occupant interaction studies are usually carried out using anthropomorphic test devices (ATD) with static airbag deployments in laboratories or using sled test platforms (current). ATDs only provide response data, such as accelerations and joint loads that are used for injury assessments. On the other hand, contact load data are lacking, but they contain critical information for understanding airbag-occupant interaction to guide injury prevention and airbag design, as well as model development. Both load magnitude and distribution data are needed. The fundamental difficulties in measuring contact load data on the compliant dummy skin need to be overcome.

The objective of this study is to explore a methodology for measuring airbag contact load on an ATD and demonstrate the concept with airbag tests. The approach is to use thin film surface

load sensors. The effort includes the calibration of the sensors, development of sensor mounting method, and the evaluation of the sensor performance under airbag load at close proximity. The tests were conducted using the Airbag Test Simulator (ATS) and a 5th percentile Hybrid-III (H-III) female dummy at out-of-position (OOP) conditions.

METHODS

Sensor System

The TekScan Model 201 individual FlexiForce sensors were selected. As shown in Figure 1a, the sensor is 0.008” thick with a 0.375” diameter sensing area and the force range can be up to 100 lb. Instead of using the TekScan individual sensor data conditioner, a 24-channel signal conditioner was constructed to allow easy synchronization of multiple sensors (Fig. 1b). Since each sensor signal output is analog, a high sampling rate can be used. The sensor data were collected using an electronic data acquisition system with a sampling rate of 10 kHz per sensor.

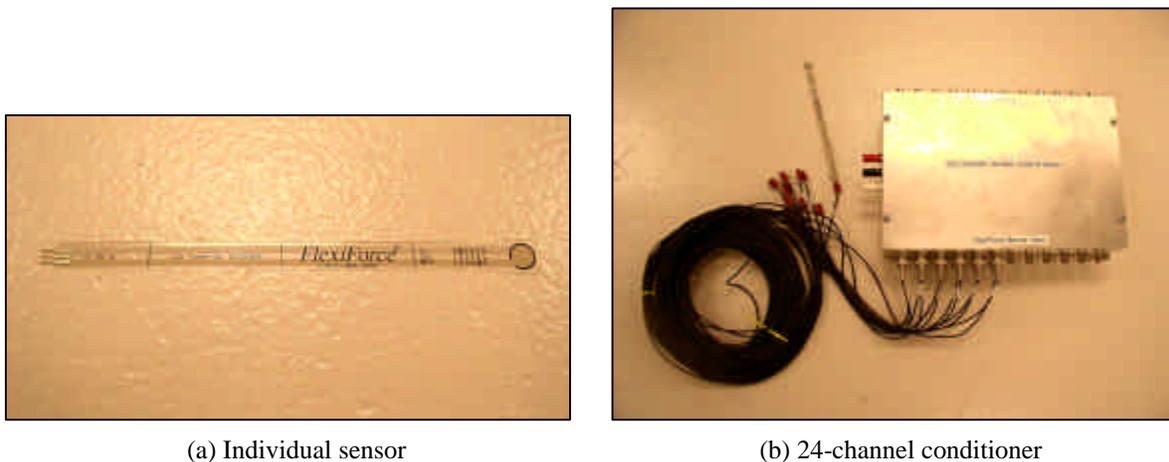


Figure 1: Thin film FlexiForce sensor system.

Each individual FlexiForce sensor was calibrated dynamically before use. The sensors were calibrated using a load cell and a force hammer. The sensor was first placed on top of a Kistler load cell (model 9071A) (Fig. 2a). A Kistler impulse force hammer (model 9724A5000) was used to hit the sensor (Fig. 2b). A calibration constant for each individual sensor was obtained by matching the sensor outputs with those from the impulse force hammer and the load cell. When calibrated, the signals from the FlexiForce sensor would match those from the force hammer and the load cell. The repeatability of the sensor outputs was verified by repeating the calibration tests at 8 and 15 days after the first test.

A special method was developed for mounting the sensor on the surface of the compliant dummy skin. A small rigid disc is first glued on top of the dummy skin, and the FlexiForce sensor is then taped or glued on top of the rigid mounting disc. Figure 3a shows a range of mounting discs that were evaluated, and Figure 3b shows the mounting of the FlexiForce sensor on the disc on top of a piece of H-III head skin. A range of 0.75-inch diameter mounting discs with different thicknesses and materials was evaluated to identify the best one. The mounting discs were evaluated by hitting the mounted sensor on top of the load cell with the impulse hammer and comparing the sensor outputs with those from the hammer and the load cell (Fig. 3b). This mounting method is needed to prevent the FlexiForce sensor from wrinkling or deforming when it is used on a compliant surface, which would render the sensor inaccurate.



(a) FlexiForce sensor on Kistler load cell (9071A)



(b) Kistler impulse hammer (9724A5000)

Figure 2: FlexiForce calibration tests.



(a) Sensor mounting discs



(b) FlexiForce sensor with disc on H-III head skin

Figure 3: Rigid sensor mounting method on compliant skin.

Airbag Tests

Fourteen calibrated FlexiForce sensors were distributed in the head and chest area of a 5th percentile female H-III dummy for airbag tests (Fig. 4). The sensors were glued on top of the rigid discs that were first glued on top of the dummy skin. The tests were conducted using the Airbag Test Simulator (Bandak, et al., 2000, and Chan, et al., 2004). The ATS is a pneumatically driven test platform that can inflate an airbag with high repeatability under well controlled inflation conditions. The ATS can be calibrated against fleet airbags to produce the same dummy response. Hence, highly repeatable tests can be carried out without the use of actual inflators. The dummy was tested at the ISO-1 (Fig. 5a) and ISO-2 (Fig. 5b) positions, also known as chin-on-bag and chin-on-wheel positions, respectively (Fig. 5). The tests were carried out without the airbag cover. All data were collected according to SAE J211 (1995).

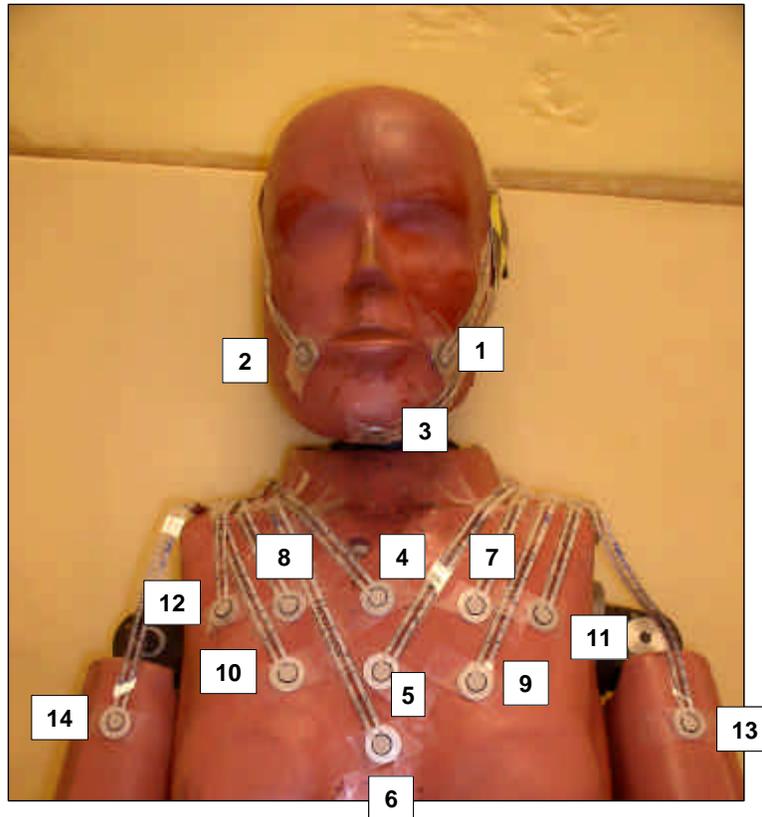
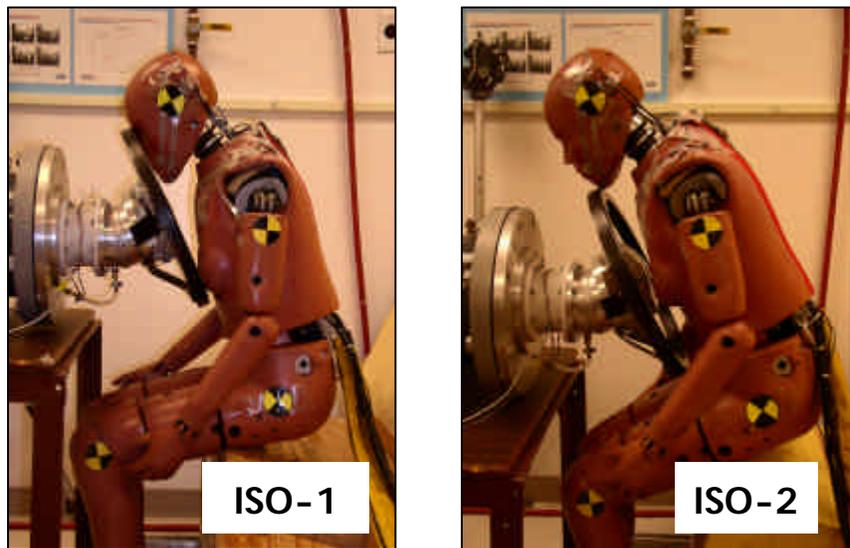


Figure 4: FlexiForce setup on Hybrid-III head and chest.



(a) Chin-on-bag

(b) Chin-on-wheel

Figure 5: ISO-1 and ISO-2 positions in front of ATS.

RESULTS

Calibration Tests

Figure 6 shows some selected time traces illustrating the FlexiForce sensor calibration results. These tests were carried out by hitting the sensor placed on top of the load cell with the impulse hammer (Fig. 2). When calibrated, the sensor peak and waveform outputs agree with the hammer and load cell outputs (Fig. 6). As shown, the FlexiForce sensor outputs agree with the peak as well as the waveform of the hammer and load cell outputs (Fig. 6). The repeatability of the FlexiForce sensor calibration was also verified by repeating the calibration tests at 8 and 15 days.

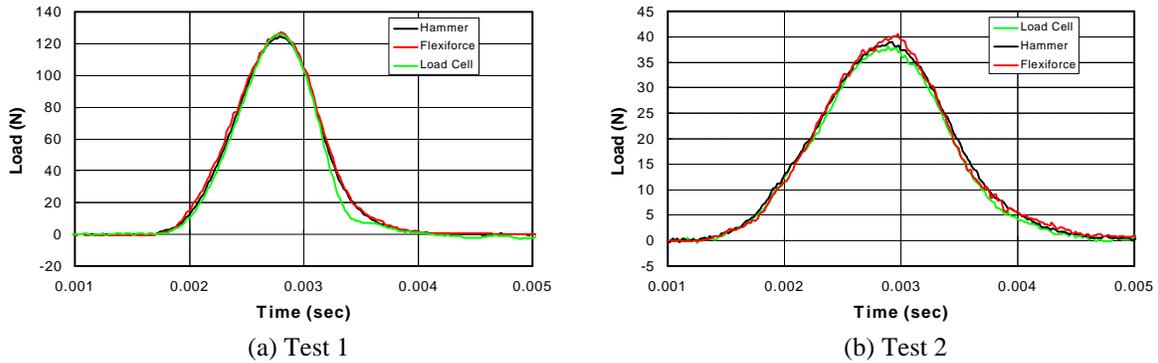


Figure 6: Calibration of FlexiForce using load cell and hammer.

When a FlexiForce sensor is placed on top of a piece of Hybrid-III skin without a backing disc, the sensor outputs do not match the hammer and load cell outputs (Fig. 7). This must be due to the wrinkling effect of the sensor when it is impacted by the hammer, resulting in inaccurate sensor output.

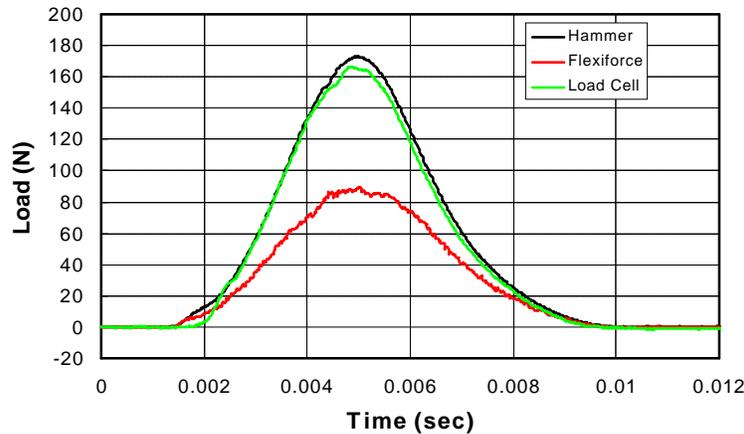


Figure 7: Response of FlexiForce sensor on bare H-III head skin.

The FlexiForce sensors performed well when they were backed by a rigid disc on top of the Hybrid-III skin. Based on extensive tests of a wide spectrum of discs, the aluminum discs with 0.75-inch diameter and 0.04-inch thickness were identified as the best ones (Fig. 3a). Figures 8-9 show the outputs of the sensor with backing from either an aluminum or a steel disc agree with the hammer and load cell outputs (Figs. 8-9). Data show that the FlexiForce sensor and the hammer

outputs are slightly higher than the load cell output for about 1 ms during initial impact (Figs. 8-9), but this is actually reasonable indicating the FlexiForce sensor captures the hammer contact load, while the load cell delays slightly due to the presence of the rigid disc. More importantly, the FlexiForce sensor followed the hammer output, since that represents the true contact load between the sensor and hammer (Figs. 8-9).

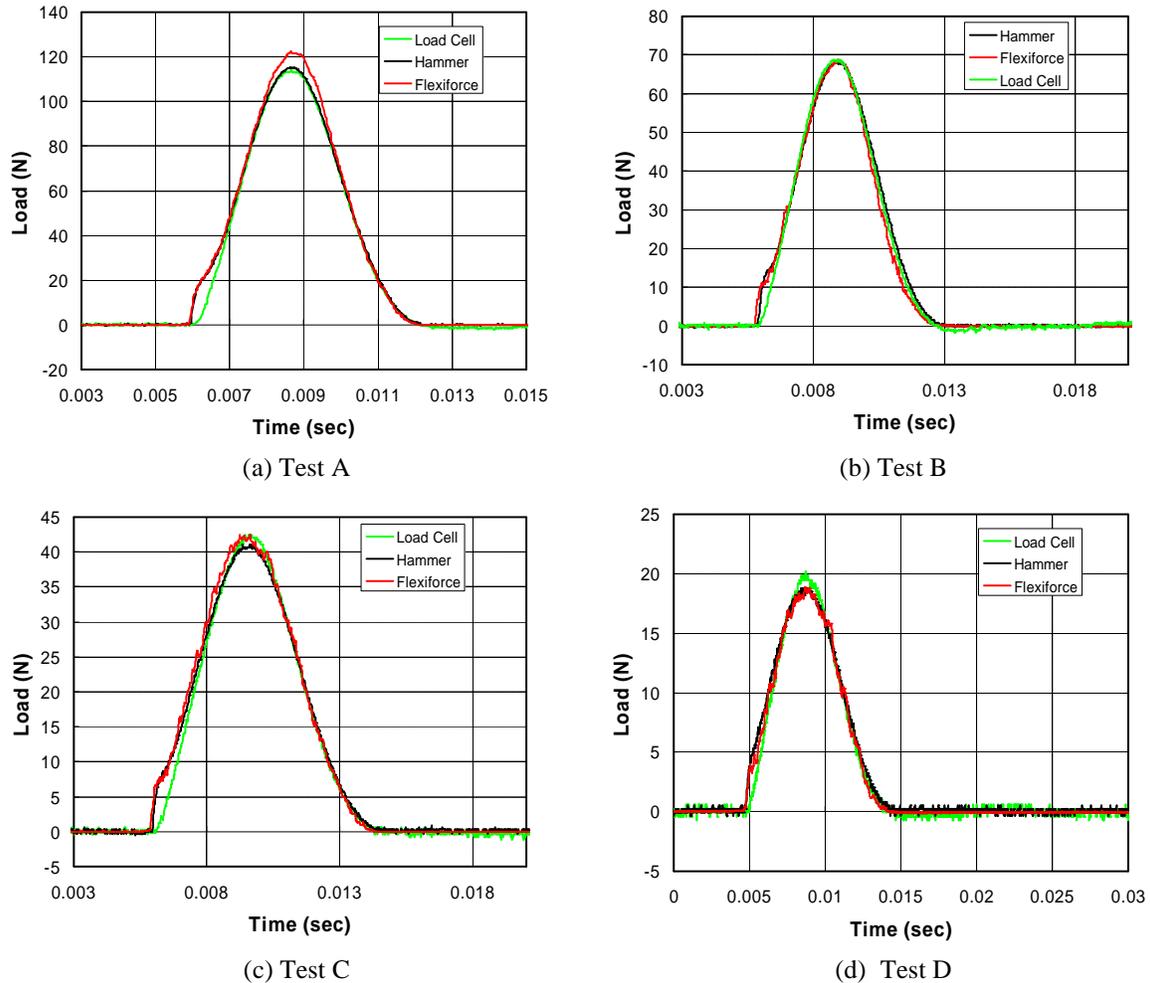


Figure 8: Evaluation of sensor mounted on aluminum disc glued to skin. Diameter=0.75”, thickness=0.04”.

Figure 10 shows the summary of the peak force comparison between the FlexiForce sensor and the calibration hammer. When the disc was taped on the Hybrid-III skin, the FlexiForce sensor peaked slightly higher than the calibration hammer (Fig. 10a). Data variability was reduced when the disc was glued on the Hybrid-III skin (Fig. 10b). Data seem to indicate a tendency for the FlexiForce sensor to peak slightly higher at the high load range (Fig. 10). Data show that the mounting disc should be glued on the dummy skin for the subsequent airbag tests and all other impact tests.

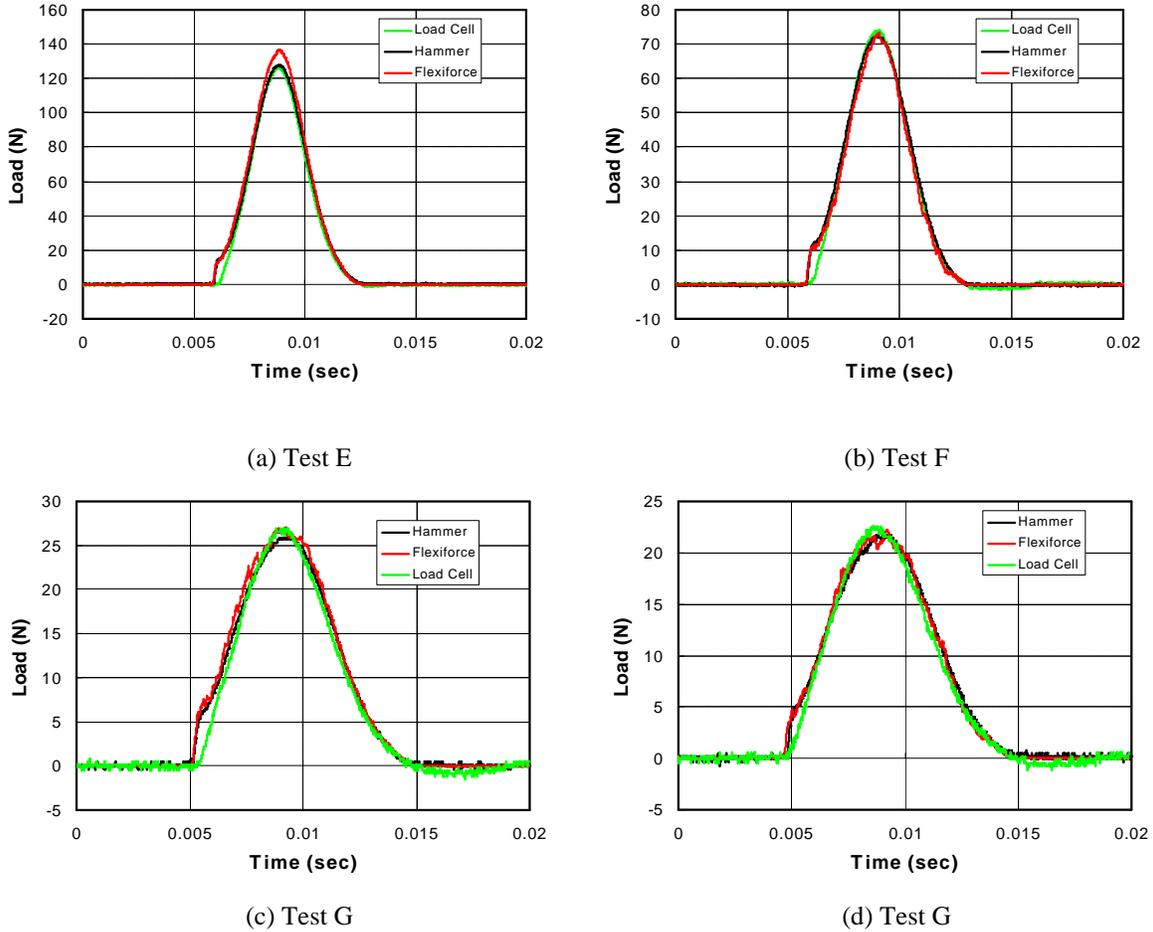
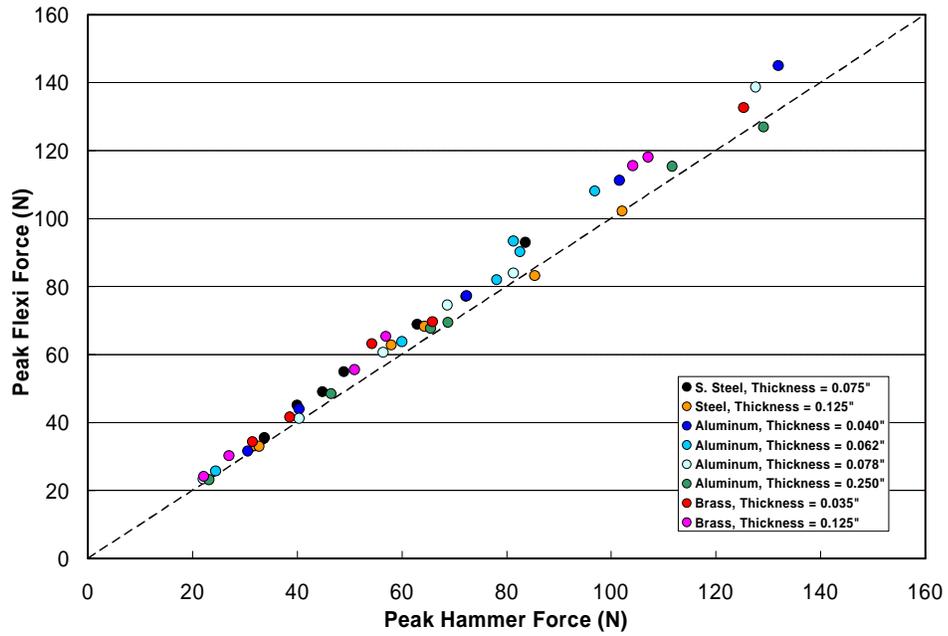


Figure 9: Evaluation of sensor mounted on steel disc glued to skin. Diameter = 0.75”, thickness = 0.032”.

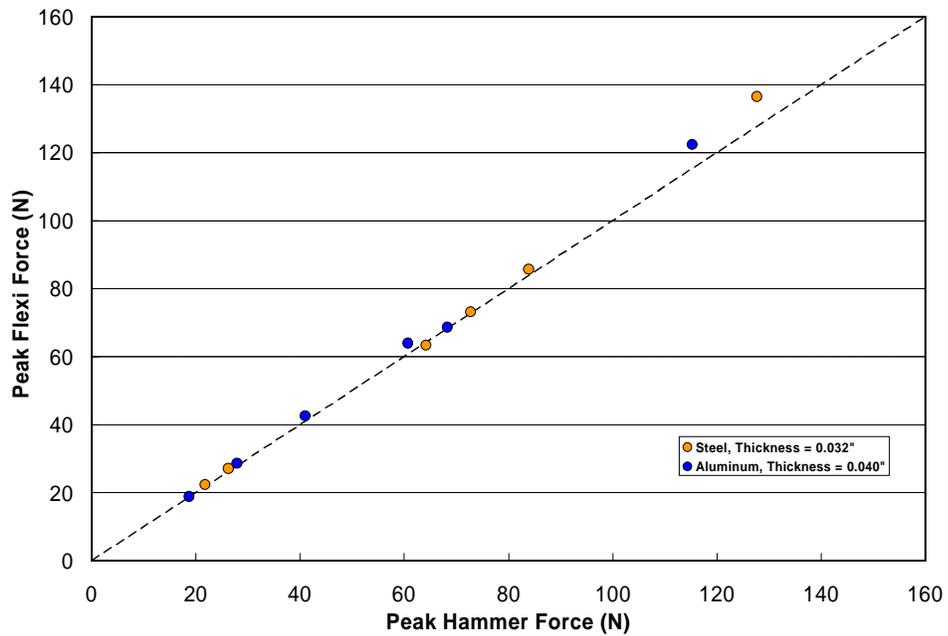
Airbag Tests

Figures 11-14 show the airbag test results with the FlexiForce sensors mounted on the dummy at ISO-1 position (Fig. 5). Figure 11 shows the FlexiForce sensor loads at three locations on the head, and Figure 12 shows the FlexiForce loads in the chest area. As shown, the sensor loads at individual locations indicate some variability between repeat tests (Figs. 11-12). Figure 13 shows the summed sensor loads for the head and the chest, respectively. The FlexiForce data show there is a tradeoff trend between the head and chest loads; namely, when the summed head load is high, test HF1D45AS323Y (Fig. 13a), the chest load is low (Fig. 13b). The opposite trend is observed for test HF1D45ASE23T (Fig. 13a, b). When all the FlexiForce loads are summed, the total load trend agrees well with the airbag pressure data (Fig. 14). In addition, the summed FlexiForce load is qualitatively fairly repeatable (Fig. 14a).

Figures 15-16 show the results for the tests with the dummy at the ISO-2 position (Fig. 5). Load variability between repeat tests at the individual locations is again observed. On the other hand, the summed FlexiForce loads on the chest are qualitatively repeatable and agree well with the airbag pressure trend (Fig. 16).



(a) Discs taped on H-III head skin



(b) Discs glued on H-III head skin

Figure 10: Summary of FlexiForce sensor disc mounting tests.

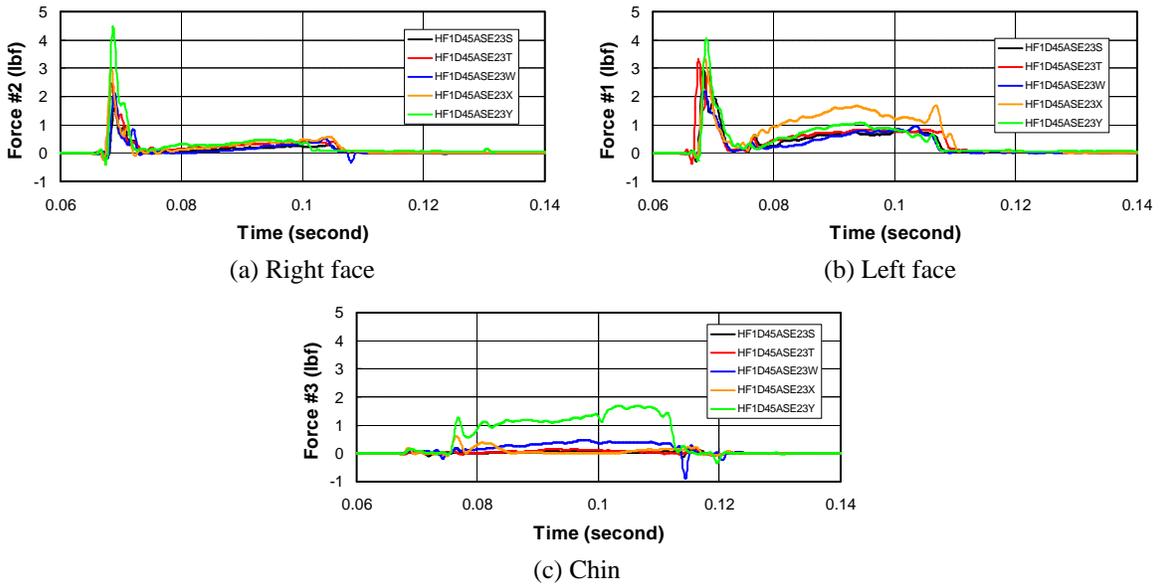


Figure 11: FlexiForce load on head (ISO-I).

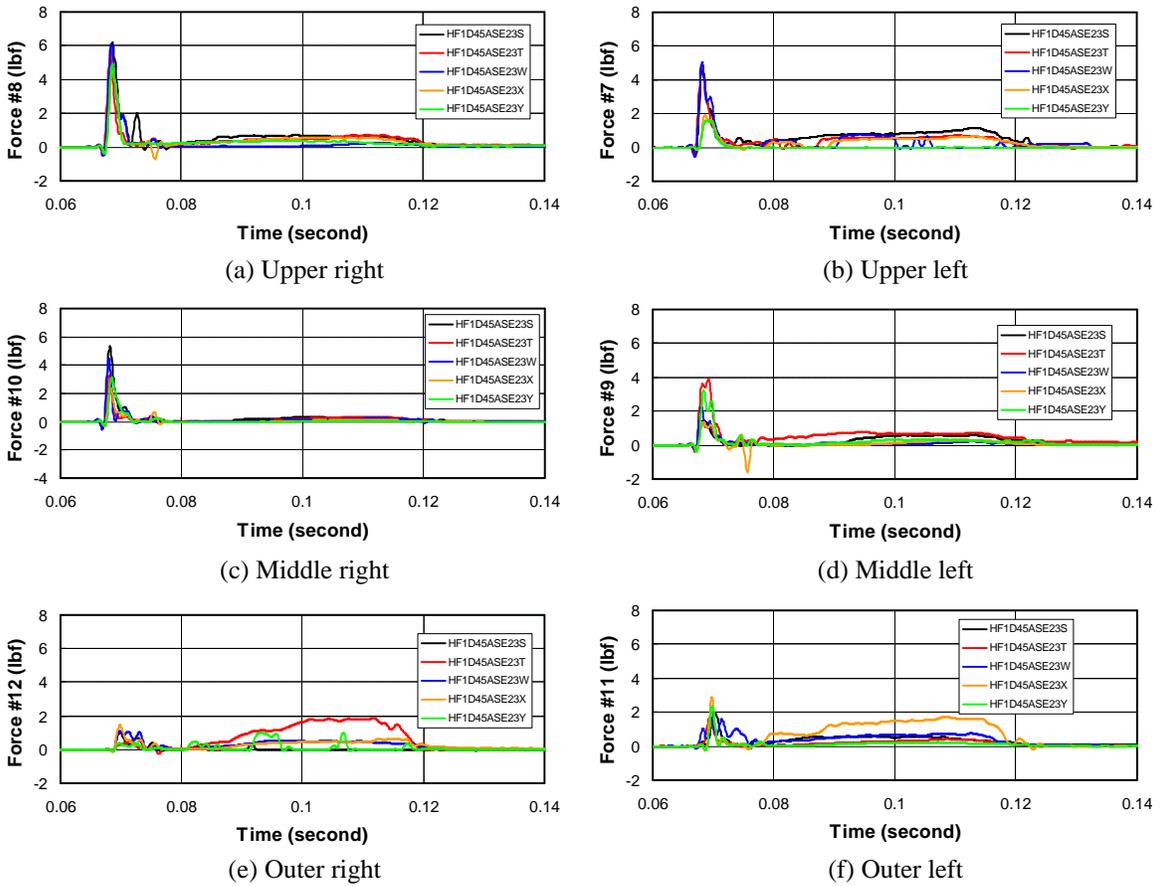


Figure 12: FlexiForce load on the chest (ISO-I)

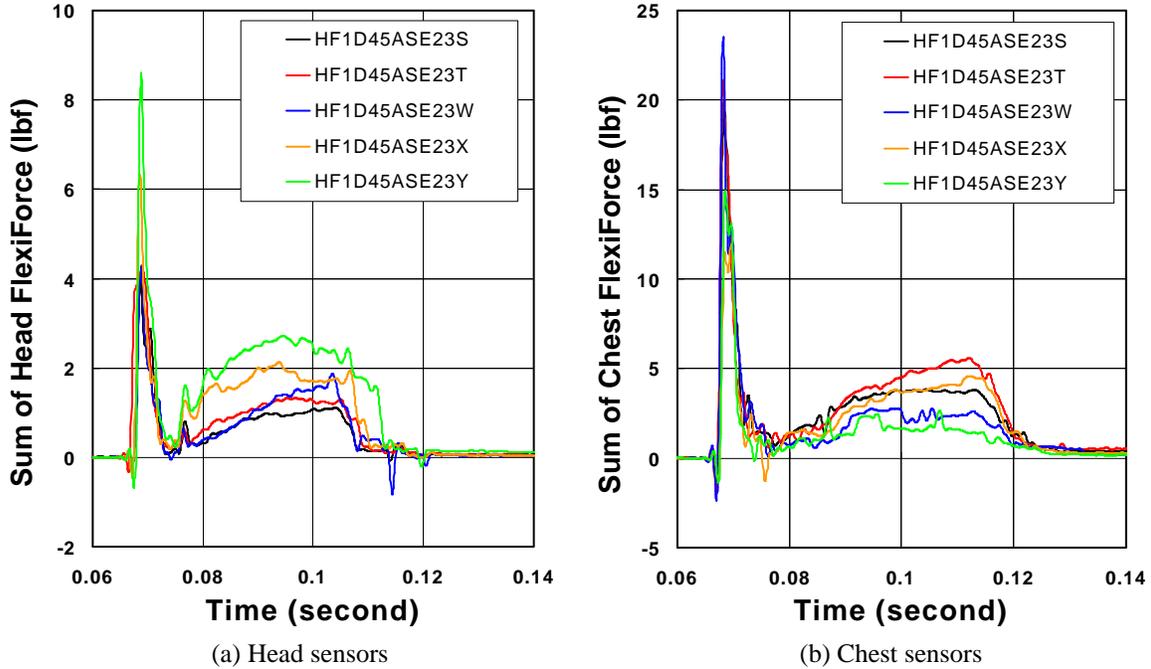


Figure 13: Comparison of sensor load distribution on the head and chest (ISO-I).

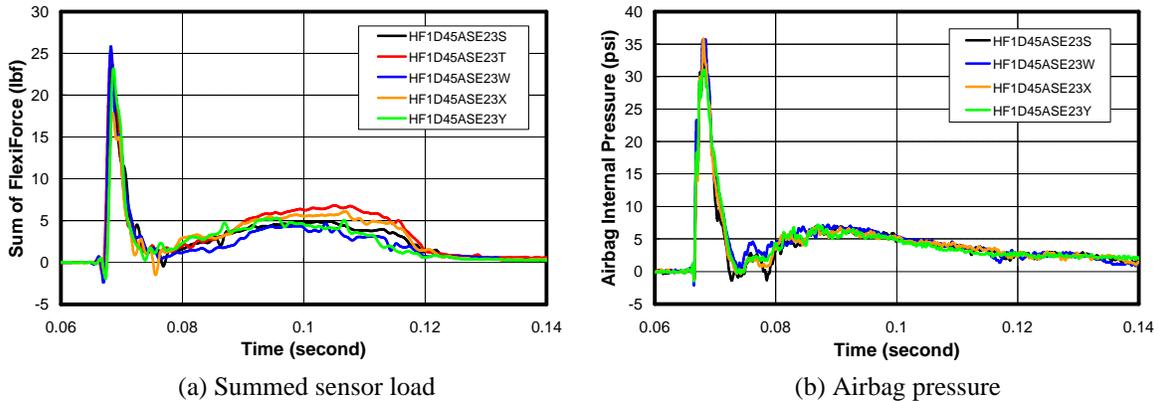


Figure 14: Comparison of summed sensor load on head, chest and arm with airbag pressure (ISO-I).

DISCUSSION

A method using rigid discs for mounting thin film FlexiForce sensors on the dummy compliant surface was explored and evaluated using airbag tests with the dummy at close proximity. The summed sensor load captured the load trends reasonably well when compared with the airbag pressure. On the other hand, load variability at individual sensor locations between repeated tests was observed. It seems that some load variability at individual locations can be real, and the causes could be due to the unwrapping effects of the airbag fabric during inflation. On the other hand, the shearing effects of the airbag fabric on the sensor outputs have not been well quantified, and thin film sensors are known to be sensitive to shearing.

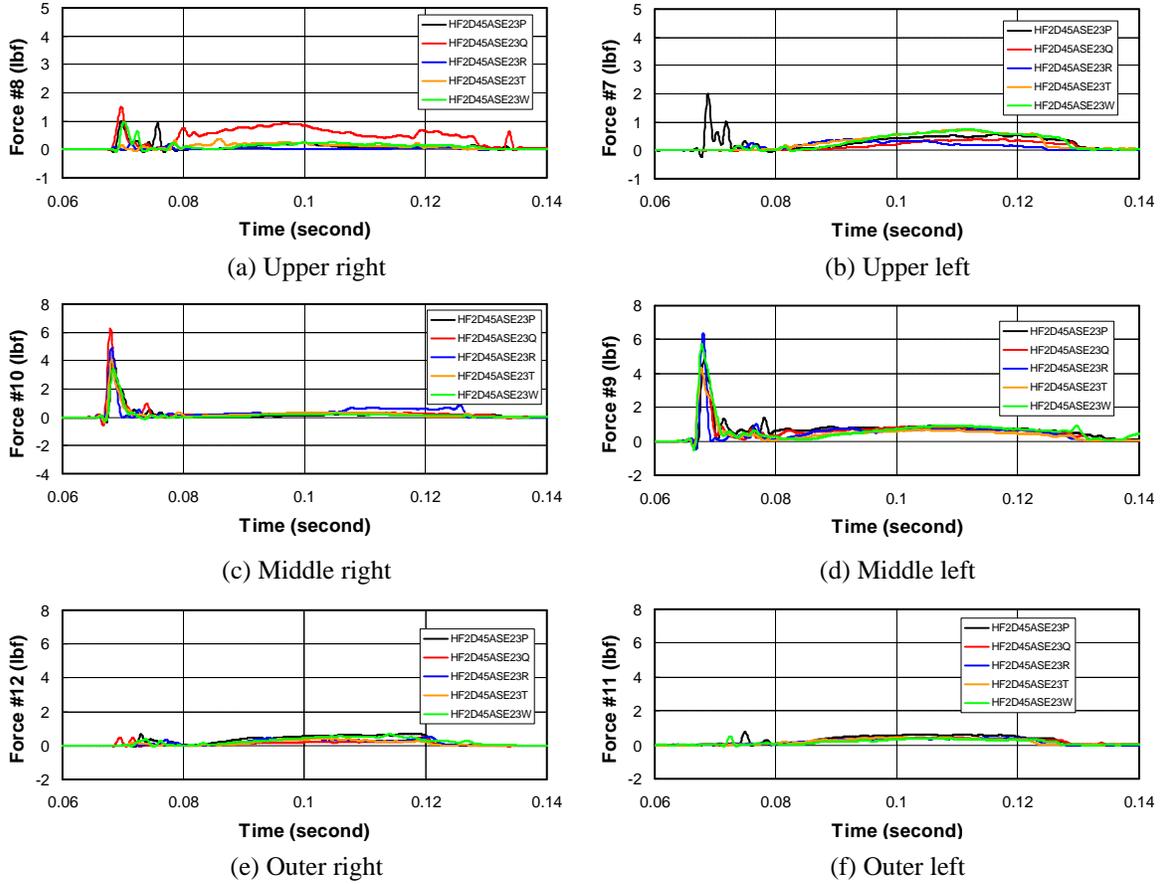


Figure 15: FlexiForce load on chest (ISO-2).

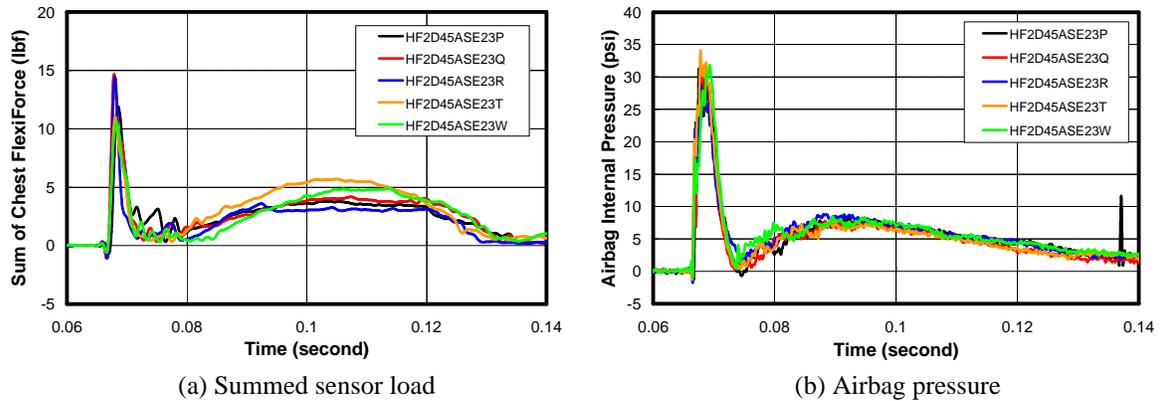


Figure 16: Comparison of summed sensor load on chest with airbag pressure (ISO-2).

The calibration of the FlexiForce sensors with disc backing was only verified using the head skin with hammer impact. It was assumed that the selected sensor-disc combination would behave similarly at all dummy locations with other compliant structural make up, but this has not been verified. More verification tests should be conducted, especially with the sensor on very soft surfaces. Furthermore, it should be noted that the individual sensors capture the local load conditions. The number of sensors needed to capture the total load will vary for different problems.

Only limited airbag tests were carried out and more validation tests are recommended for each specific application. The results obtained are encouraging and could lead to an effective way to measure contact loads on compliant surfaces that can be applied to many biomechanics research investigations.

ACKNOWLEDGEMENTS

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DISCUSSION

PAPER: **Development of Methodology to Measure Airbag Contact Load**

PRESENTER: ***Philemon Chan, JAYCOR***

QUESTION: *Stephan Duma, Virginia Tech*

Nice presentation. We've actually been using these for about two years in a lot of our skin abrasion research. We kind of went through the same stumbling blocks you went through. What we found is it's all about bending that sensor and whether it's, you know, a deformable substrate--[Right.]--or whatever. One of my questions is: When we were doing these airbag deployments the same way, unless you go with like 200 of these, how do you start to interpret some of the data because there's so much? Even when you're at, maybe, 10 cm spacing, there's a lot happening between that. I mean, do you feel comfortable, in the plots that you're showing, that there's nothing significant happening between your stations?

ANSWER: No. We're not saying that yet. At least this is additional information that we have, on top of just dummy response data. I think that at the end, you have to look at the least the data that you have and see maybe you can do some fitting to them and then maybe interpret them against the dummy response, and then perform some inverse dynamics calculations to give you a better evaluation of what really is happening. But, these individual data that collect, individual spots, can be useful in model validation to see if you're really predicting the force at the location correctly.

Q: No, I think it's very useful. I think the interpretation between points is the difficult part.

A: Yes, that's something that we--

Q: An enormous amount.

A: Yeah, we are thinking about. Very good point.

Q: *Frank Pintar, Medical College of Wisconsin*

I don't know if we use the same sensors, but we found that some of these very low-profile or thin-film sensors are influenced by that sheer load. You made a comment about the sheering load that occurs with the airbag, so I would encourage you to--in your calibrations as they induce a sheer load--to see if the normal load is affected by that. We found that, at least the sensors we were working with--

A: Yes. That's what we are doing right now--trying to find some controlled way to evaluate the sheering effect. So, yeah.

Q: *Guy Nusholtz, Daimler/Chrysler*

Why do you think that most of the variability is a function of your experimental process? With airbag deployment, you can see huge gradients or differences in pressures produced, particularly during the deploying process. Now once the airbag is deployed, that ceases to exist. We've measured as much as 30 psi difference in pressure coming from an airbag. And the other part of it is: Airbags are generally very variable, particularly in the deployment process, and you can get very different deployment trajectories even with exactly the same airbags. You're gonna have--How are you gonna sort through the differences between experimental problems and what's physically a chaotic problem?

A: Now, our dummy data that we have obtained showed pretty good repeatability of dummy response, like acceleration and joint loads. Also, the airbag pressure that we obtained from our airbag test system are fairly repeatable. They are like within not more 10, 15%. So, we don't see 30% variability from our tests.

Q: How are you measuring? What pressure are you measuring?

A: We have a sensor right inside the airbag on, you know, taped or glued to a rigid surface.

Q: Like on McCann?

A: Excuse me?

Q: The structure?

A: Yeah, right. Right.

Q: That's holding the airbag. The gradient that I'm talking about is if you move a pressure transducer along--[Okay.]--around inside of the airbag system, there will be places inside there which will be -2 psi and places as high as 500 psi, depending on the density of the material at that time. And as you get out, say, 10" or 10 cm away, you can--during the deployment process--see gradients, as you move a couple inches way, as much as a factor of 30:1. That's the type of pressure. You're just talking about--

A: We're just measuring at the same location at that time. Yeah. We didn't look for the spatial uniformity.

Q: You didn't go for gradients. You're just--

A: Yeah, we haven't looked at that. Yeah. That's a good point. There's more evaluation that we will want to carry out to see what really is variable, what really is chaotic. Yeah.

Q: *John Melvin, Tandelta, Inc.*

It's not clear to me why you want to make this measurement. What is the end goal? I don't think that was stated anywhere?

A: One of the motivations is in model development and model validation. What we are comparing, most of the time now, is just responses. You can get the dummy response correct for the wrong reason. It's not clear, how--what, for a model, the load that you actually applied between the airbag and the dummy should be known actually before you just evaluate how the results come out. So--and, we believe understanding how the airbag interacts with the occupant or the dummy would provide a lot of insight in understanding how the loads are applied.

Q: Maybe in the chest I could understand that although chest deflection would probably tell you really what's happening. But with the head, Rick Shae and I published a paper years ago: You can use the head as an inertially compensated load cell with the neck loads and 3-D acceleration to not only calculate the load on the head, but where the center of pressure is without doing anything else. So I think there's already a mechanism in the dummy to allow you to calculate the total load. So, I don't--So unless you had a lot of pressure sensors everywhere, I don't know how you're gonna integrate to get the whole answer. That's sort of the other question was brought about 200 sensors, or whatever.

A: Well, we'll see how many you need; but using the internal load cell to back out external load, really is the inverse process. How do you know that's correct?

Q: Well, it works. We've proven it. It's very easy to--It's called Simple Rigid Body Mechanics.

A: Okay. Thank you.