CRASH TESTS TO RECONSTRUCT NASS CASES OF CHILD FATALITY/INJURY FROM AIR BAGS

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ABSTRACT

This research program attempted to reconstruct cases from the National Automotive Sampling System (NASS) in which children, not in child seats, had been killed or seriously injured because of the deploying air bags and cases where there was minor injury with air bag deployment. The main objective was to compare injury measures from an instrumented child dummy to the actual injuries suffered by children in crashes and determine if a mathematical relationship exists between body region AIS level on the children and corresponding measures on the dummy. A secondary objective was to evaluate injury measures on the 5th percentile Hybrid III in the driver position, not necessarily as a simulation of the crash event. This paper presents the results of the test program and the comparison of measured dummy reponses to the actual occupant injuries in the crashes from the selected NASS cases.

INTRODUCTION

Cases from the NASS Special Crash Investigations (SCI) where children had been killed and the cause of death was attributed to air bag deployment were selected for reconstruction. In addition, cases of children with less severe injuries in a seating location with an air bag deployment were selected from the NASS Crashworthiness Data System (CDS.) In all cases the children were about 5 to 7 years old and were not in child safety seats. It was desired to select child passenger injuries of all levels, MAIS 1 through 6, hopefully, to allow for a wide range of dummy injury measures for comparison in the subsequent testing. The main objective of the comparison of injury measures from instrumented child dummies in tests to the actual injuries suffered by children in crashes is to determine if a relationship exists between body region AIS level on the children and corresponding measures on the dummy. A secondary objective is to evaluate injury measures on the 5th percentile Hybrid III in the driver position, not necessarily as a simulation of the crash event. The crash test program was conducted by Calspan Corporation in Buffalo, New York.

Six NASS cases were selected for simulation: specifically, the child passenger kinematics and interaction with the passenger air bag. It was desired that the selected case children injuries represent a range of AIS levels which may provide a mathematical relationship discussed above. The selection of cases was also limited to those in which the child was approximately the age, size and weight of the six-year-old Hybrid III test surrogate (48 pounds and 47 inches.) As shown in Table 1 all injured children were between 5 to 7 years old; however there was some variance in height and weight. It was felt however that the 6-year-old Hybrid III dummy would provide a reasonable representation of the children's kinematics and interactions with the deploying air bag.

CASE DESCRIPTIONS

The six NASS cases selected are shown below (3 child fatality cases are SCI, and 3 NASS-CDS cases, one with MAIS 3, and 2 with MAIS 1 level):

NASS Case	Outcome	Highest AIS
SCI 95-21	Fatality	5 - Brain
SCI 95-23	Fatality	5 - Brain
SCI 93-07	Fatality	5 - Brain, Neck*
95-43-154J	Serious Injury	3 - Brain
95-74-126J	Minor Injury	1 - Face
95-04-40E	Minor Injury	1 - Face

*Neck tension most probably caused brain stem injury

The descriptions of the occupants, seating positions, impact velocities and injuries, comparing the NASS case with the test are found in Tables 1 through 4. A short narrative of each NASS case is given below.

Case SCI 95-21 - A 1995 mini-van (subject vehicle) impacted the left side of a 1992 full size passenger car at about 9 o'clock and impact speeds of about 30 to 35 kmph on each vehicle. The seven-year-old female passenger, wearing only the lap belt portion of the belt system, was on the edge of the seat and was thrown forward due to pre-crash braking into close proximity to the deploying air bag. The driver was not injured.

Case SCI 95-23 - A 1993 mid-size passenger car (subject vehicle) rear impacted a stopped 1990 full size passenger car with about 50 percent left overlap on subject car and impact speed of about 29 kmph. The unbelted five-year-old female passenger was sitting normally in the seat and was thrown forward into close proximity to the deploying air bag due to pre-crash braking.

Case SCI 93-07 - A 1993 mid-size passenger car (subject vehicle) rear impacted a stopped 1986 subcompact passenger car with about 75 percent left overlap on the subject car and an impact speed of about 21 kmph. The six-year-old unbelted female passenger was sitting normally in the seat and was thrown forward due to pre-crash braking (ABS) into close proximity to the deploying air bag.

Case NASS-CDS 43-154J - A 1995 full size passenger car (subject vehicle) impacted the left side of a 1991 compact passenger car at about 9 o'clock and impact speeds of about 24 kmph on the subject vehicle and 19 kmph on the other vehicle. The five-year-old unbelted male passenger was sitting normally in the seat and was thrown forward due to pre-crash braking into close proximity to the deploying air bag.

Case NASS-CDS 74-126J - A 1995 subcompact passenger car (subject vehicle) impacted the left, front side of a 1994 full size passenger car at 9 o'clock and impact speeds of 43 and 24 kmph on the subject and other vehicle, respectively. The seven-year-old belted female passenger was seated normally and was essentially in this position at time of air bag deployment.

Case NASS-CDS 04-40E - A 1994 subcompact passenger car (subject vehicle) impacted the front of a 1987 subcompact passenger car at impact speeds of 24 and 67 kmph on the subject and other vehicle, respectively. The five-year-old belted female passenger was sitting normally in the seat and, although there was pre-impact braking, she was essentially in this position at time of air bag deployment.

TEST CONDITIONS

The driver position in the tests was occupied by an instrumented 5th percentile, female Hybrid III dummy. These were not to be simulations of the driver crash event but to give additional information on the 5th percentile dummy injury responses when interacting with an air bag. However, as it turned out some of the drivers in the NASS cases could, possibly, be represented by the 5th percentile, female Hybrid III dummy. A comparison of characteristics of test dummies and occupants of the selected NASS cases are shown in Table 1, with a judgement on whether the dummy was an adequate representation of the occupant. The driver dummies were positioned and restrained as described in the NASS case reports for all but case 1 (NASS-SCI-95-21.)

The specific make/model vehicles, impact angles and relative location of initial impact were replicated as described in the NASS case reports for the staged crash tests, except for test 4 (NASS-CDS-43-154J.) The schematic in this case report presented the impact as into the A-pillar/door of the struck vehicle; however, from the photographs it appeared that the A-pillar and door were virtually undamaged. Thus, the initial impact location was moved forward to replicate the photographic evidence.

In most cases the recorded impact velocities appeared too low to produce velocity changes sufficient to deploy the air bags. To provide a higher likelihood for air bag deployment, the target test velocities were slightly higher than reported in the NASS cases; however, an electronic firing circuit was also installed to induce deployment if the vehicles sensing system did not trigger deployment. The time to deployments were estimated based on the crash conditions and the switch for firing was set to a somewhat later time to give the vehicle sensor system the opportunity to fire before inducing deployment. It was necessary to induce deployment in 3 of the 6 crash tests. The Contractor's tow system configuration is able to develop velocities of one vehicle moving and one stationary or velocity ratio's of 1:1, 1:2 or other integer multiples at almost any angles of impact. Thus, if the two vehicles velocities are not in these ratios the closest ratio is used and the desired closing velocity is simulated (Table 3).

In the first 4 reconstructed NASS cases, the child passengers suffered serious or fatal injuries due to being in close proximity to the air bag at the time of deployment. These cases all involved pre-crash braking. Development of methods for simulating pre-crash braking were beyond the scope of the program. The NASS-SCI reports provide likely scenarios of the occupants motion throughout the crash event and this information was used to position the child at the time of impact for the first 3 SCI cases. NASS-CDS cases do not contain this level of detail on occupant motion; however a variable "posture" is given which describes how the occupant was seated prior to the crash. For case 4 (95-43-154J), the posture was listed as "unknown," but was assumed to be "normal" before braking; however, due to braking it was assumed that the unbelted child moved forward and was on the edge of the seat, a few inches from the instrument panel at initial impact. The last two cases were children who were properly belted and it was assumed that they were in essentially a "normal" seating position and posture at time of impact as was the assumption with all driver 5th percentile female dummies in the tests.

In the first test the child dummy was initially positioned forward in the seat and held in place by heavy fishing line which was to be cut at time of impact. During "run-up" the pull force of the towing system was erratic causing jostling of the dummy and eventually breaking the fishing line. Thus, at time of impact, not only was the impact velocity too high but the child passenger dummy was back in the seat in a position not simulating the child's position in the NASS crash. Because of the high speed and the position of the dummy this test was considered an invalid simulation for the child passenger. For the remaining tests the tow system performed more smoothly and steel wire was used to more securely position the dummy, and it appeared that the child dummy crash kinematics and position were probably a good representation of the NASS crash event.

TEST RESULTS

The maximum values of the recorded injury measures for each test and the corresponding case AIS levels for neck, head and chest are shown in Table 4 and graphically shown in Figures 1 through 6. None of the figures for the child passenger show a strong relationship between reported NASS injuries and recorded test measures. In general, the recorded injury measures in the test appeared higher than would be expected for the reported NASS injuries, especially on the neck for both the driver and passenger. The current injury assessment reference values (IARV's) for head, chest and neck are shown in Table 5 (NHTSA Report, "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems", National Transportation Biomechanics Research Center, April 1998.).

6-Year-Old Child Dummy Results - Of the valid cases, the only serious or greater neck injury in the table (AIS 5 in NASS case CA93-07) was not listed in the case report but was assigned based on the mechanism of the type of brain injuries suffered by the child. Tension in the cervical spine could pull on the brain stem and cause the injuries listed. Relating NASS case injuries to neck tension shows minor injury up to about 3500 newtons and then AIS 5 at about 6000 newtons; however, in test 4 (case 43-154J) the 6-year-old child dummy experiences a tension of about 5500 newtons with no reported neck injury in the simulated case (Figure 1.) Extremely high flexion moments were experienced on the 6-year-old child dummy in three of the four valid simulation tests (from about minus 180 to minus 280 newton-meters or 4.5 to 7 times the IARV) with minor neck injury in two of the NASS cases but an AIS 5 in the third (Figure 2.) Head injury appears to show an expected trend; however, the child dummy with the highest HIC (1866) had the third highest head AIS in the corresponding NASS cases. Unlike the neck injury measures, which appear to be magnitudes higher than the corresponding NASS injury outcomes, the head injury measures appear to be in the "ball park" of the actual injuries, i.e., HICs from about 800 to 1900 corresponding to head AIS$\geq$3 (Figure 3.)

The agency is currently developing an injury criteria for the neck which combines the normalized forces and moments into a single indicator of neck injury.

Table 5.
Injury Assessment Reference Values for Body Regions

Body Region	Injury Criteria	6-Year-Old Child Dummy	5th-Percentile Female Dummy
Head	HIC (36 ms clip)	1000	1000
Chest	G's V*C (m/sec) [1]	65 1	60 1
Neck	Tension+ (N) Compression- (N) Flexion+ (N-M) Extension- (N-M)	3000 3000 140 40	3200 3200 210 60

[1] **V*C = Max. {1.3*V*[δ/(chest depth)]}**; where δ is chest deflection and V is sternum to spine velocity

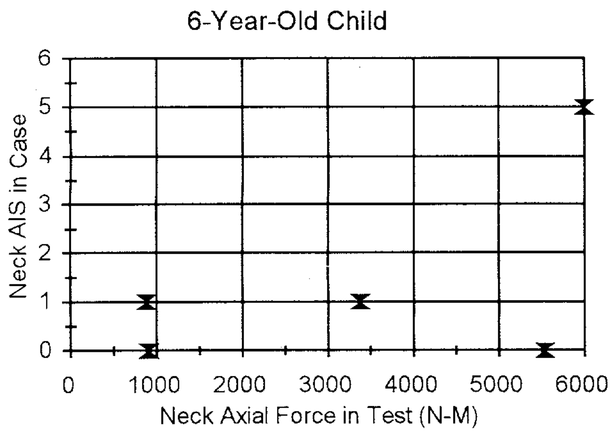

Figure 1. Neck Axial Force (Test) vs. Neck AIS in Case.

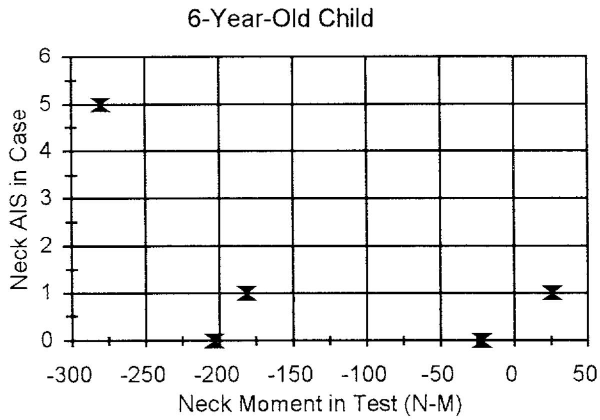

Figure 2. Neck Moment (Test) vs. Neck AIS in Case.

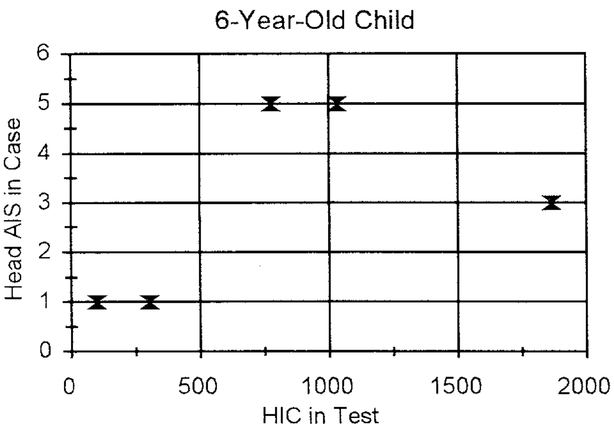

Figure 3. HIC (Test) vs. Head AIS in Case.

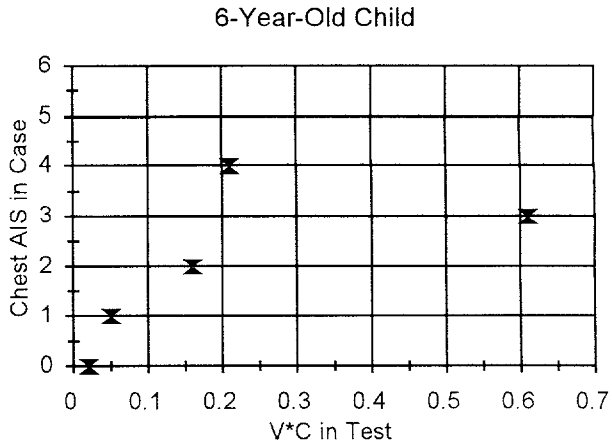

Figure 4. V*C (Test) vs. Chest AIS in Case.

The measure V*C is selected as the indicator of chest injury for the child dummies especially for out-of-position dummies where "blast" loadings occur. There appears to be a "weak" relationship between chest AIS and V*C from Figure 4; however, all values of V*C were relatively low and not indicative of the actual injury levels in the cases. Chest AIS was well distributed among the five NASS cases with an AIS 4, 3, 2, 1 and 0.

__5th Percentile Female Dummy Results__ - All drivers in the NASS cases were either uninjured or suffered minor injuries, except case 5 (74-126J, Table 4.) The 5'4", 140 pound female in this case suffered an AIS 5 chest injury. However, for comparison, the chest G's and V*C in the test with similar restraint and position but a smaller dummy, were low (Chest G's of 29 and V*C of 0.3.) Since the test surrogate for the driver may not be a reasonable simulation of the NASS case driver, the driver tests should generally be viewed simply as evaluation tests of the 5th percentile female dummy interactions with air bags.

Except for neck moments, and one borderline neck tension, all injury measures on the 5th percentile female dummy in the tests were well below the IARV's shown above (the maximum HIC was 290 and chest G's were 29.) The driver dummy neck extension moments in two of the tests were magnitudes higher than the IARV of -60 newton-meters: the dummy experienced -156 newton meters in test 1 and -194 newton-meters in test 3 (Figure 6.) The dummy in test 2 also experienced a high neck

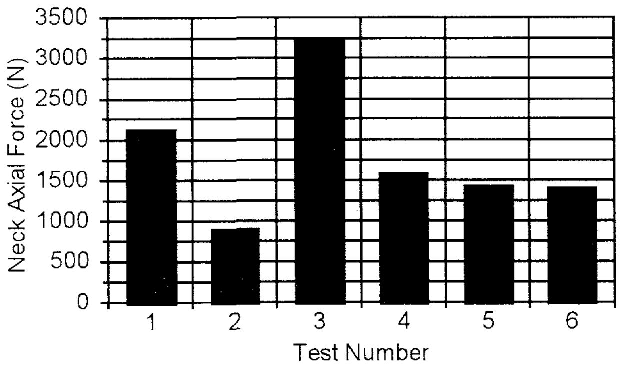

Figure 5. Neck Axial Force (Test) vs. Neck AIS in Case.

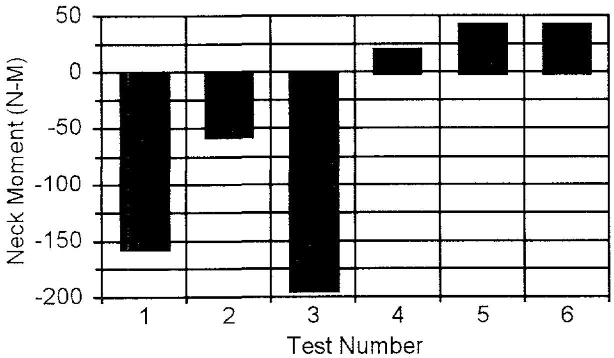

Figure 6. Neck Moment (Test) vs. Neck AIS in Case.

extension moment of 57 newton-meters. In tests 1, 2 and 3 the 5th percentile driver dummies were normally seated with the seat forward. Lap/shoulder belts were used in tests 1 and 2 and no belts were used in test 3.

CONCLUSIONS

Neck injury measures on 6-year-old child Hybrid III dummies in the tests were not always consistent with injuries to children of similar age and size in the selected NASS cases simulated by the tests. The simulation of the child with the highest neck injury (AIS 5) produced the highest neck extension moment (-280.0 newton-meters) and neck tension (6000 newtons) on the 6-year-old child Hybrid III dummy (SCI CA93-07, test 3.) However, one case (NASS 43-154J, test 4) reported no neck injury to the child but the neck injury responses on the 6-year-old child Hybrid III dummy were well above the IARV's for the neck: 5534 newtons neck tension and 204 newton-meters neck extension moment.

As discussed above no neck injury was reported in NASS case CA93-07 but was assigned an AIS 5 based on the mechanism of the type of brain injuries suffered by the child. This may also be true in some of the other cases of head injury where neck loading may directly, or indirectly, contribute to the brain injury. However, information to reach this conclusion was not evident in the other NASS reports.

The 5th percentile female Hybrid III dummy was placed in the driver position in the tests to evaluate the interaction with the air bag, and not, necessarily, as a simulation of the driver in the NASS case crash event. However, since several of the drivers were female, the NASS reported restraint, seat position and posture were simulated for the corresponding crash test. All injury measures on the 5th percentile female Hybrid III dummy were fairly benign, except with regard to neck injury and specifically neck flexion moments. In two of the tests the IARV's for neck flexion moment were exceeded and in one test the neck tension IARV was marginally exceeded, with the neck flexion moment being much higher than the IARV in two of the tests.

Table 1.
Comparison of Test Dummy to Case Occupant Sizes

	Driver		Passenger		Valid Simulation of Occupant Size?	
Test # NASS Case	**Driver Dummy**	**Case Driver**	**Passenger Dummy**	**Case Child Passenger**	**Driver**	**Passenger**
1 SCI 95-21	5th% Female 4'11", 105 lbs	45 year-old male, 6'2", 173 lbs	6-year-old Child, 3'11", 48 lb's	7 year-old female, 4'3", 55 lbs	N	Y
2 SCI 95-23		33 year-old female, 5'6", 170 lbs		5 year-old female, 3'"10", 45 lbs	N	Y
3 SCI 93-07		34 year-old female, 5'0", 90 lbs		6 year-old female, 3'8", 51 lbs	Y	Y
4 95-43-154J		40 year-old female, 5'4", 130 lbs		5 year-old male, 3'4", 41 lbs	?	Y
5 95-74-126J		34 year-old female, 5'4", 140 lbs		7 year-old female, 4'0", 71 lbs	?	Y
6 95-04-40E		44 year-old female, 5'6", 165 lbs		5 year-old female, 4'0", 65 lbs	N	Y

Table 2.
Comparison of Test Dummy to Case Occupant Seating Positions and Belt Use

Test # NASS Case	Braking?	Occupant Position	Pre-Impact or Pre-Braking: Case Driver	Pre-Impact or Pre-Braking: Case Passenger	@ Impact/Post-Braking: Test Driver	@ Impact/Post-Braking: Test Passenger
1 SCI 95-21	Y (ABS)	**Posture**	Normal	Vertical	Normal	20° forward
		Seat Pos.	Rear	Rear	Forward	Rear
		Occupant Pos.	Normal	Legs over seat	Normal	Edge of seat
		Belt Use	L/S Proper	Lap only	L/S Proper	Lap only
2 SCI 95-23	Y (12')	**Posture**	Normal	Normal	Normal	Vertical
		Seat Pos.	Forward	Mid	Forward	Mid
		Occupant Pos.	Normal	Normal	Normal	Edge of seat
		Belt Use	L/S Proper	None	L/S Proper	None
3 SCI 93-07	Y (ABS)	**Posture**	Normal	Normal	Normal	Vertical
		Seat Pos.	Forward	Mid	Forward	Mid
		Occupant Pos.	Normal	Normal	Normal	Edge of seat
		Belt Use	None	None	None	None
4 95-43-154J	Y (7')	**Posture**	Normal	Unknown	Normal	Vertical
		Seat Pos.	Mid/Fwd.	Mid/Fwd.	Mid/Fwd.	Mid/Fwd
		Occupant Pos.	Normal	Normal	Normal	Legs over seat
		Belt Use	L/S Proper	None	L/S Proper	None
5 95-74-126J	N	**Posture**	Normal	Normal	Normal	Normal
		Seat Pos.	Mid/Fwd.	Mid/Fwd.	Mid/Fwd.	Mid/Fwd.
		Occupant Pos.	Normal	Normal	Normal	Normal
		Belt Use	L/S Proper	L/S Proper	L/S Proper	L/S Proper
6 95-04-40E	Y (ABS)	**Posture**	Normal	Normal	Normal	Normal
		Seat Pos.	Mid/Rear	Rear	Mid/Fwd	Rear
		Occupant Pos.	Normal	Normal	Normal	Normal
		Belt use	L/S Proper	L/S Proper	L/S Proper	L/S Proper

Table 3.
NASS Reported Crash Speeds and Crash Test Speeds

Test # (Case #)	NASS Impact Speed (KPH): Vehicle 1	NASS Impact Speed (KPH): Vehicle 2	Crash Test Speed (KPH): Vehicle 1	Crash Test Speed (KPH): Vehicle 2	Configuration	Type of Deployment
1 (SCI 95-21)	35	32	47	47	Front-left	Normal
2 (SCI 95-23)	29	0	39	0	Front-rear	Normal
3 (SCI 93-07)	21	0	28	0	Front-rear	Induced
4 (95-43-154J)	24	19	29	29	Front-left	Induced
5 (95-74-126J)	43	24	45	23	Front-left	Induced
6 (95-04-40E)	24	67	24	72	Angle front-front	Normal

Table 4.
Injury Responses in Tests Compared to NASS Case Injuries

	Case# (Test #)	HIC	Neck Tension (N)	Neck Moment (N-M)	Neck Shear (N)	VC (M/S)	Chest G	Maximum AIS Levels			Comments
								Neck	Head	Chest	
Child Passenger	**CA95-21 (1)**	56	-585	32.8	-374	0.12	20.8	3	5	4	Invalid speed, dummy position
	CA95-23 (2)	776	3374	-181.8	2932	0.61	49.9	1	5	3	
	CA93-07 (3)	1034	6000	-280.0	4512	0.21	16.9	5*	5	4	*Neck tension caused brain injuries
	43-154J (4)	1866	5534	-203.9	3883	0.16	34	0	3	2	
	74-126J (5)	100	879	25.8	438	0.02	29.1	1	1	0	
	04-40E (6)	302	904	-22	507	0.05	47	0	1	1	
Driver	**CA95-21 (1)**	200	2119	-155.9	1849	0.13	24.7	0	0	0	Invalid speed, dummy size
	CA95-23 (2)	38	897	-57.3	622	0.04	10.2	0	0	0	Invalid dummy size, 5'6", 170# F.
	CA93-07 (3)	290	3222	-194.2	3106	1.99	29	0	1	1	5', 90#, F
	43-154J (4)	23	1571	20.8	272	0.12	13	0	1	0	? dummy size, 5'4", 130#, F
	74-126J (5)	104	1420	42.3	657	0.3	26.7	0	0	5	? dummy size, 5'4", 140#, F
	04-40E (6)	108	1395	-42	-548	0.06	41	1	0	1	? dummy size, 5'6", 165# F.