INJURY BIOMECHANICS RESEARCH
Proceedings of the Twenty-fourth International Workshop

Assessing Arm Injury Potential From Deploying Air Bags

Kristie L. Johnston, Kathleen DeSantis Klinich, Daniel A. Rhule
Transportation Research Center, Inc.

Roger A. Saul
National Highway Traffic Safety Administration

ABSTRACT

A study conducted using the National Accident Sampling System (NASS) found an increase in upper extremity injuries when drivers were restrained by a seat belt and air bag as opposed to a seat belt alone. These injuries were attributed to forces from the air bag deploying or the air bag projecting the arm into vehicle components or the upper body of the driver. Two evaluation methods were used to assess the extent of injury and aggressiveness of different driver side air bags. The RAID [4], developed by Conrad Technology, and the Hybrid III instrumented arm, tested at the Vehicle Research and Test Center, were used in static testing to evaluate the effect of air bags on the arm.

The positions of the RAID and the Hybrid III arm simulated the arm in four different turning positions with the forearm across the center of the wheel. Both devices recorded arm moments and accelerations. Film analysis determined the cause of the peak resultant moment for each bag in the four configurations. The Hybrid III was able to attribute half of the moments that surpassed the Injury Assessment Reference Values (IARV) to forces from the air bag when deployed in close proximity to the forearm, while the other half of the moments that surpassed the IARV were from contact with the head, neck and chest of the dummy. In contrast, the RAID only recorded accelerations and moments due to the air bag but was unable to account for contact between the arm and the occupant or vehicle's interior. The Hybrid III instrumented arm and the RAID gave similar rankings of the severity of the different air bags.

INTRODUCTION

The main goal of the initial phase of the arm/air bag program was to determine if the RAID and Hybrid III instrumented arm led to similar conclusions regarding the arm injury potential of different air bag systems. To do this, testing was performed with the Hybrid III instrumented arm at the Vehicle Research and Test Center (VRTC) using the same testing configurations and air bags as those used with the RAID testing device.

BACKGROUND

Arm Injury/Air Bag Interaction Studies

A recent NHTSA study (conducted by Conrad Technology) found a higher incidence of arm injury in National Accident Sampling System (NASS) cases in accidents involving air bags. When drivers were restrained by only a three-point belt, about 1% experienced upper extremity injuries. Of those drivers restrained by both three-point belts and air bags, 4% suffered arm injuries. A more detailed NASS study of 36 specific cases of upper extremity injury to drivers found that half occurred in low impact collisions ($\Delta V<24$ km/hr), half occurred while turning, and half resulted in injuries with an AIS>3. Seventy percent of the injuries with an AIS>3 were inflicted on the radius and ulna. The increase in upper extremity injuries was attributed to two possible mechanisms. The first are direct forces from the air bag deploying on the arm. The second mechanism involves the air bag throwing the arm with high velocity into the driver body or vehicle surroundings.[2]

Another study conducted by the University of Michigan, Transportation Research Institute (UMTRI), has shown that upper extremity injuries usually occur in the form of abrasions, contusions, sprains and fractures in the forearm, wrist and fingers. It was found that these minor injuries occur in approximately 20%-25% of their sample data. These injuries were contributed to the forces afflicted by the air bag as it deploys (where the bag reaches velocities of 160-320 km/h), and contact with the occupant and vehicle surroundings. [3]

RAID

The RAID arm simulator was developed by Conrad Technologies Inc., to evaluate air bag severity relative to arm injury in a static laboratory setting. A drawing of the device appears in Figure 1. Its basic structure consists of a 46 cm aluminum tube and weighs 3 kg (not including the weight of the hand mass of .25 kg). The connecting end of the RAID allows it to swing freely in all directions. The free hanging end of the RAID consists of a concentrated hand mass. The length of the RAID was extended to 46 cm to protect the pivot attachments from the deploying air bag. This is longer than the Hybrid III forearm (approximately 28 cm), but is shorter than the entire length of the Hybrid III instrumented arm (approximately 58 cm).

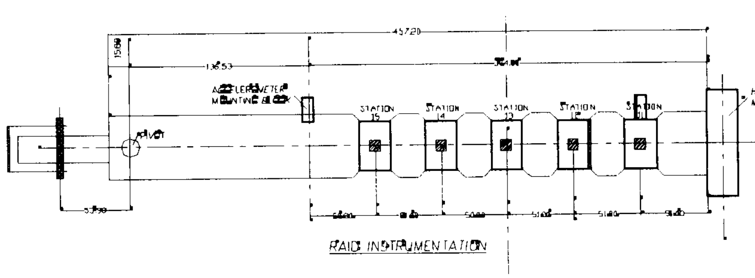

Figure 1-- RAID testing device (mm)

Five strain gage "stations" permit measurement of x and y moments along the length of the RAID, as seen in Figure 1. To conduct laboratory testing of different air bags, the steering wheel is mounted vertically to a test fixture. The RAID pivot is connected to a crossbar located above the steering wheel, so it hangs vertically and represents an arm positioned across a steering wheel. The distance between the RAID and steering wheel can be controlled by moving the crossbar.

Hybrid III Instrumented Arm

The Hybrid III instrumented arm was developed to allow evaluation of air bag severity with a dummy in a vehicle setting. As illustrated in Figure 2, the structure of the device is the standard Hybrid III dummy forearm and hand which weighs approximately 1.5 kg. The instrumented arm was equipped with four sets of strain gages and two accelerometers (as seen in Figure 2).

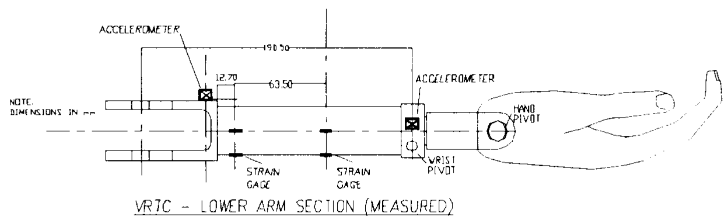

Figure 2--Hybrid III Instrumented Arm (mm)

RAID/Hybrid III Instrumented Arm Structural Comparison

Because of structural differences between the RAID and Hybrid III instrumented arm, the kinematics and measured responses of the two systems are expected to be different. The Hybrid III arm can bend at both the elbow and the shoulder, while the RAID testing device has only one joint at a location relative to a human arm about halfway between the elbow and shoulder. If we view each device as a beam in bending, the differences in length, diameter, material, and end conditions will lead to different responses to the same input.

Figure 3 shows the RAID and Hybrid III instrumented arm in a scaled comparison. The devices are lined up relative to how they are positioned to the steering wheel rim during testing. For the RAID, the hand mass is centered over the rim, while the junction of the Hybrid III hand and thumb is the approximate rim location of the Hybrid III instrumented arm. The side-by-side comparison indicates that none of the strain gage stations on the RAID line up with those of the Hybrid III instrumented arm.

Arm Injury Criteria

An IARV was estimated in both the RAID and Hybrid III instrumented arm initial testing programs. The total dynamic bending moment for the arm was estimated to be 115 N*m for the RAID device.[1] A similar estimate was completed at VRTC to find a range for the peak load for males and for females. For the VRTC estimate, the female bending moment tolerance was 70-90 N*m, while the male tolerance was 120-150 N*m.[2]

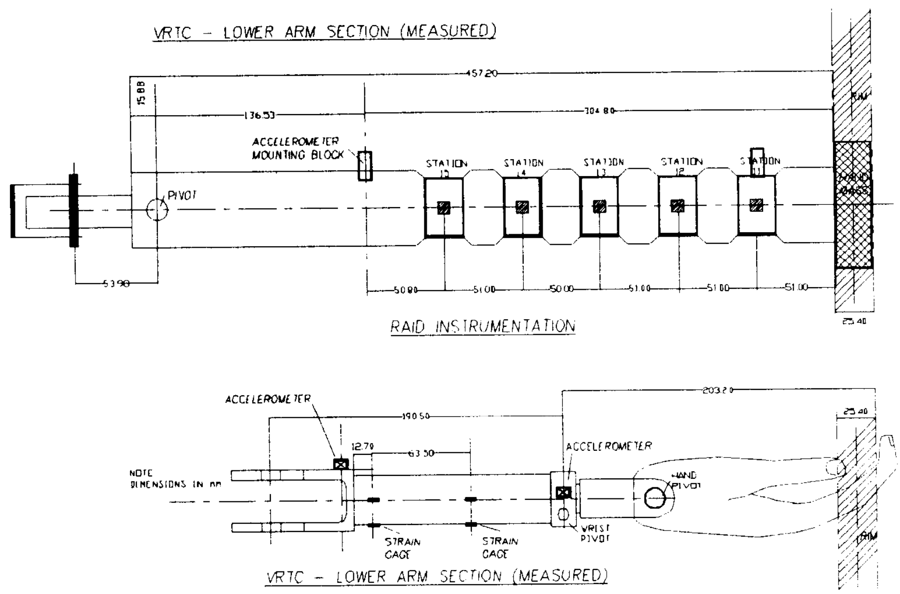

Figure 3--Comparison of RAID and Hybrid III instrumented arm (mm)

PROCEDURE

Test Configurations

The RAID was tested in a variety of different configurations that varied the orientation of the arm device relative to the steering wheel, and the distance between the arm and the air bag module. Four of the RAID configurations were selected for comparison testing with the Hybrid III instrumented arm, and were designated V-1, V-2, V-3, and V-4 as described in Table 1.

Table 1: Test Configurations

VRTC Configuration	Conrad Configuration	Nominal Distance from Wheel	Hand/Elbow "Clock" Position		Wheel Rotation	
			H3 Inst Arm	RAID	H3 Inst Arm	RAID
V-1	I-1.3 cm	1.3 cm	11/4	11/4	90° CCW	90° CCW
V-2	V-7.6 cm	7.6 cm	10/4	12/6	60° CCW	0°
V-3	V-1.3 cm	1.3 cm	10/4	12/6	60° CCW	0°
V-4	VI-1.3 cm	1.3 cm	10/4	~12/6	150° CCW	90°

As mentioned before, the RAID testing protocol called for hanging the device from a pivot in front of the steering wheel. The wheel was turned and shifted to achieve the desired distance and orientation relative to the arm. Since the Hybrid III instrumented arm was being evaluated on the dummy seated in a sled buck, the setup was limited by how close the upper arm could be positioned to the dummy's torso without twisting the dummy. For example, the RAID hand/elbow was placed in the 12 and 6 o'clock positions in configurations V-2 & V-3. With the dummy sitting centered in front of the wheel, it was not possible to place the elbow at the 6 o'clock position without moving the dummy's torso. Instead, the elbow was placed at a feasible angle (elbow at four o'clock) and the wheel was rotated to position the air bag seam relative to the arm in the same way it was positioned relative to the RAID. The same type of adjustment was done in the other configurations to keep the forearm and air bag seam orientations consistent with the RAID test conditions.

Figures 4, 5, and 6 illustrate specific examples of Hybrid III instrumented arm and RAID testing configurations. The arm positions are shown together with the amount of wheel rotation required. In all figures, the Hybrid III instrumented arm position is on the left and the RAID configuration on the right. The details regarding each setup are also included in Table 1, as are the configuration designations used by Conrad Technologies.

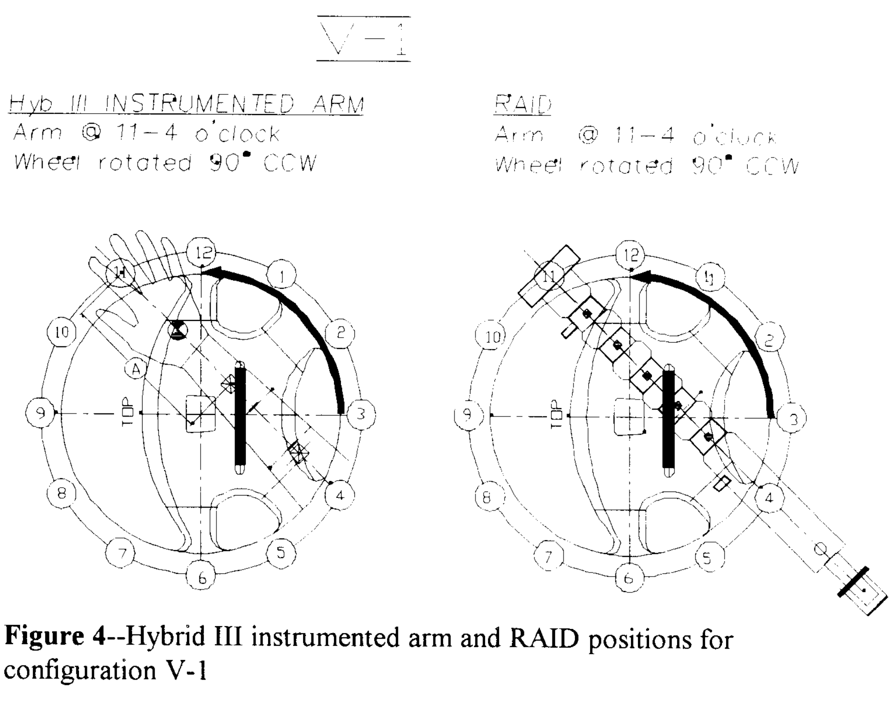

Figure 4--Hybrid III instrumented arm and RAID positions for configuration V-1

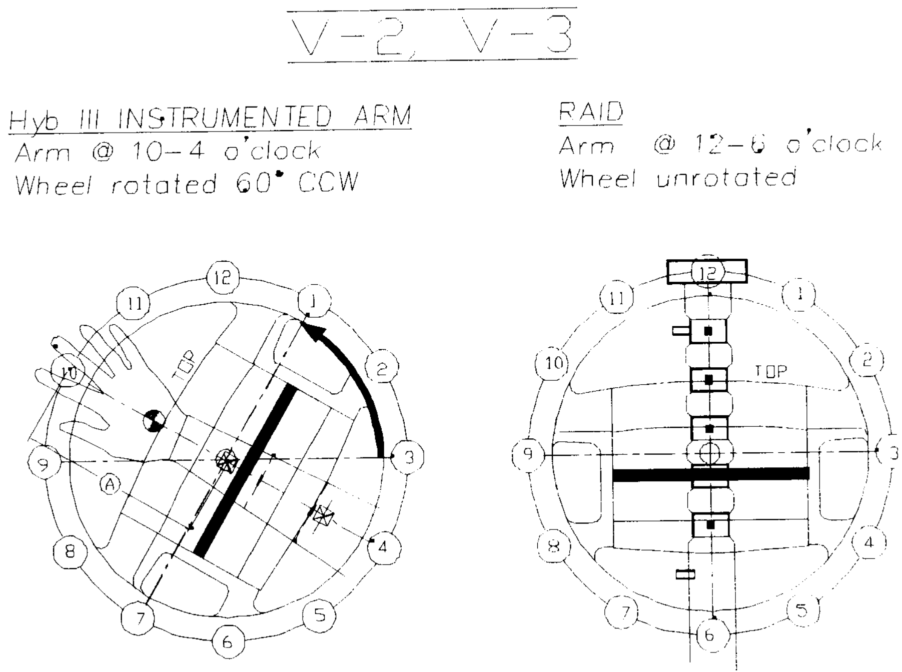

Figure 5--Hybrid III instrumented arm and RAID positions for configurations V-2 and V-3

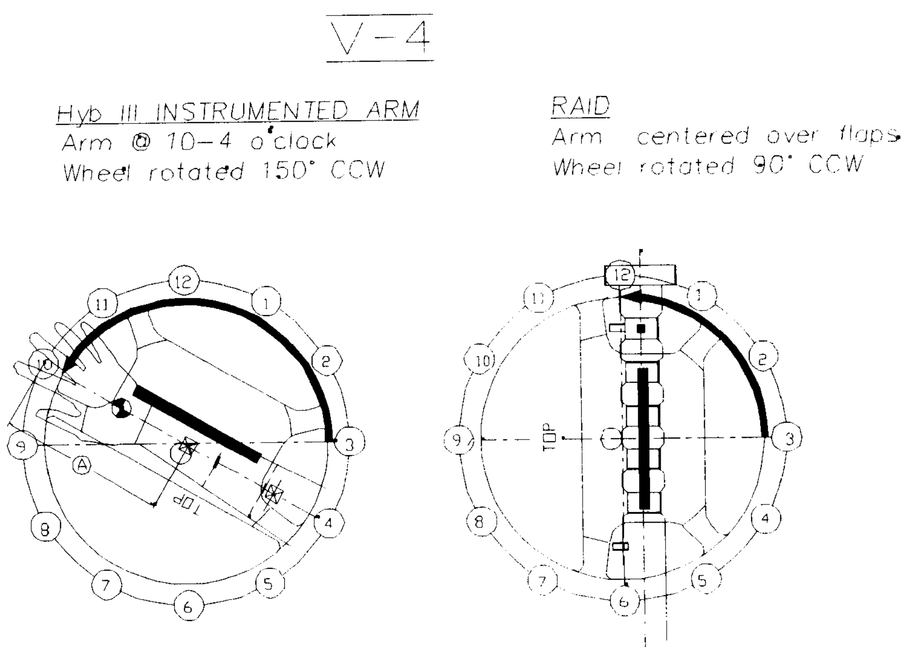

Figure 6--Hybrid III instrumented arm and RAID positions in configuration V-4

Hybrid III Instrumented Arm Test Matrix

In addition to using four of the same configurations from the RAID testing, the Hybrid III instrumented arm program also used four of the same air bag systems. The four air bag systems have been arbitrarily labeled H, J, K and L followed by the model year. For example, a 1995 model J would be noted as J-95. The RAID system was tested at least once in each configuration with four different air bags. Table 2 shows the Hybrid III instrumented arm test matrix. Each of the four air bag systems was tested in the V-1, V-2 and V-3 positions. Only the K-93 and the J-95 were tested in the V-4 position, because the RAID data indicated lower measured moments for this configuration.

Table 2--Hybrid III Instrumented Arm Test Matrix

VRTC Designation	K-93	J-95	L-92	H-91
V-1	✔	✔ ✔✔✔	✔	✔
V-2	✔	✔	✔	✔
V-3	✔	✔	✔	✔
V-4	✔	✔	Not Tested	

The J-95 air bag was tested with the Hybrid III instrumented arm four times in the V-1 position to determine repeatability. In addition, some questions were raised regarding the Hybrid III thumb position on the steering wheel. Therefore, the thumb was placed under the rim for the first three tests and over the rim on the fourth test.

Table 3 summarizes additional tests performed in the V-1 and V-3 positions. Each bag was tested once in each configuration. The results generated by the 1994 air bags were compared with the corresponding 1996 models' results to assess any improvement in the later year model.

Protocol

The Hybrid III instrumented arm tests were conducted statically using a sled buck as the test fixture. The setup is shown in Figure 7. The dummy was positioned on a generic metal seat which could be shifted toward or away from the steering wheel. The steering wheel was attached to a column that allowed adjustment of the column and steering wheel angles. For the initial part of this program, the same steering wheel angle and column angle were used since the difference in vehicle measurements for the four air bags tested was minimal. The steering wheel and the column angles were set at 25°. Two ventilators were placed in front of the buck to contain the post-test air bag exhaust.

Table 3--Fleet Vehicle Test Matrix		
VEHICLE	**CONFIGURATION V-1 (Conrad I @ 1.3 cm)**	**CONFIGURATION V-3 (Conrad V @ 1.3 cm)**
A-94	✔	✔
A-96	✔	✔
G-96	✔	✔
H-96	✔	✔
F-94	✔	✔
F-96	✔	✔
D-96	✔	✔
I-96	✔	✔
B-96	✔	✔
E-94	✔	✔
E-96	✔	✔

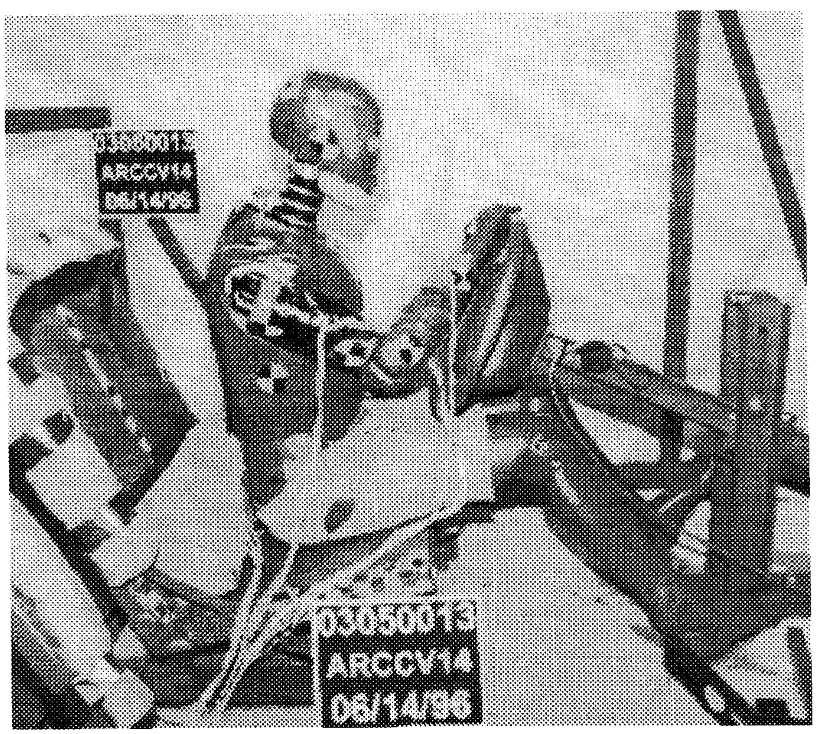

Figure 7--Test set-up

Prior to each test, a series of measurements were taken to ensure consistent placement of the dummy. Before each test, the dummy's face was painted with chalk to indicate the points of contact between the dummy's face, arm, air bag and the test buck. The event was captured on high speed film and high speed video. Still pictures also were taken before and after each test.

Table 4 reflects the channels recorded in each test and the channel filter class at which the data was computed.

Table 4--Channel Classes

Abbreviations & Channel Descriptions	Channel Filter Class
Mid-forearm x and y moment	600
Proximal forearm x and y moment	600
Distal forearm x, y, z accelerations	1000
Proximal forearm x, y, z accelerations	1000
Distal upper arm x, y, z accelerations	1000
Proximal upper x, y, z accelerations	1000
Head x, y, z accelerations	1000
Chest x, y, z accelerations	1000
Chest deflection	180
Neck forces in the x, y and z directions	1000
Neck moments in the x and y directions	600

RESULTS

This section summarizes test results of the Hybrid III instrumented arm and the RAID comparison in the V-1 through V-4 configurations, the fleet air bag results in the V-1 and V-3 configurations, and the J-95 repeatability test summary.

There are two main events that occurred in the following tests which contributed to moments surpassing the IARV. The first was caused by direct contact between the air bag and the Hybrid III instrumented arm at the time the air bag was deployed. This event usually occurred within the first 15 msec of each test (referred to as an 'air bag injury'). The second event that contributed to moments that surpassed the IARV was caused by contact between the Hybrid III arm and body (referred to as a 'contact injury'). This usually occurred at times greater than 20 msec. Table 5 contains a summary of the RAID and Hybrid III instrumented arm data, followed by the times at which the data was recorded.

Table 5--Air Bag Assessment

		ARM				RAID			
		K-93	**L-92**	**J-95**	**H-91**	**K-93**	**L-92**	**J-95**	**H-91**
Configuration V-1 Nominal 1.3 cm distance Wheel rotated 90° CCW (seam usually vertical) Arm from 11 to 4 o'clock	Peak resultant wrist acceleration (g)(ms)	512 @5.2	184 @6.4	200 @6.0	544 @6.6	135	71	55	116
	Peak Resultant moment (Nm) (ms)	135.6 @5.7	78.1 @8.6	83.5 @8.2	106 @15.1	483	313	213	436
	Wrist Velocity at 15 ms (km/h)	76.6	21.9	30.4	77.2	98	50	32	77
	Air bag ranking	4	1	2	3	4	2	1	3
Configuration V-2 Nominal 7.6 cm distance Wheel rotated 30° CCW (arm perpendicular to seam) Arm from 10 to 4 o'clock	Peak resultant wrist acceleration (g)(ms)	660 @8.2	138 @8.6	301 @6.8	NO DATA		39	72	106
	Peak resultant moment (Nm) (ms)	181.3 @8.5	65.1 @9.4	80.5 @8.1	107.7 @9.6	370	121	273	328
	Wrist Velocity at 15 ms (km/h)	44.7	11.2	26.4	NO DATA	109	60	43	62
	Air bag ranking	4	1	2	3	4	1	2	3
Configuration V-3 Nominal 1.3 cm distance Wheel rotated 30° CCW (arm perpendicular to seam) Arm from 10 to 4 o'clock	Peak resultant wrist acceleration (g)(ms)	518 @8.3	330.3 @5.8	235.3 @7.4	497 @8.2	137	57	64	183
	Peak Resultant moment (Nm) (ms)	238.7 @8.9	117 @6.4	144.3 @9.1	233.5 @8.6	522	290	343	617
	Wrist Velocity at 15 ms (km/h)	61.7	29.8	34.4	49.8	111	76	79	97
	Air bag ranking	4	1	2	3	4	1	2	3
Configuration V-4 Nominal 1.3 cm distance Wheel rotated 120° CCW (arm parallel to seam) Arm from 10 to 4 o'clock	Peak resultant wrist acceleration (g)(ms)	769 @5.0		278 @7.5		133	55	63	183
	Peak resultant moment (Nm) (ms)	197.6 @6.5		103.3 @9.4		525	280	340	620
	Wrist Velocity at 15 ms (km/h)	83.6		44.8		118	77	79	98
	Air bag ranking	2		1		3	1	2	4

*Injury criteria for peak moments are 120-150 N*m for men and 70-90 N*m for women.
Preliminary Results from Arm/RAID Comparison Testing

HYBRID III INSTRUMENTED ARM/RAID COMPARISON

Configuration V-1

Films reviewed of configuration V-1 showed very little contact between the dummy's arm, face or chest for all air bag systems. In all tests, the forearm seemed to rotate away from the wheel while the upper arm stayed still until later in the event. As seen in Table 6, the injury summary shows moments exceeding the IARV occurred from air bag contact, while one isolated case actually occurred when the arm was thrown to the side causing an excessive inertial load from the elbow locking. All of the peak wrist accelerations occurred in the first 10 msec and were therefore results of the air bag deployment.

Configuration V-2

Contact injuries were evident in two of the four tests in the V-2 position. In the J-95 and H-91 air bags, the arm contacted the chest and continued upward into the chin and neck. These moments caused by contact were not severe enough to surpass the IARV, but the forces afflicted by the air bag at deployment exceeded the proposed female IARV (as indicated in the first two columns of Table 6). The L-92 and K-93 air bags on the other hand, caused the arm to travel in an upward direction directly contacting the chin. These moments surpassed the proposed male and female IARV.

Configuration V-3

Configuration V-3 had the same hand, elbow, and steering wheel position as configuration V-2. However, in configuration V-2 the forearm was placed 7.6 cm from the module and in configuration V-3, the forearm was placed at a distance of 1.3 cm from the module. This decrease in distance subjected the arm to some higher forces when the air bag was deployed.

Unlike configuration V-2, where the Hybrid III arm contacted the chest of the dummy in each case, chest contact was only evident in one of the vehicles (K-93). The other three vehicles (J-95, L-92 and H-91) experienced direct contact between the Hybrid III arm and the head and neck (without contacting the chest). This seemed to produce higher moments than the cases in which the arm slid up the chest.

The resultant moments for the V-3 position were a little more severe than the results from the V-2 position. The proximal placement to the point of air bag deployment increased the magnitude of the moments. As seen in Table 6, configuration V-2 registered two moments that exceeded the proposed female injury criteria. On the other hand, configuration V-3 registered one moment that exceeded the proposed male IARV and two that exceeded both the male and female proposed IARV.

Configuration V-4

The K-93 and the J-95 air bags were the only bags tested in the V-4 position due to nonessential findings at Conrad Technology compared to the other configurations. Contact between the arm and the dummy was evident in each test, although the highest injury potential moment was caused by the air bag (as indicated by the second and third columns of Table 6). The K-93 forced arm contact high on the chest, then upward to the face. The J-95 caused direct contact between the hand and the face of the dummy resulting in a moment which exceeded the proposed male IARV.

The resultant moments registered portray the more mild characteristics of this configuration compared to the other three positions. The K-93 arm test obtained the most force from the air bag and not from contact in this position. The J-95 results were a little more severe than they were in the V-1 and V-2 positions simply because there was contact with the J-95 bag in this configuration and not in the others.

Table 6--Hybrid III Injury Summary						
Air Bag & Configuration	**Injury From Air Bag**		**Injury From Contact**		**Injury From Elbow Locking**	
	Proximal	**Distal**	**Proximal**	**Distal**	**Proximal**	**Distal**
K-93 V1					✚	✗
L-92 V1	✔					
H-91 V1		✔	✔			
J-95 V1	✔					
K-93 V2			✚			
L-92 V2			✚			
H-91 V2	✔					
J-95 V2	✔					
K-93 V3	✚					
L-92 V3			✗	✔		
H-91 V3	✚			✔		
J-95 V3	✗					
K-93 V4	✚					
J-95 V4			✗			
J-95 V11	✔					
J-95 V12			✗			
J-95 V13	✔					
J-95 V14	✔					

HYBRID III INSTRUMENTED ARM/RAID DISCUSSION

Table 6 reflects the peak resultant moments (N*m) relative to the proposed IARV, and the events that caused the peak moment. Values are from the ARM/RAID comparison testing only. A ✔ represents a moment that would be equivalent to the IARV for a fifth percentile female (70-90 N*m), an ✗ represents a moments that would be equivalent to the 50th male IARV (120-150 N*m) and a ✚ represents any moment that exceeds 150 N*m. The first column represents air bag injuries and the second column represents contact injuries. The third column represents moments created when the arm is projected horizontally to the side of the dummy and the elbow is in a locked position. The location of the maximum moment as recorded at the proximal or distal moment strain gage locations (Figure 2) is also noted.

The Hybrid III instrumented arm/RAID peak resultants for configuration V-1 through V-4 are listed in Table 5. For comparative purposes, only the first 20 msec of the Hybrid III arm data is considered here. This eliminated responses occurring due to dummy contact and thus provided a better comparison with the RAID.

For each of the following configurations some trends between the Hybrid III instrumented arm and the RAID data are evident. The peak resultant moments for the RAID configurations measured much higher and surpassed the IARV for both men and women in every case. On the other hand, the Hybrid III moment measurements surpassed the female IARV in each case, but less than half the time for male IARV. Since women seem to be the subject of arm injury more often than men, the above IARV may be suitable for the Hybrid III instrumented arm. Scaling factors would have to be applied to develop IARV specific to the RAID device.

The difference in wrist velocities can be accounted for by analyzing the differences in the two testing devices. The RAID velocities were recorded at values almost twice as high as Hybrid III instrumented arm values. This is most likely due to the difference in the weight and set up of the two different test devices. As the air bag deployed, the Hybrid III forearm generally moved while the upper arm remained stationary. This allows us to contribute higher accelerations in the Hybrid III testing to the mass of the lower arm being less than that of the RAID. This difference in weight would produce the different accelerations experienced by each of the test devices.

The difference in results can also be attributed to different kinematics between the two systems. The Hybrid III arm cannot move freely in any direction because its motion is dependent on the movement of the rest of the dummy. If the arm is moving, the elbow and upper arm and body will restrict some of its motion while also moving backwards to absorb some of the initial force from the air bag. On the other hand the RAID is attached to an immobile support so the arm reacts to all of the force applied to it.

Despite the difference in kinematics some parallel conclusions do exist in the air bag assessment rating between the Hybrid III instrumented arm and the RAID. The RAID and the Hybrid III arm device ranked configurations V-2 and V-3 exactly the same while V-4 was able to differentiate between the most and least aggressive bags. For configuration V-1 the air bag ratings were very similar. The L-92 and the J-95 bags were found to be the least aggressive bags while the

K-93 and the H-91 were found to be the most aggressive bags. The evaluation methods used to assess the air bags used with the Hybrid III arm were not stringent. The Hybrid III arm tests were ranked by the magnitude of the resultant moments, accelerations and velocities. For example, the bag with the highest resultant moment was ranked #4, or most aggressive. The bag with the lowest moments and accelerations was ranked #1, or least aggressive. There is some ambiguity to the ranking system, and other parameters could slightly sway the ranking of the bags. Nevertheless, the two systems were able to accurately differentiate between the most and least aggressive systems.

FLEET AIR BAG RESULTS

The fleet air bag testing was conducted on 1994 and 1996 systems. For three of the systems, tests were conduced on both 1994 and 1996 models, while the remaining units were tested only for the 1996 model. The 1994 and 1996 model year air bag module performances were compared to assess improvements. In the charts which follow, the injury reference ranges for the male (Male IC, M-Max IC) and female (Female IC, F-Max IC) IARV are indicated by the straight horizontal lines.

Fleet Vehicles in Position V-1

The charts that follow show the peak resultant moments for the fleet vehicles in the V-1 position. Figure 8 depicts the improvement between the A, F and E, 1994 and 1996 air bags. Each vehicle's aggressiveness improved in the more recent model year. The 1994 models all surpassed the peak male IARV while the 1996 model year was decreased. The E vehicle's moments had the most dramatic reduction form 1994 to 1996, but still exceeded the female IARV.

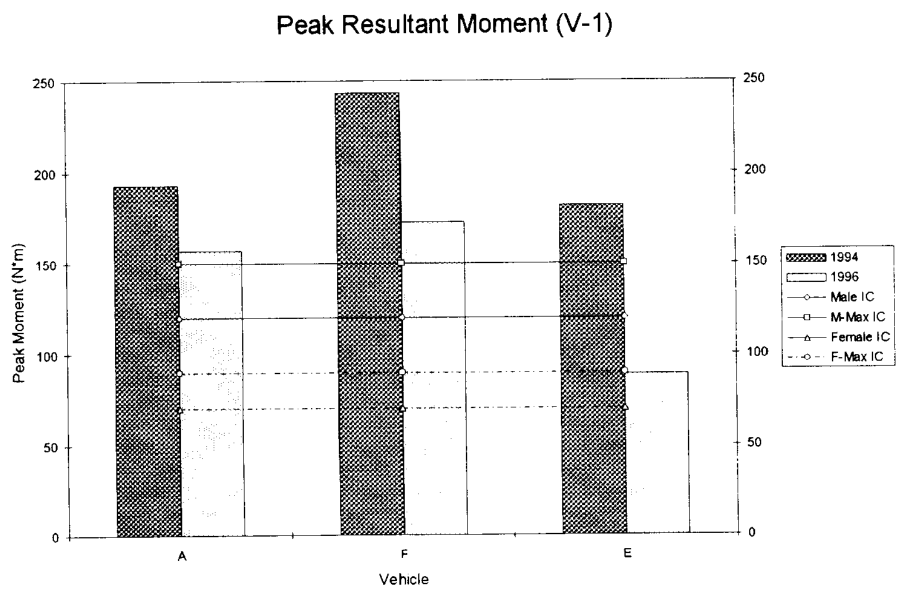

Figure 8--1994, 1996 Fleet Air Bag Comparison in the V-1 Configuration

The other vehicle performances ranged from very aggressive (exceeding the peak male criteria) to non-aggressive (not exceeding the lowest female IARV). As seen in Figure 9, the G-96 and the H-96 both surpassed the IARV substantially while the I-96 and the D-96 fell within the maximum male IARV. The B-96 moments created during the test did not exceed either the male or female IARV.

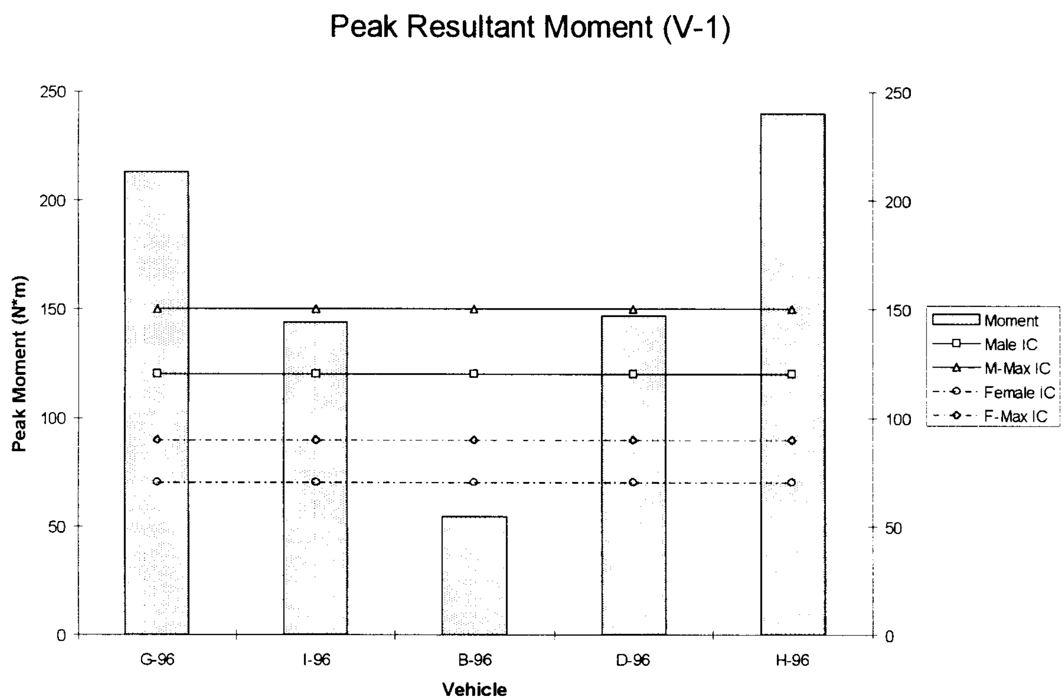

Figure 9--1996 Fleet Air Bag in the V-1 Configuration

Fleet Vehicles in the V-3 Position

The following results show the Fleet air bags in the V-3 position. As illustrated by the bar graphs (Figures 10 & 11), this is a much more severe position than the V-1 position. Figure 10 indicates a significant improvement for the 1996 model year air bags. The 1994 model year air bags all exceed the peak male IARV. The 1996 model year air bags for these three models all registered slightly within the male injury range or midway between the maximum and minimum female IARV. The remaining 1996 air bag systems all exceeded both the male and female IARV as shown in Figure 11.

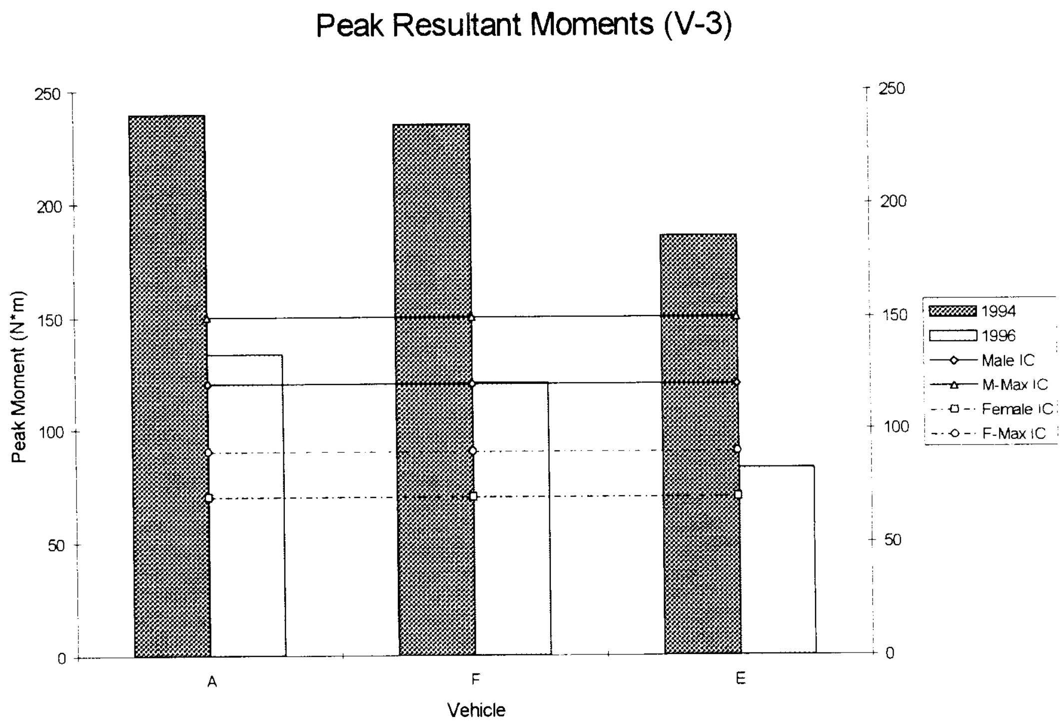

Figure 10--1994, 1996 Fleet Air Bag Comparison in the V-3 Configuration

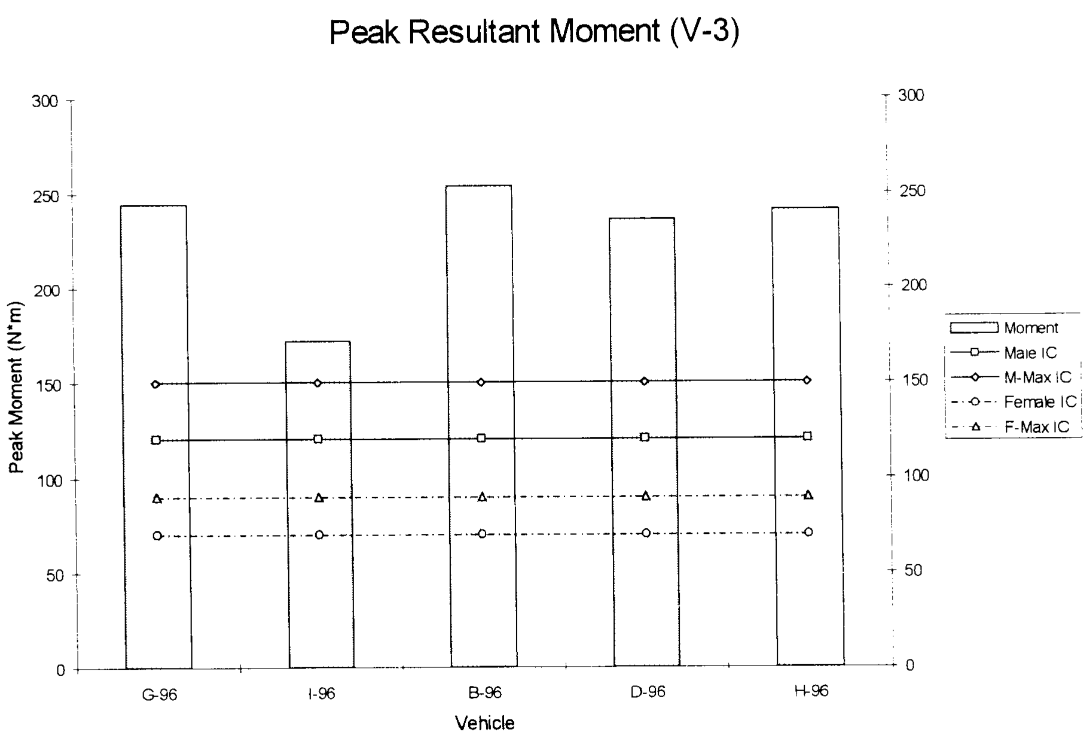

Figure 11--1996 Fleet Air Bag in the V-3 Configuration

REPEATABILITY

Configuration V-1

The following tests were done to demonstrate consistency in the test results for a given test configuration. Four tests were run using the same air bags, configuration and set up. The dummy was placed in the V-1 position, with its arm in the 11 o'clock and 4 o'clock position. The steering wheel was rotated 90° CCW. Table 7 describes the events seen on film.

Table 7--Film Review (Repeatability)

Vehicle	Film Comments
J-95 Test #1	Thumb under wheel Arm thrown to side, no contact
J-95 Test #2	Thumb under wheel Wrist brushes chin then goes off to side
J-95 Test #3	Thumb under wheel Arm thrown to side, no contact
J-95 Test #4*	Thumb over wheel Arm thrown to side, no contact

Table 8 shows the magnitude of the resultant accelerations for the four J-95 repeatability tests. The first three tests were performed with the thumb placed under the steering wheel. In order to check the effect of the thumb position on the wheel, test #4 was conducted with the dummy's thumb placed above the wheel. There was no significant difference in the data to indicate that the thumb affected the test results. Test #2 registered higher in most of the accelerations and the lower arm elbow resultant moment because the dummy's arm contacted the dummy's face during the test. In test #1, 3 and 4, the arm was thrown from the bag and the hand was very close to experiencing contact with the dummy's face and head. Therefore, any slight variation in the air bag or test set up could have caused the contact and was not considered in the repeatability aspect of the testing. For comparison, the point of contact was filtered out of the data in order to obtain a better comparison of the data. The following table reflects the moments with the contact point filtered out for Test #2, but the graphs of the moments do not. The point of contact was left in to show the magnitude and time at which it occurred.

The following graphs (Figure 12) show that the tests were very consistent with the exception of the moment created by contact in the second test. When the hand brushed the chin creating a moment at about 30 msec, an increase in the velocity can be noted on the graph. If this event were omitted from the analysis, the graphs of the distal and proximal moments and the velocity curves track each other very well. The distal moments all peak just before 10 msec and are all going back to zero by 20 msec. The proximal moments also peak before 10 msec and return to zero at the same times.

Table 8--Resultant Accelerations (Repeatability)				
Channel/units/ description	**J-95 Test #1**	**J-95 Test #2**	**J-95 Test #3**	**J-95 Test #4***
ARLRGL (g, msec) Wrist resultant	200.1 6.0	219.5 5.8	222.0 5.3	251.1 7.3
ARRML (Nm, msec) Lower arm midshaft resultant moment	23.2 8.3	21.9 10.3	33.0 8.5	21.2 9.3
ARRMU (Nm, msec) Lower arm elbow resultant moment	83.5 8.2	107.5 10.3	103.6 8.6	74.9 9.3
VELOCITY @ 15 ms (m/msec)	27.1	35.7	27.4	27.7

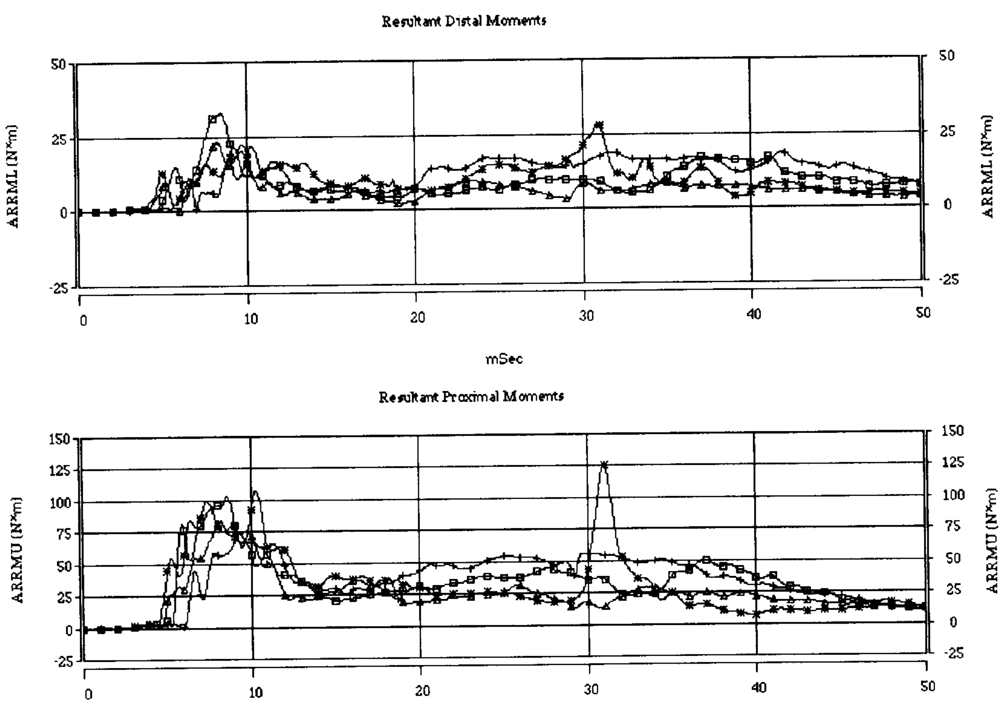

Figure 12--Proximal and Distal Moment Curves for J-95 Repeatability

DISCUSSION & CONCLUSIONS

The Hybrid III instrumented arm and the RAID were fairly consistent in differentiating between the severity of the different air bag systems. The RAID and the Hybrid III moments and velocities registered at different magnitudes, but each measured the same bags as having the highest moments at given velocities relative to the other systems. Both devices recorded the K-93 and the H-91 as the bags with the highest peak moments and the J-95 and the L-92 with the lowest peak moments. A moment vs. velocity scatter graph was used to portray the severity of each air bag system as measured by the Hybrid III (Figure 13) and RAID (Figure 14) devices. Each air bag model and year labels are preceded by its configuration designation (for example, J-95 in the V1 position is designated V1-J-95). The K-93 and H-91 were found to be the most severe air bags in the V-3 position, since they measured both the highest moments and velocities. In addition, the graphs also show that each device was able to correlate the severity of the moment with the velocity. Both graphs show a somewhat linear relationship between an increase in velocity and an increase in the moment recorded.

Both the Hybrid III and RAID devices recorded moments and accelerations resulting from deployment of the air bag systems. The Hybrid III was also able to detect moments created when the arm contacted the dummy's head, neck or chest. The RAID could assess severity of the bag based solely on the moments and accelerations applied by the air bag and could not account for any injury potential resulting from contact.

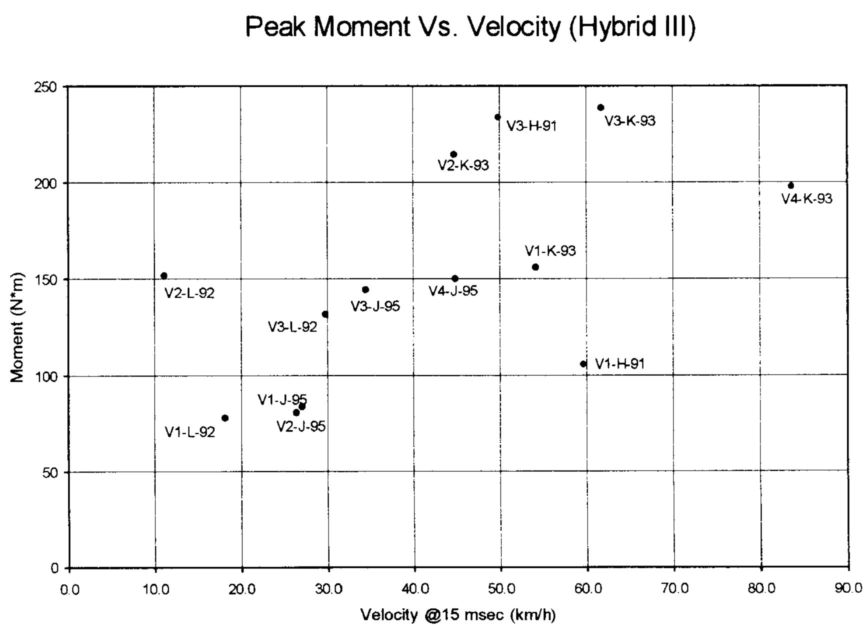

Figure 13--Hybrid III Moment Summary

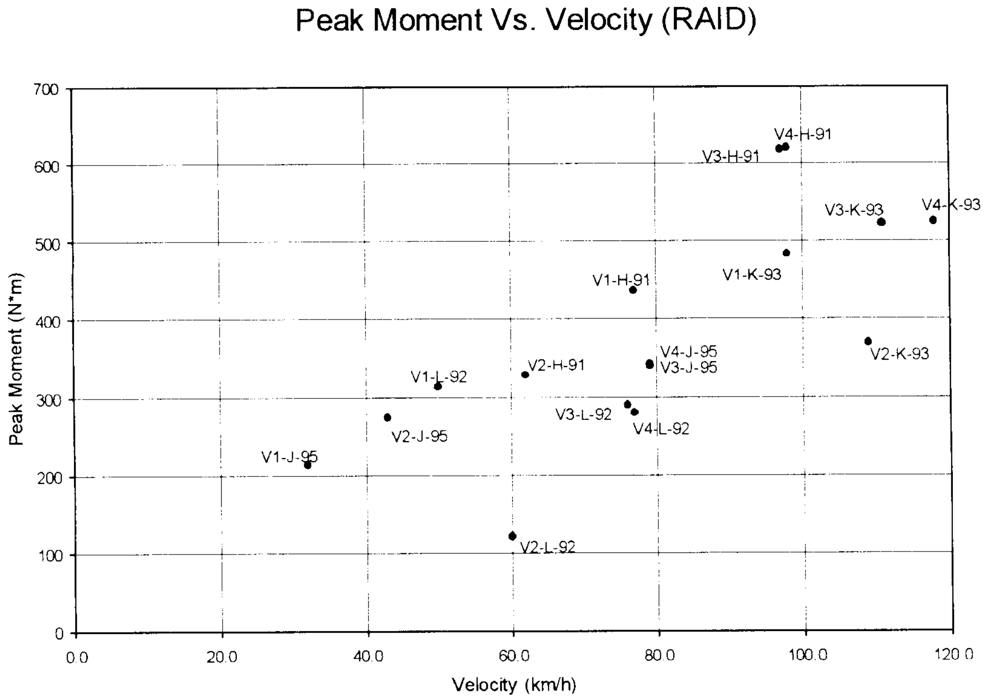

Figure 14--RAID Moment Summary

The RAID and the Hybrid III did not share the same kinematics, therefore, the moment and velocity magnitudes differed from each other. The RAID was an aluminum structure which made it somewhat lighter (3.25 kg) than the Hybrid III arm (4.54 kg), and connected at a joint acting as the elbow. The Hybrid III was heavier and was able to move at the elbow and the shoulder. The Hybrid III movement was also governed by the dummy which played a role in how the arm moved and inevitably created different moments and velocities than the RAID.

The Hybrid III moment measurements were the same order of magnitude as the proposed IARV. The Hybrid III testing mostly exceeded the female injury IARV of 70-90 N*m, but not always the male IARV of 120-150 N*m. The RAID moments registered rather high, and would have implied a high likelihood of forearm fracture in all systems for both male and females. However, since IARV are device-specific, different values would need to be determined for use with the RAID.

Based upon these results, the Hybrid III instrumented arm was selected for testing of fleet air bag systems. While both the RAID and Hybrid III devices appeared capable of distinguishing air bag deployment severities, the Hybrid III device offered two advantages over the RAID. First, the Hybrid III device provided the potential for assessment of arm interaction with the occupant and vehicle interior which was more realistic than the RAID. Secondly, the moment measured with the Hybrid III was of generally the same magnitude as the proposed arm IARV. This was felt to be more consistent with the available accident data.

ACKNOWLEDGMENTS

Our recognition goes to Ken Welty and Rob Jacobs for test set up, Herman Jooss for photography, and Gerda England for AutoCAD drawings. Our thanks also extends to Conrad Technologies Inc., for their cooperation and communication with us throughout the initial stage of this program.

REFERENCES

1. Conrad Technologies Inc., Personal Communications and Internal Correspondences, 1996.

2. Saul, R. A., et al., "Hybrid III Dummy Instrumentation and Assessment of Arm Injuries During Air Bag Deployment," SAE Paper No. 962417, Fortieth Stapp Car Crash Conference, 1996

3. Huelke, D. F., et al.,"Upper Extremity Injuries Related to Airbag Deployments," The Journal of Trauma: Injury Infection, and Critical Care, Vol. 38, No. 4, Pages 482-488, Williams & Wilkins, 1995

4. Kuppa, S. M., et al., "RAID-An Investigative Tool to Study Air Bag/ Upper Extremity Interactions," SAE International Congress and Exposition, SAE Paper No. 970399, 1997

DISCUSSION

PAPER: **Airbag Evaluation Using an Instrumented Hybrid III Arm**

PRESENTER: Dan Rhule, Transportation Research Center

QUESTION: Risa Scherer, Ford Motor Company
In your presentation, you are showing injury criteria for a small female but you are testing with the 50th arm.

ANSWER: Right.

Q: Shouldn't you be using a 5th arm instead?

A: That's a good question. I don't really know how to answer that. I guess we just developed one arm to do the testing and compared those values to the proposed injury criteria. You have an excellent point. They're probably should be different biomechanical size arms, one for the 5th and one for the 95th.

Q: Guy Nusholtz, Chrysler Corporation
The new injury mechanism (I think we've seen that in the field), where the arm comes back and strikes so that's not exactly a new phenomena that is occurring. The question is: "how do you determine what is from inertial loading and what is from punch out?" Is that due to when it happens in time?

A: Yes, the timing. Just looking at the timing and reviewing the film. The inertial loading occurred well beyond any contact with the bag. If you saw the picture, the inertial loading occurred when the arm was about to here.

Q: So that's related to how the elbow is interacting with the arm?

A: Exactly.

Q: How have you checked the biomechanics of the elbow in this particular device?

A: It is a Hybrid III arm and if the Hybrid III elbow is biomechanically correct .....

Q: IF the Hybrid III elbow goes back biomechanically correct?

A: Yes, that is what I said. Maybe I didn't say the "if" loud enough. Big "IF".

Q: OK. Thank you.

Q: Larry Schneider, UMTRI

I have a question about the injury criteria and the location of your maximum moments. I think you show the maximum peak moments at the proximal end of the arm and yet don't we see most of the injuries at the distal end of the radius.

A: That's a good question. Roger Saul did the review of the Yamada data to come up with the injury criteria so I couldn't answer that.

Q: So, I think you have to be cautious about comparing these proposed injury criteria levels for males and females which again may be based upon mid-shaft bending moments or whatever with the results we are getting from a dummy arm.

A: Right.

Q: (unknown speaker)

I have one question. Did you do any distance variation on your test as Mitch did in RAID because some injury was caused by initial punch out but is that because of the cover contact with arm or is that because of airbag deployment?

A: My understanding is that it was due to contact with the cover but I don't really have the answer for that question. Sorry.