



# Advanced Restraint Systems (ARS) Final Report

## Appendices

*CAMP*

*Advanced Restraint Systems*



Mercedes-Benz

*Advanced Restraint Systems*

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16. Abstract This report presents a summary of the work performed during the Advanced Restraint Systems (ARS) project. The primary objective of this effort was to evaluate the potential benefit of using pre-crash information associated with two unique crash configurations (one vehicle-to-vehicle scenario and one vehicle-to-object scenario) to tailor an advanced restraint system to the occupant and crash type. The project work encompassed the CAE analysis of these two crash modes, as well as the identification, development, integration and physical evaluation of a prototype advanced restraints system within a targeted baseline vehicle environment. For each mode, injury assessments were made for the small, mid-size and large driver and passenger occupants in either a combination of CAE and vehicle testing or with solely CAE analysis. With 3 different occupants and 2 crash modes at 2 different speeds, 24 different "load cases," 12 for the driver and 12 for the passenger, were studied. This project was conducted by the Crash Avoidance Metrics Partnership (CAMP) ARS Consortium (Ford Motor Company, General Motors and Mercedes-Benz).			
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## Foreword

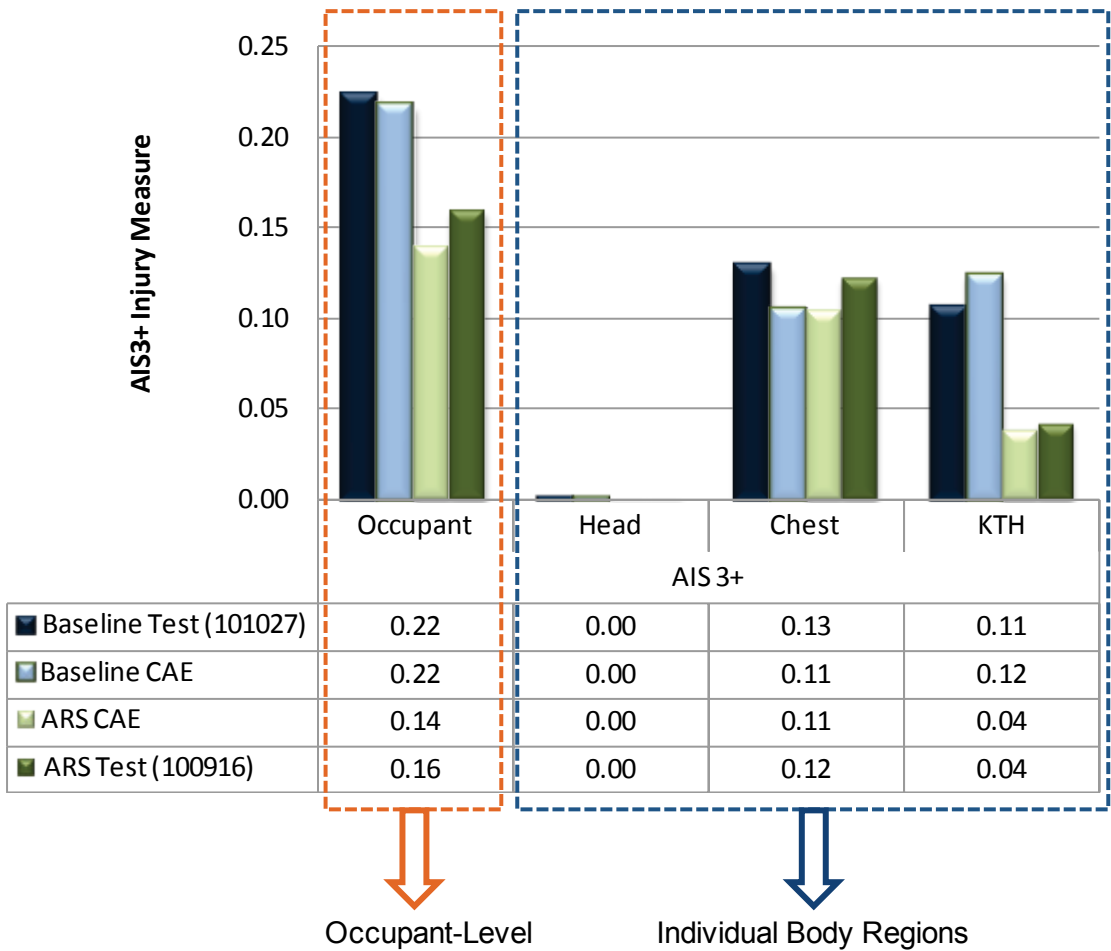
The primary objective of the ARS Project was to evaluate the potential benefit of using pre-crash information associated with two unique crash configurations (one vehicle-to-vehicle scenario and one vehicle-to-object scenario) to tailor an advanced restraint system to the occupant and crash type. The project work encompasses the CAE analysis of these two crash modes, as well as the identification, development, integration and physical evaluation of a prototype advanced restraints system within a targeted baseline vehicle environment. For each mode, injury assessments made for the small, mid-size and large driver and passenger occupants in either a combination of CAE and vehicle testing or with solely CAE analysis. With 3 different occupants and 2 crash modes at 2 different speeds, 24 different “load cases,” 12 for the driver and 12 for the passenger, were studied.

The Appendices that follow - organized according to occupant size - provide the key data used to compare the performance of the advanced restraint system to that of the baseline PVP restraint system for each of the 24 load cases examined during the project. Appendix A pertains to the 5th percentile female, Appendix B to the 50th percentile male, and Appendix C to the 95th percentile male.

For each load case, the following information is provided:

- A table summarizing the recommended ARS configuration and deployment times determined through the CAE DOE optimization studies described in Section 7.6 of this report.
- A summary of peak ATD injury values measured in the vehicle tests (if applicable) and CAE analysis for both the baseline and advanced restraint systems.
- Plots of the AIS3+ and AIS2+ injury measures for the baseline and advanced restraint systems at the occupant level, as well as for individual body regions. An illustration is shown in the example plot on the following page. The y-axis values (titled “AIS3+ Injury Measure” in the example) were calculated based on the injury risk curve equations provided by NHTSA (Table 6) for the individual body regions (denoted along the x-axis as “Head,” “Chest,” and “KTH” in the example) and the combined Occupant Injury Measure (OIM) equations described in Section 4 (denoted along the x-axis as “Occupant”).

Please note that Table 6, Section 4 and Section 7.6 are located in the main body of the Final Report.



**Example Figure - Plot of AIS3+ Injury Measure Summary**

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## List of Acronyms

AIS	Abbreviated Injury Scale
ARS	Advanced Restraint System
ARSC	Advanced Restraint Systems Consortium
ATD	Anthropomorphic Test Device
CAE	Computer Aided Engineering
CAMP	Crash Avoidance Metrics Partnership
CDS	Crashworthiness Data System
CG	Center of Gravity
CMM	Coordinate Measuring Machine
DAB	Driver Air Bag
DLT	Dynamic Locking Tongue
DOE	Design of Experiments
EA	Energy Absorbing
FARS	Fatality Analysis Reporting System
FE	Finite Element
FEA	Finite Element Analysis
FLx	Female Lower Extremity
FMVSS	Federal Motor Vehicle Safety Standard
FSP	Front Seat Passenger
GES	General Estimates System
HIC	Head Injury Criteria
HIC15	Head Injury Criterion 15 ms
Hybrid III	Hybrid III (Anthropomorphic Test Device)
Hybrid III 5F	Hybrid III 5 <sup>th</sup> Percentile Female ATD
Hybrid III 50M	Hybrid III 50 <sup>th</sup> Percentile Male ATD
Hybrid III 95M	Hybrid III 95 <sup>th</sup> Percentile Male ATD
HSAB	Head Side Air Bag
HYGE	Hydraulically Controller Gas Energized
IARV	Injury Assessment Reference Value
IAV	Injury Assessment Value
IEA	Intelligent Energy Absorbing
IIHS	Insurance Institute for Highway Safety
IP	Instrument Panel

KAB	Knee Air Bag
LPT	Lap Anchor Pretensioner
LTAP-OD	Left Turn Across Path – Opposite Direction
MADYMO	MAthematical DYnamic MOdeling
MAIS	Maximum Abbreviated Injury Scale
MDB	Moving Deformable Barrier
MSB	Motorized Seat Belt
MSR	Motorized Seat Ramp
MY	Model Year
NASS	National Automotive Sampling System
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
ODB	Offset Deformable Barrier
OIM	Occupant Injury Measure
PAB	Passenger Air Bag
PDOF	Principal Direction of Force
PVM	Programmable Venting Module
PVP	Prototype Vehicle Platform
RPT	Retractor Pretensioner
RTI	Revised Tibia Index
Takata	TK Holdings, Inc.
THOR-FLx	THOR Female Lower Extremity (NHTSA Advanced ATD)
THOR-Lx	THOR Male Lower Extremity (NHTSA Advanced ATD)
TRC	Transportation Research Center, Inc.
TTO	Time-to-Open
Volpe	Volpe National Transportation Systems Center
USDOT	U.S. Department of Transportation

## Appendix A 5th Percentile Female Occupant (HIII 5F)

### A.1 Background

The physical sled and vehicle crash testing for the 5th percentile female was conducted with a HIII 5F ATD retrofitted with THOR-FLx legs. The corresponding CAE evaluations were conducted using a virtual HIII 5F ATD with HIII legs since a THOR-FLx CAE model was not available at the time the simulations were conducted. During the course of the ARS Project, a contract was established with a second CAE supplier to develop a CAE model for the THOR-FLx legs. Although not used during the CAE DOE optimization studies, these models were eventually successfully integrated with the HIII 5F ATD model, and the baseline PVP and recommended ARS configurations were rerun with the THOR-FLx CAE models for the eight load cases involving the 5th female. The results from these additional CAE runs are provided in the following tables and were the basis for comparing the two restraint systems for the load cases that relied on CAE analysis.

All testing and CAE analysis with the HIII 5F ATD was conducted at the full-forward seating position, with the seat at approximately the mid-height position according to the current FMVSS208 seating procedure. In addition, the D-ring was at the full-up position.

### A.2 Driver

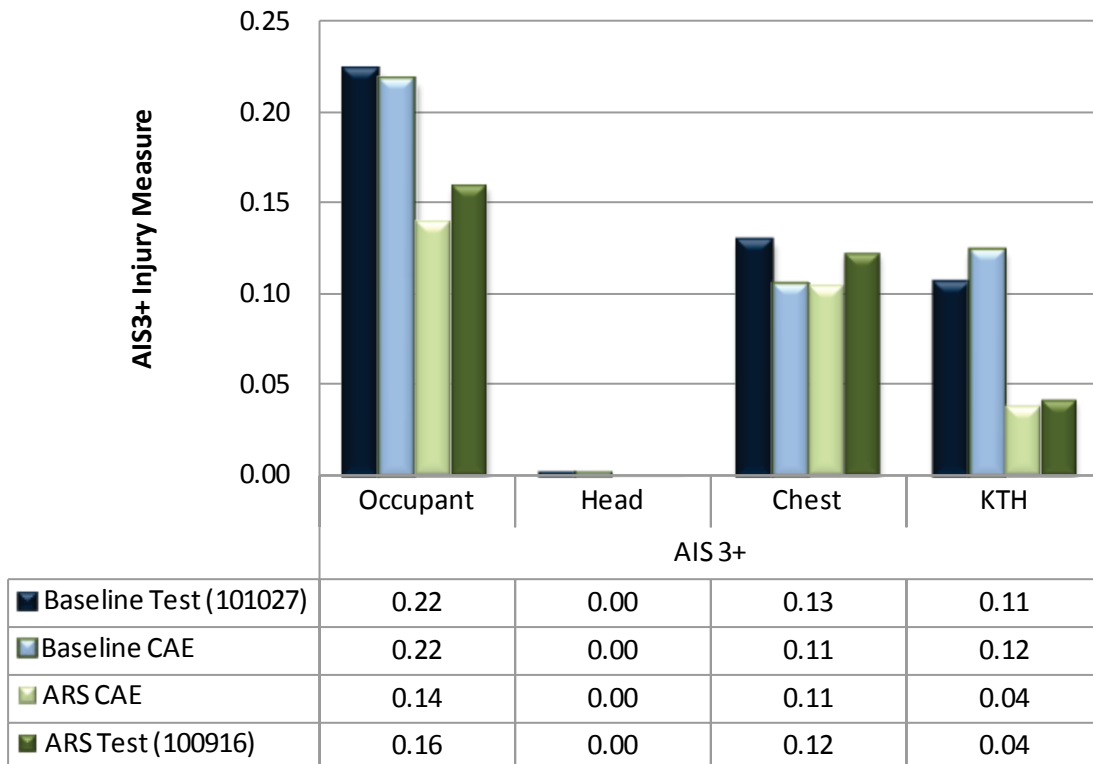
#### A.2.1 MDB35, HIII 5F

Table A.1 – ARS Configuration/Deployment Times for MDB35, HIII 5F Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	12
	Stage 2	162
	PVM Deploy Time	47
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	12
	Retractor IEA Switch Time	22
Seat Ramp		ON

**Table A.2 – Summary of Peak Injury Values for MDB35, HIII 5F Driver**

Injury Criteria	Baseline Test (101027)	Baseline CAE	ARS CAE	ARS Test (100916)
HIC (15ms)	192	192	156	136
Neck NIJ	0.52	0.48	0.66	0.68
Chest Deflection (mm)	31	27	27	30
Chest Accel - 3ms (g)	51	49	39	38
Left Femur Fz (kN)	5.96	6.33	3.68	3.88
Right Femur Fz (kN)	3.92	3.48	3.52	2.80
Left Upper Tibia Fz (kN)	2.77	3.64	2.80	2.61
Right Upper Tibia Fz (kN)	2.26	3.41	2.20	1.52
Left Lower Tibia Fz (kN)	3.54	4.16	3.60	3.27
Right Lower Tibia Fz (kN)	3.91	4.89	2.45	1.77



**Figure A.1 – AIS3+ Injury Measure Summary for MDB35, HIII 5F Driver**

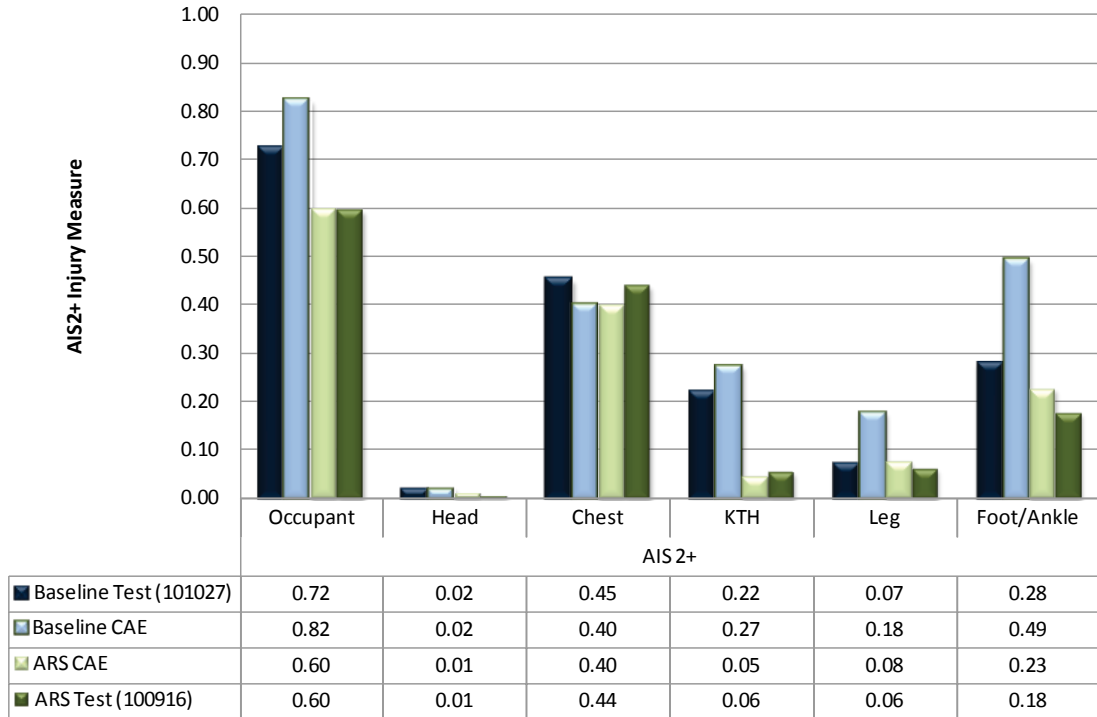


Figure A.2 – AIS2+ Injury Measure Summary for MDB35, HIII 5F Driver

A.2.2 MDB25, HIII 5F

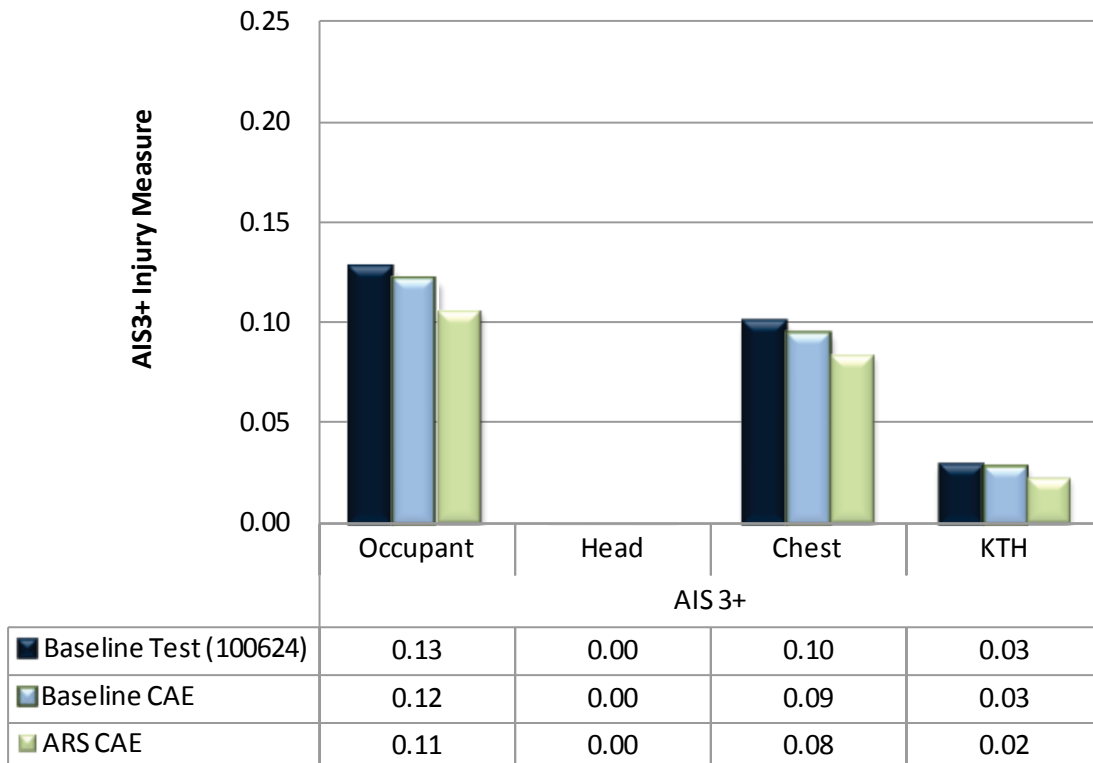
Table A.3 – ARS Configuration/Deployment Times for MDB25, HIII 5F Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	18
	Stage 2	168
	PVM Deploy Time	53
Knee Air Bag		OFF
Seat Belt System	Retractor PT	OFF
	Lap Anchor PT	18
	Retractor IEA Switch Time	28
Seat Ramp		OFF



**Table A.4 – Summary of Peak Injury Values for MDB25, HIII 5F Driver**

Injury Criteria	Baseline Test (100624)	Baseline CAE	ARS CAE
HIC (15ms)	164	161	167
Neck NIJ	0.41	0.41	0.50
Chest Deflection (mm)	26	25	23
Chest Accel - 3ms (g)	39	37	36
Left Femur Fz (kN)	3.09	3.03	2.59
Right Femur Fz (kN)	1.14	2.68	1.57
Left Upper Tibia Fz (kN)	2.10	2.63	2.26
Right Upper Tibia Fz (kN)	0.54	2.34	0.86
Left Lower Tibia Fz (kN)	2.00	1.40	0.85
Right Lower Tibia Fz (kN)	1.14	1.92	1.69



**Figure A.3 – AIS3+ Injury Measure Summary for MDB25, HIII 5F Driver**

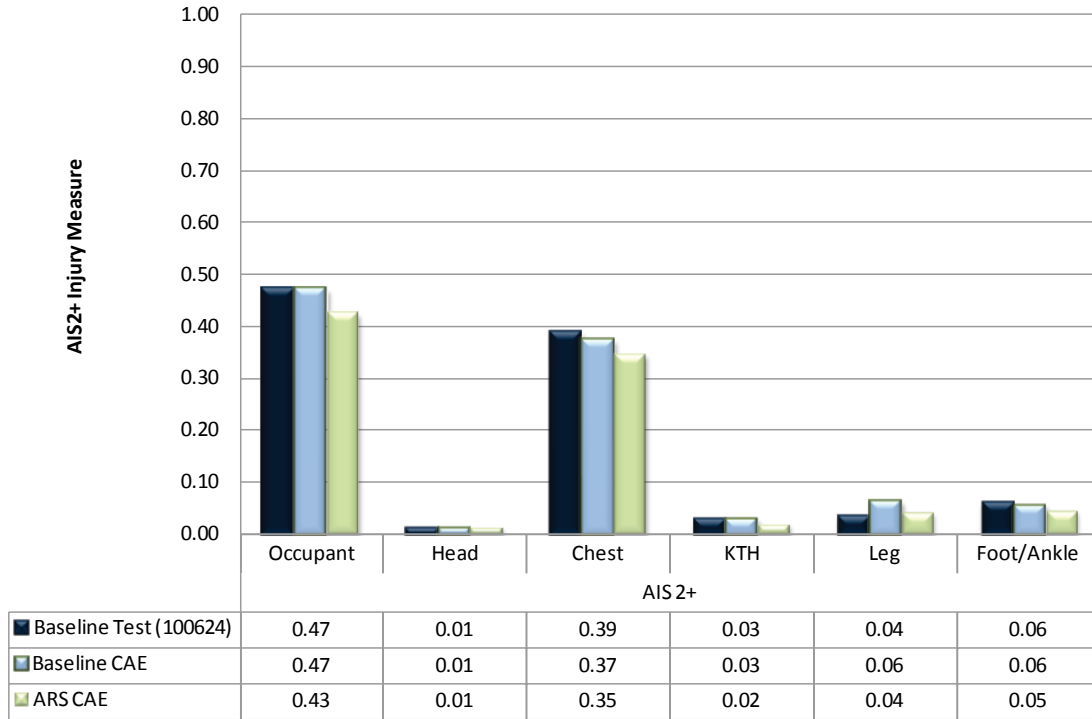


Figure A.4 – AIS2+ Injury Measure Summary for MDB25, HIII 5F Driver

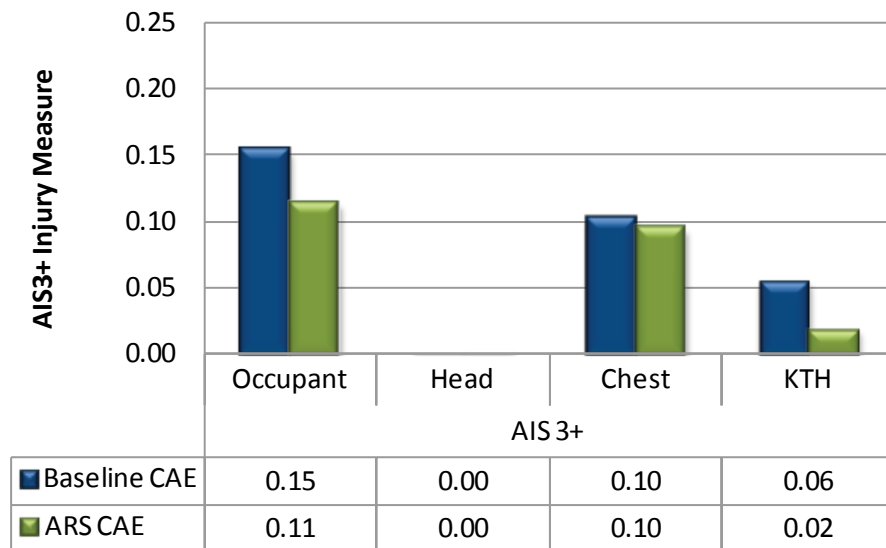
A.2.3 Pole35, HIII 5F

Table A.5 – ARS Configuration/Deployment Times for Pole35, HIII 5F Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	34
	Stage 2	184
	PVM Deploy Time	69
Knee Air Bag		34
Seat Belt System	Retractor PT	34
	Lap Anchor PT	34
	Retractor IEA Switch Time	44
Seat Ramp		ON

**Table A.6 – Summary of Peak Injury Values for Pole35, HIII 5F Driver**

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	211	217
Neck NIJ	0.53	0.54
Chest Deflection (mm)	27	25
Chest Accel - 3ms (g)	48	45
Left Femur Fz (kN)	4.23	1.64
Right Femur Fz (kN)	4.47	2.12
Left Upper Tibia Fz (kN)	1.58	1.23
Right Upper Tibia Fz (kN)	1.65	1.10
Left Lower Tibia Fz (kN)	1.76	1.49
Right Lower Tibia Fz (kN)	1.35	2.12



**Figure A.5 – AIS3+ Injury Measure Summary for Pole35, HIII 5F Driver**

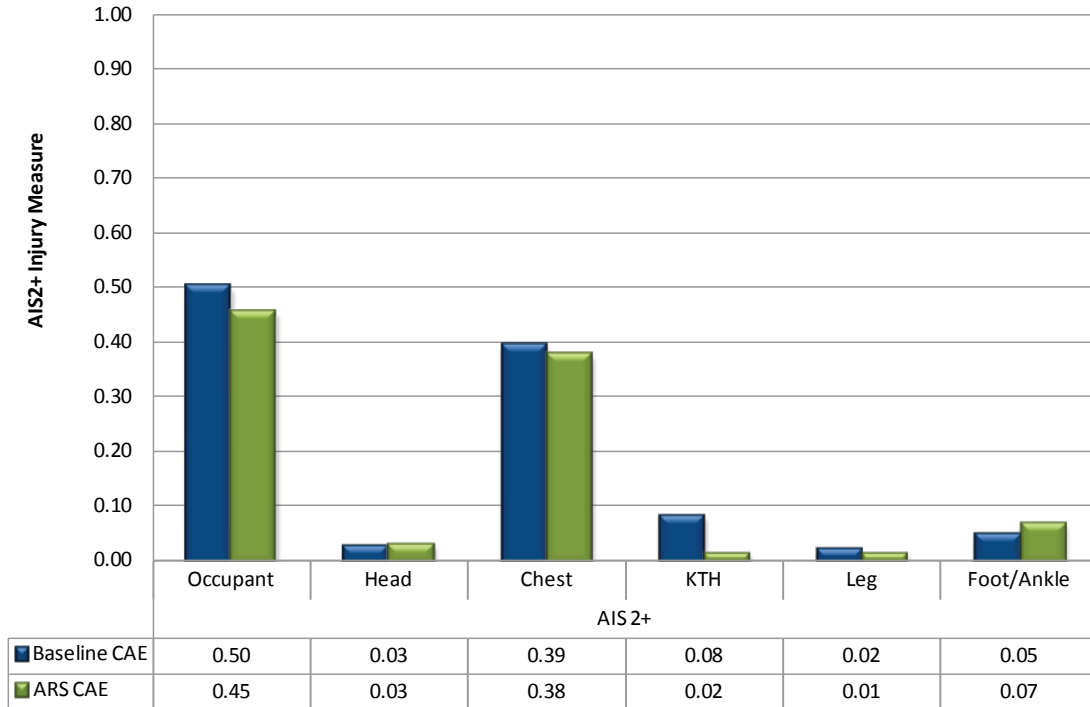


Figure A.6 – AIS2+ Injury Measure Summary for Pole35, Hill 5F Driver

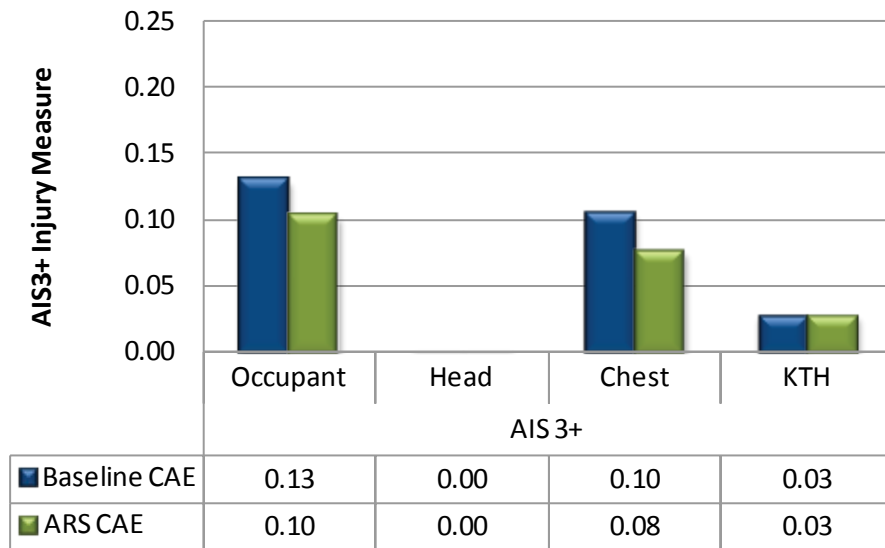
A.2.4 Pole25, Hill 5F

Table A.7 – ARS Configuration/Deployment Times for Pole25, Hill 5F Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	40
	Stage 2	190
	PVM Deploy Time	75
Knee Air Bag		OFF
Seat Belt System	Retractor PT	40
	Lap Anchor PT	40
	Retractor IEA Switch Time	50
Seat Ramp		ON

**Table A.8 – Summary of Peak Injury Values for Pole25, HIII 5F Driver**

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	157	185
Neck NIJ	0.41	0.45
Chest Deflection (mm)	27	21
Chest Accel - 3ms (g)	37	38
Left Femur Fz (kN)	2.63	2.96
Right Femur Fz (kN)	2.99	2.59
Left Upper Tibia Fz (kN)	1.75	2.26
Right Upper Tibia Fz (kN)	1.54	1.60
Left Lower Tibia Fz (kN)	1.12	0.72
Right Lower Tibia Fz (kN)	1.15	1.69



**Figure A.7 – AIS3+ Injury Measure Summary for Pole25, HIII 5F Driver**

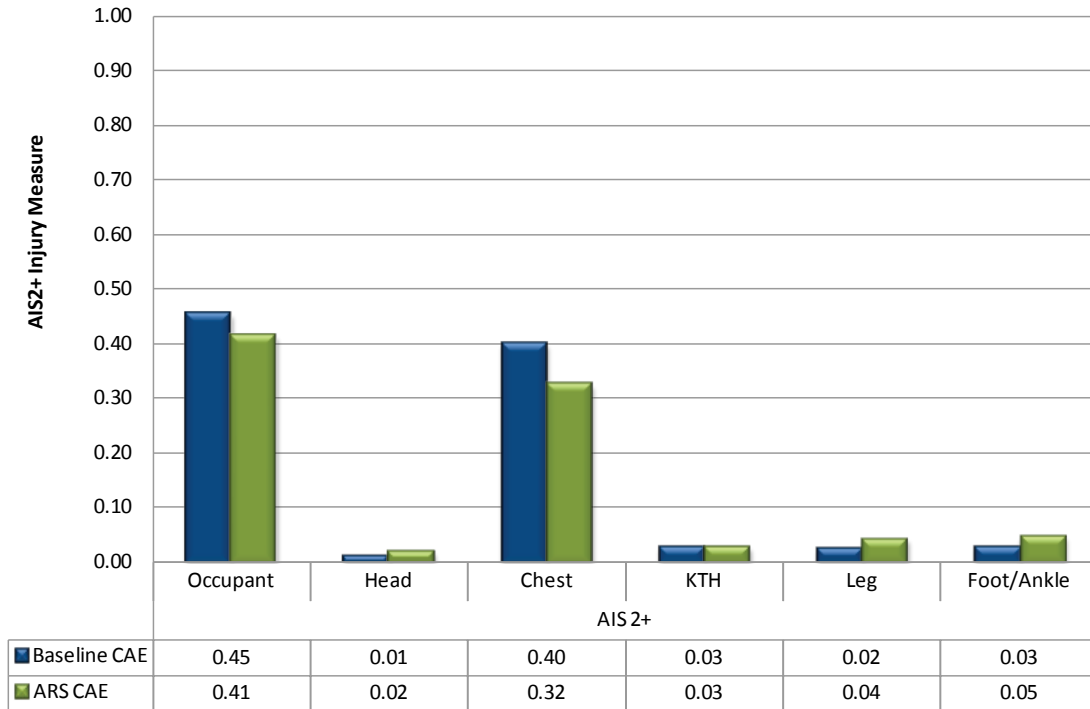


Figure A.8 – AIS2+ Injury Measure Summary for Pole25, HIII 5F Driver

### A.3 Passenger

#### A.3.1 MDB35, HIII 5F

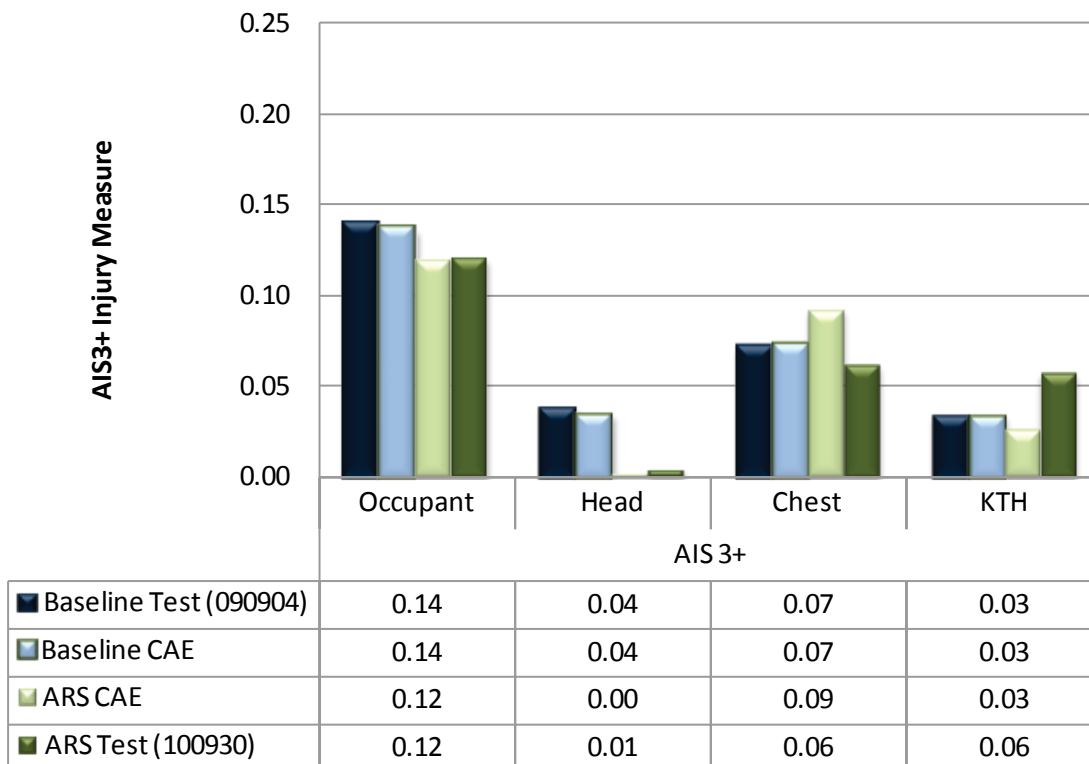
Table A.9 – ARS Configuration/Deployment Times for MDB35, HIII 5F Passenger

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	12
	Stage 2	17
	PVM Deploy Time	52
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	18
	Retractor IEA Switch Time	22
Seat Ramp		ON

**Table A.10 – Summary of Peak Injury Values for MDB35, Hill 5F Passenger**

Injury Criteria	Baseline Test (090904)	Baseline CAE	ARS CAE	ARS Test (100930)
HIC (15ms)	467	453	214	259
Neck NIJ	0.58	0.51	0.42	0.38
Chest Deflection (mm)	20	20	25	17
Chest Accel - 3ms (g)	47	46	47	46
Left Femur Fz (kN)	3.44	3.44	2.92	4.58
Right Femur Fz (kN)	1.71	2.29	1.72	2.65
Left Upper Tibia Fz (kN)	4.46*	4.34	1.81	4.23
Right Upper Tibia Fz (kN)	2.03	1.94	1.07	2.88
Left Lower Tibia Fz (kN)	5.36*	5.23	2.02	4.80
Right Lower Tibia Fz (kN)	3.07	2.89	2.58	2.69

\*Left THOR-FLx leg damaged during Test 090904



**Figure A.9 – AIS3+ Injury Measure Summary for MDB35, Hill 5F Passenger**

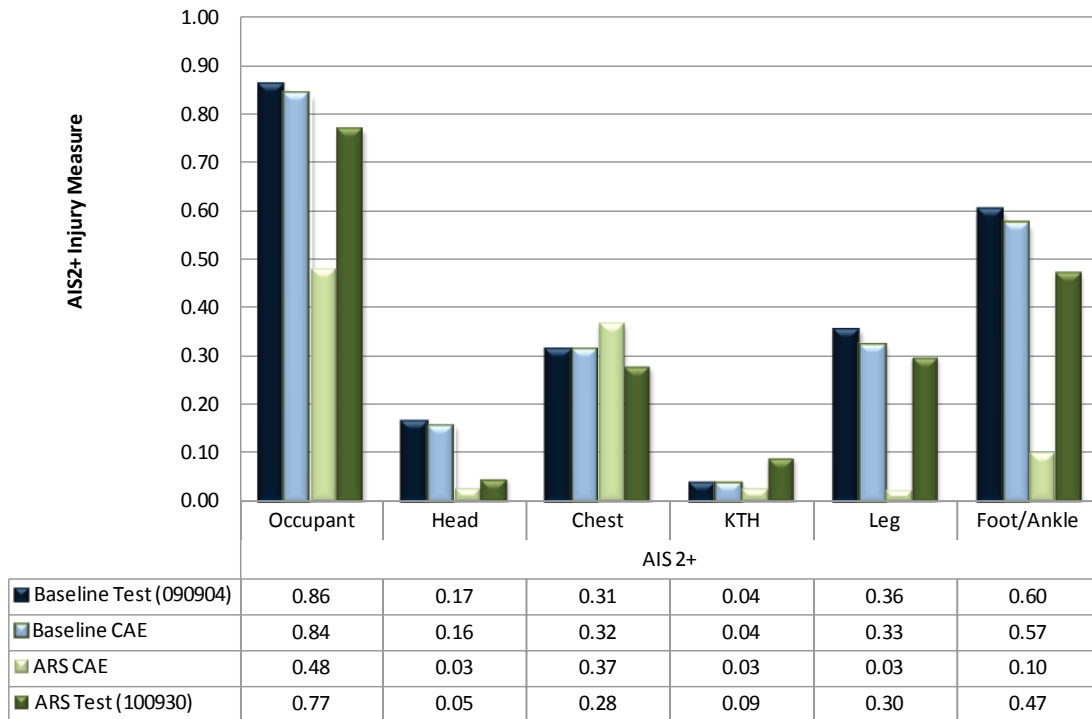


Figure A.10 – AIS2+ Injury Measure Summary for MDB35, HIII 5F Passenger

A.3.2 MDB25, HIII 5F

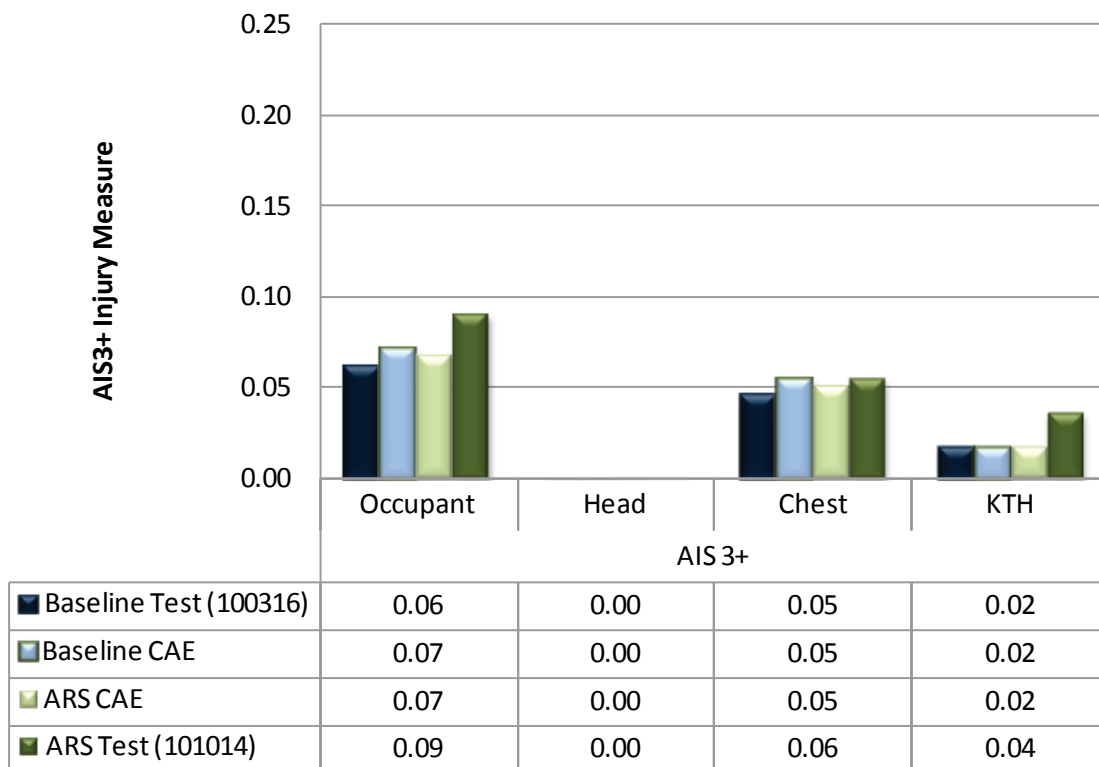
Table A.11 – ARS Configuration/Deployment Times for MDB25, HIII 5F Passenger

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	18
	Stage 2	23
	PVM Deploy Time	58
Knee Air Bag		OFF
Seat Belt System	Retractor PT	OFF
	Lap Anchor PT	18
	Retractor IEA Switch Time	28
Seat Ramp		OFF



**Table A.12 – Summary of Peak Injury Values for MDB25, HIII 5F Passenger**

Injury Criteria	Baseline Test (100316)	Baseline CAE	ARS CAE	ARS Test (101014)
HIC (15ms)	76	91	90	178
Neck NIJ	0.40	0.26	0.25	0.42
Chest Deflection (mm)	11	15	14	15
Chest Accel - 3ms (g)	26	27	30	41
Left Femur Fz (kN)	1.59	1.55	2.03	3.58
Right Femur Fz (kN)	1.93	1.95	1.48	1.30
Left Upper Tibia Fz (kN)	1.49	1.45	1.91	0.98
Right Upper Tibia Fz (kN)	0.81	0.69	0.67	0.88
Left Lower Tibia Fz (kN)	2.17	1.20	1.45	1.54
Right Lower Tibia Fz (kN)	1.32	1.33	1.14	No Data



**Figure A.11 – AIS3+ Injury Measure Summary for MDB25, HIII 5F Passenger**

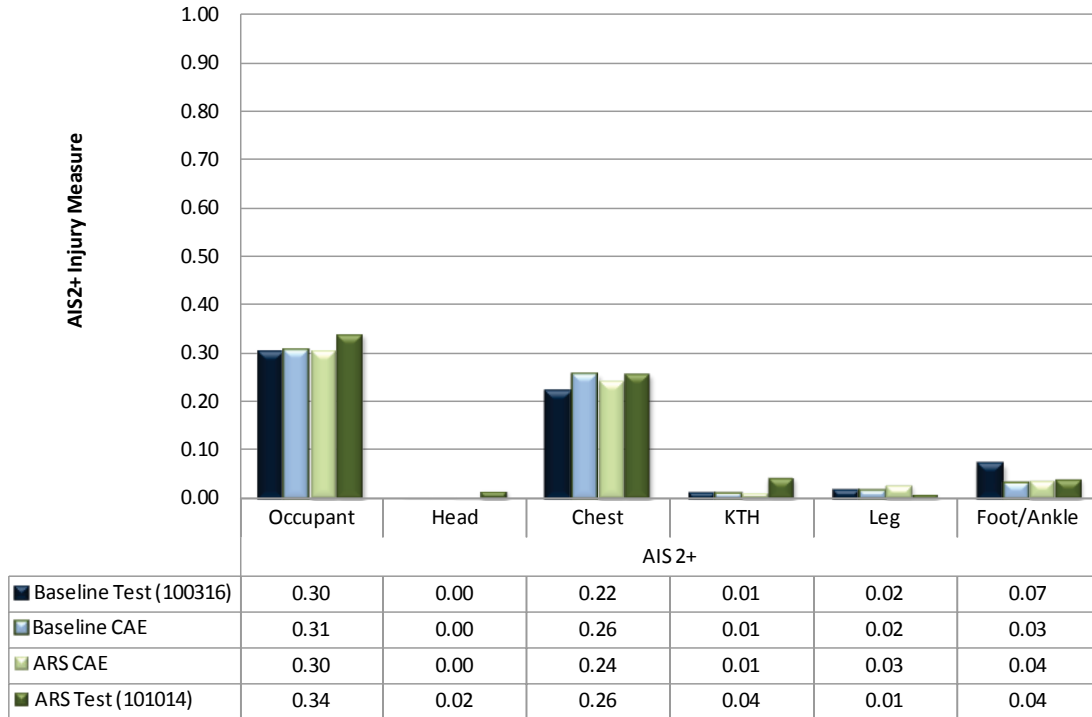


Figure A.12 – AIS2+ Injury Measure Summary for MDB25, HIII 5F Passenger

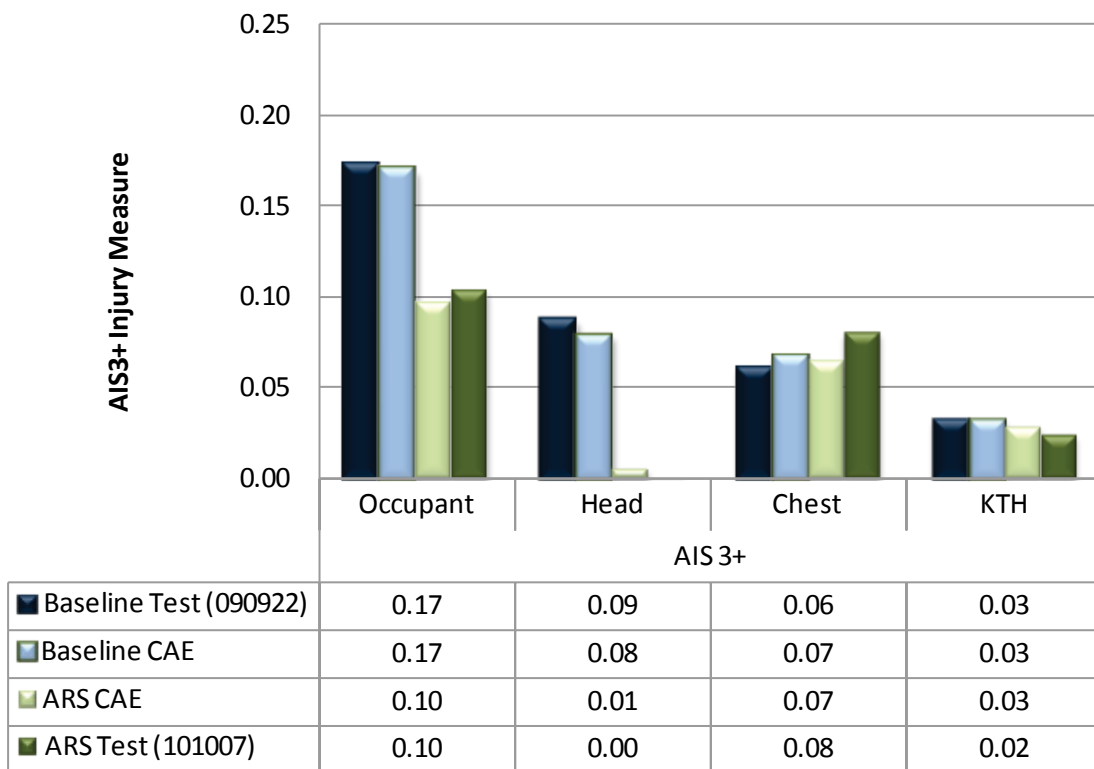
A.3.3 Pole35, HIII 5F

Table A.13 – ARS Configuration/Deployment Times for Pole35, HIII 5F Passenger

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	25
	Stage 2	30
	PVM Deploy Time	55
Knee Air Bag		25
Seat Belt System	Retractor PT	25
	Lap Anchor PT	25
	Retractor IEA Switch Time	35
Seat Ramp		ON

**Table A.14 – Summary of Peak Injury Values for Pole35, HIII 5F Passenger**

Injury Criteria	Baseline Test (090922)	Baseline CAE	ARS CAE	ARS Test (101007)
HIC (15ms)	632	607	261	156
Neck NIJ	0.38	0.38	0.34	0.32
Chest Deflection (mm)	17	19	18	22
Chest Accel - 3ms (g)	44	43	45	41
Left Femur Fz (kN)	3.36	3.35	3.07	2.70
Right Femur Fz (kN)	1.90	3.21	2.18	2.56
Left Upper Tibia Fz (kN)	2.65	2.70	1.91	2.46
Right Upper Tibia Fz (kN)	1.57	1.98	1.49	2.42
Left Lower Tibia Fz (kN)	2.99	3.15	1.35	3.27
Right Lower Tibia Fz (kN)	2.51	2.84	3.22	2.91



**Figure A.13 – AIS3+ Injury Measure Summary for Pole35, HIII 5F Passenger**

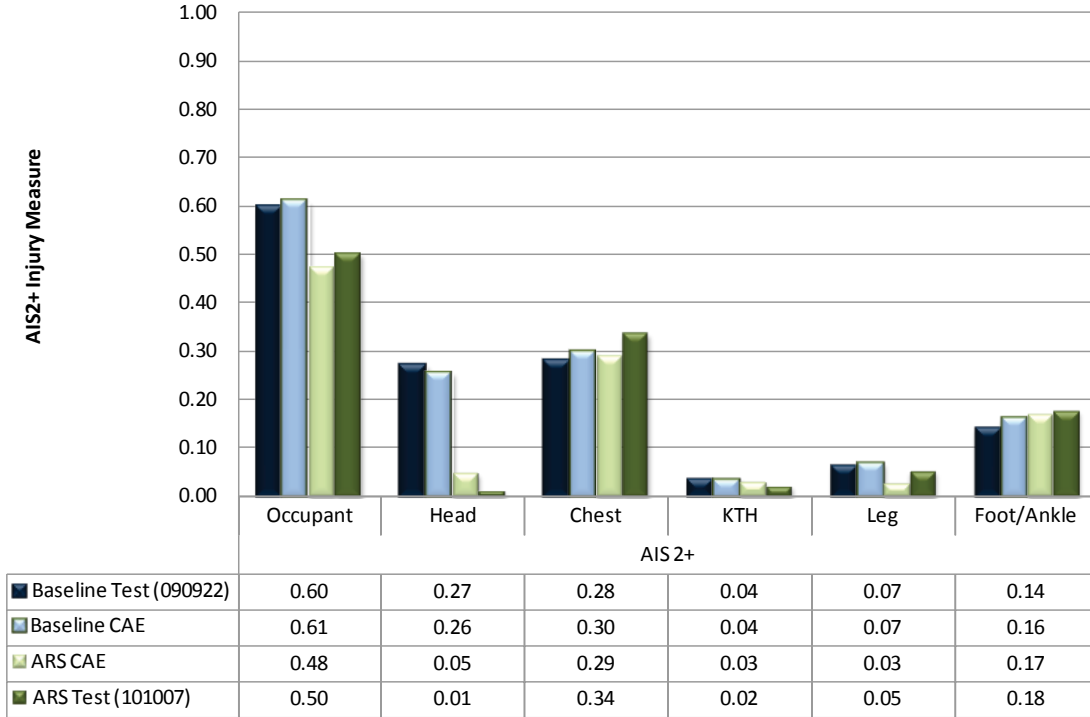


Figure A.14 – AIS2+ Injury Measure Summary for Pole35, Hill 5F Passenger

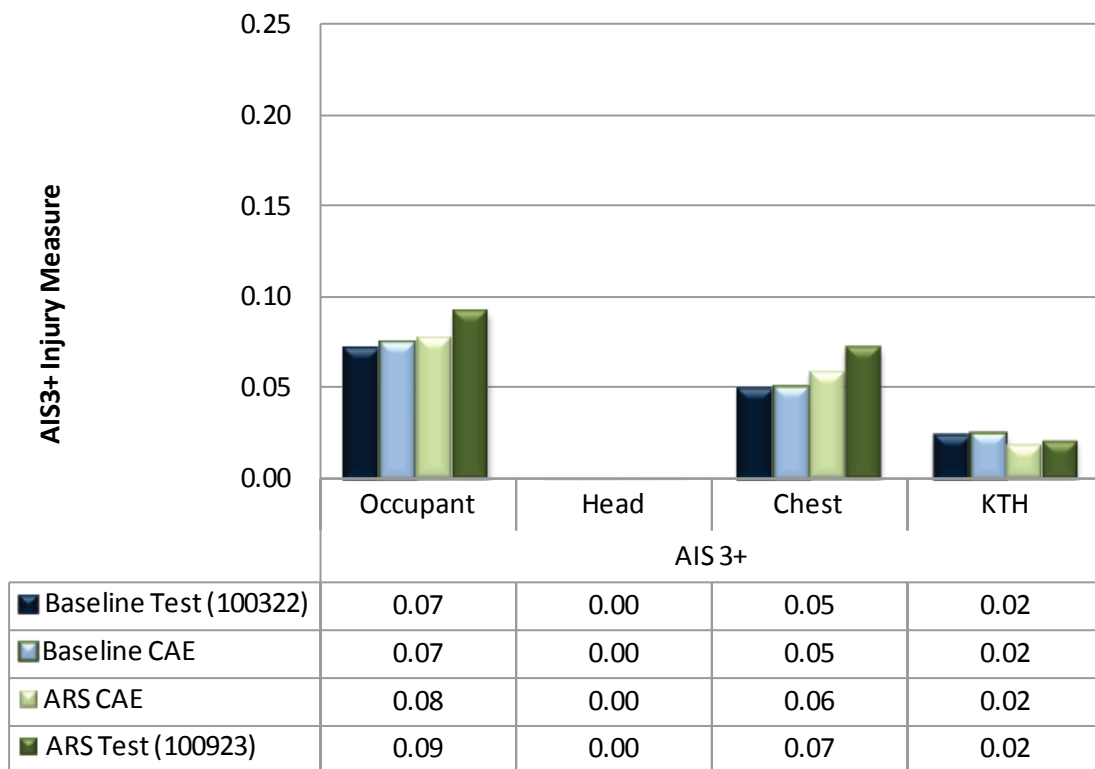
A.3.4 Pole25, Hill 5F

Table A.15 – ARS Configuration/Deployment Times for Pole25, Hill 5F Passenger

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	40
	Stage 2	45
	PVM Deploy Time	75
Knee Air Bag		OFF
Seat Belt System	Retractor PT	40
	Lap Anchor PT	40
	Retractor IEA Switch Time	50
Seat Ramp		ON

**Table A.16 – Summary of Peak Injury Values for Pole25, HIII 5F Passenger**

Injury Criteria	Baseline Test (100322)	Baseline CAE	ARS CAE	ARS Test (100923)
HIC (15ms)	76	95	115	147
Neck NIJ	0.34	0.35	0.28	0.32
Chest Deflection (mm)	13	14	16	20
Chest Accel - 3ms (g)	28	30	32	30
Left Femur Fz (kN)	2.62	2.72	1.91	1.90
Right Femur Fz (kN)	2.03	2.08	2.19	2.37
Left Upper Tibia Fz (kN)	1.67	1.23	1.64	1.72
Right Upper Tibia Fz (kN)	0.23	1.06	1.10	1.14
Left Lower Tibia Fz (kN)	2.51	1.65	2.45	2.51
Right Lower Tibia Fz (kN)	0.42	0.96	1.05	1.38



**Figure A.15 – AIS3+ Injury Measure Summary for Pole25, HIII 5F Passenger**

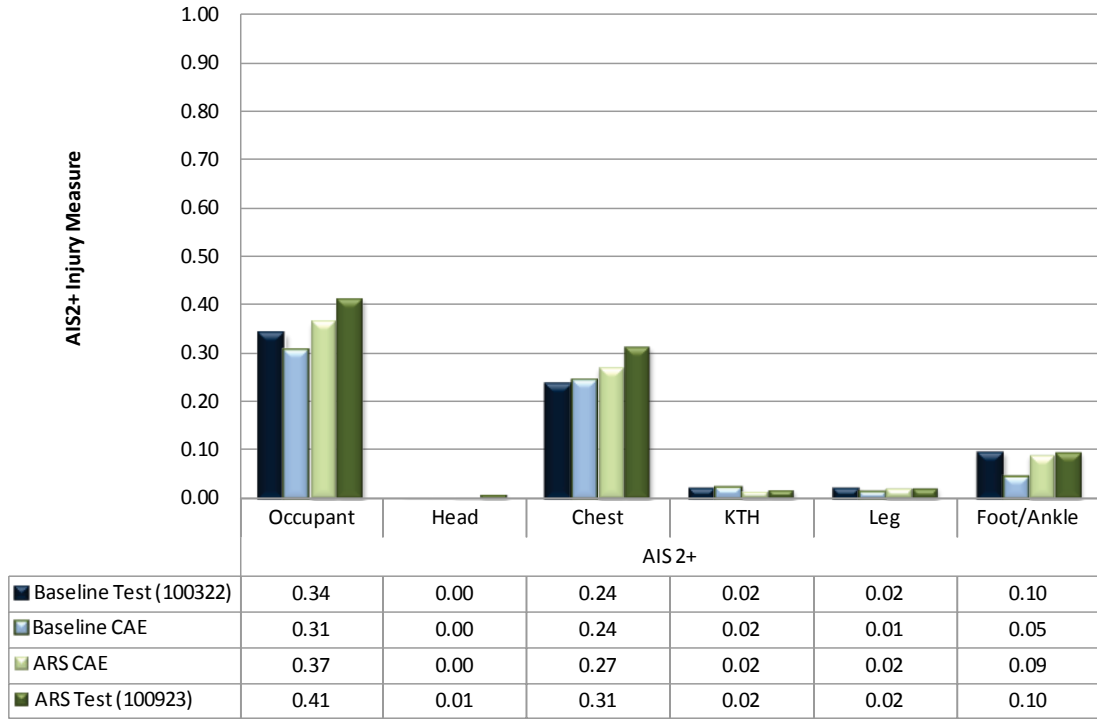


Figure A.16 – AIS2+ Injury Measure Summary for Pole25, Hill 5F Passenger

## Appendix B 50th Percentile Male Occupant (HIII 50M)

### B.1 Background

The physical sled and vehicle crash testing for the 50th percentile male was conducted with a HIII 50M ATD, retrofitted with THOR-Lx legs. The corresponding CAE evaluations were conducted using a virtual HIII 50M ATD that incorporated CAE models of the THOR-Lx legs.

All testing and CAE analysis with the HIII 50M ATD was conducted at the mid-track/full-down seating position, and the D-ring was at the full-up position.

### B.2 Driver

#### B.2.1 MDB35, HIII 50M

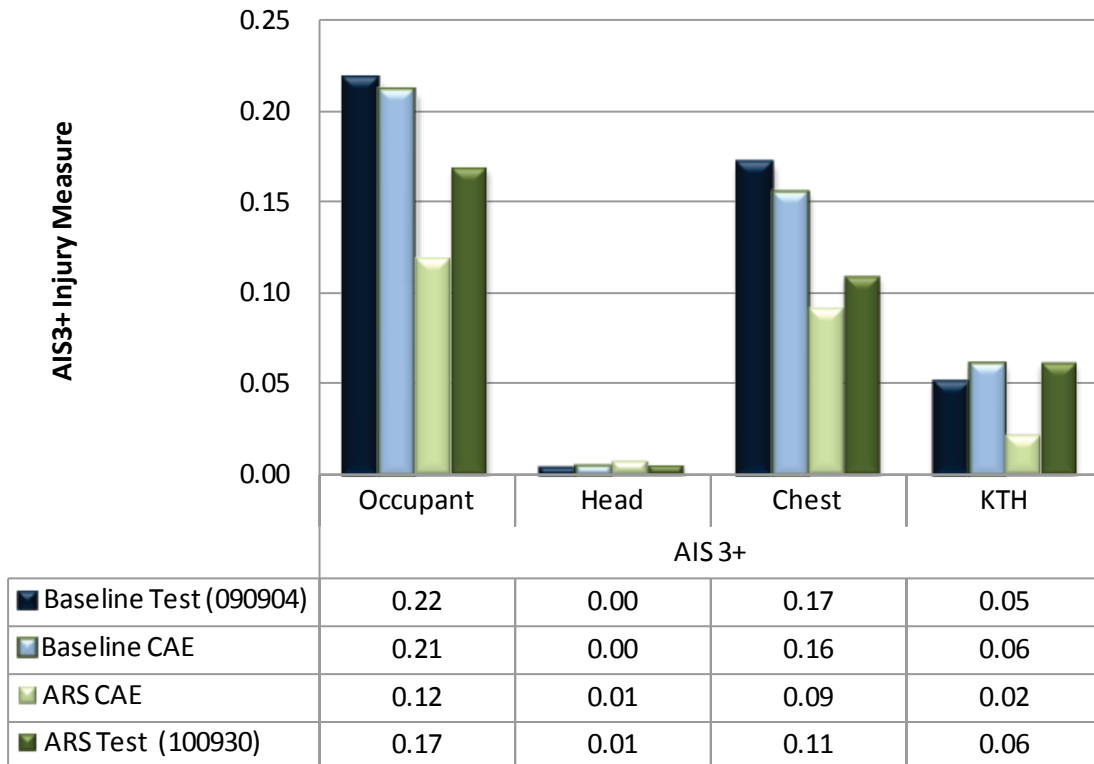
**Table B.1 – ARS Configuration/Deployment Times for MDB35, HIII 50M Driver**

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	12
	Stage 2	22
	PVM Deploy Time	72
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	12
	Retractor IEA Switch Time	47
Seat Ramp		ON

**Table B.2 – Summary of Peak Injury Values for MDB35, HIII 50M Driver**

Injury Criteria	Baseline Test (090904)	Baseline CAE	ARS CAE	ARS Test (100930)
HIC (15ms)	244	254	290	267
Neck NIJ	0.37	0.44	0.34	0.38
Chest Deflection (mm)	45	43	30	34
Chest Accel - 3ms (g)	52	47	42	47
Left Femur Fz (kN)	2.78	2.78	3.64	6.92
Right Femur Fz (kN)	6.33	6.90	2.51	6.23
Left Upper Tibia Fz (kN)	1.88	2.13	3.99	3.14
Right Upper Tibia Fz (kN)	2.61*	4.79	5.17	1.80
Left Lower Tibia Fz (kN)	3.28	3.46	5.66	4.75
Right Lower Tibia Fz (kN)	6.38*	5.83	5.76	2.38

\*Right THOR-Lx leg damaged during Test 090904



**Figure B.1 – AIS3+ Injury Measure Summary for MDB35, HIII 50M Driver**



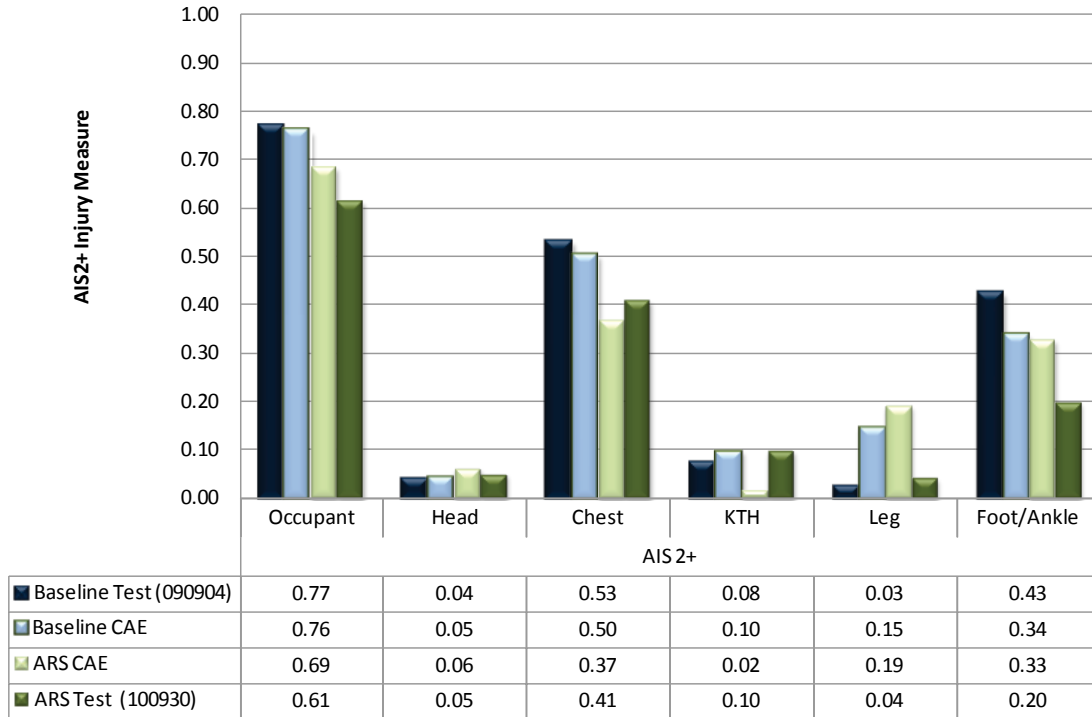


Figure B.2 – AIS2+ Injury Measure Summary for MDB35, HIII 50M Driver

B.2.2 MDB25, HIII 50M

Table B.3 – ARS Configuration/Deployment Times for MDB25, HIII 50M Driver used in Test 101108

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	18
	Stage 2	28
	PVM Deploy Time	73
Knee Air Bag		OFF
Seat Belt System	Retractor PT	18
	Lap Anchor PT	24
	Retractor IEA Switch Time	48
Seat Ramp		ON

**Table B.4 – Recommended ARS Configuration/Deployment Times for MDB25, HIII 50M Driver based on CAE Analysis Conducted after Test 101108**

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	18
	Stage 2	28
	PVM Deploy Time	73
Knee Air Bag		OFF
Seat Belt System	Retractor PT	OFF
	Lap Anchor PT	18
	Retractor IEA Switch Time	48
Seat Ramp		OFF

**Table B.5 – Summary of Peak Injury Values for MDB25, HIII 50M Driver**

Injury Criteria	Baseline Test (100316)	Baseline CAE	ARS CAE	ARS Test (101108)	Final ARS CAE
HIC (15ms)	109	112	134	73	107
Neck NIJ	0.29	0.30	0.27	0.25	0.30
Chest Deflection (mm)	27	31	30	31	23
Chest Accel - 3ms (g)	30	31	30	32	34
Left Femur Fz (kN)	2.80	2.60	2.10	2.46	0.50
Right Femur Fz (kN)	2.02	3.20	4.40	2.27	3.54
Left Upper Tibia Fz (kN)	1.64	1.70	1.60	1.28	1.22
Right Upper Tibia Fz (kN)	0.31	2.10	2.12	0.85	2.21
Left Lower Tibia Fz (kN)	2.20	2.10	1.40	2.23	2.18
Right Lower Tibia Fz (kN)	1.54	1.70	1.77	2.17	1.86

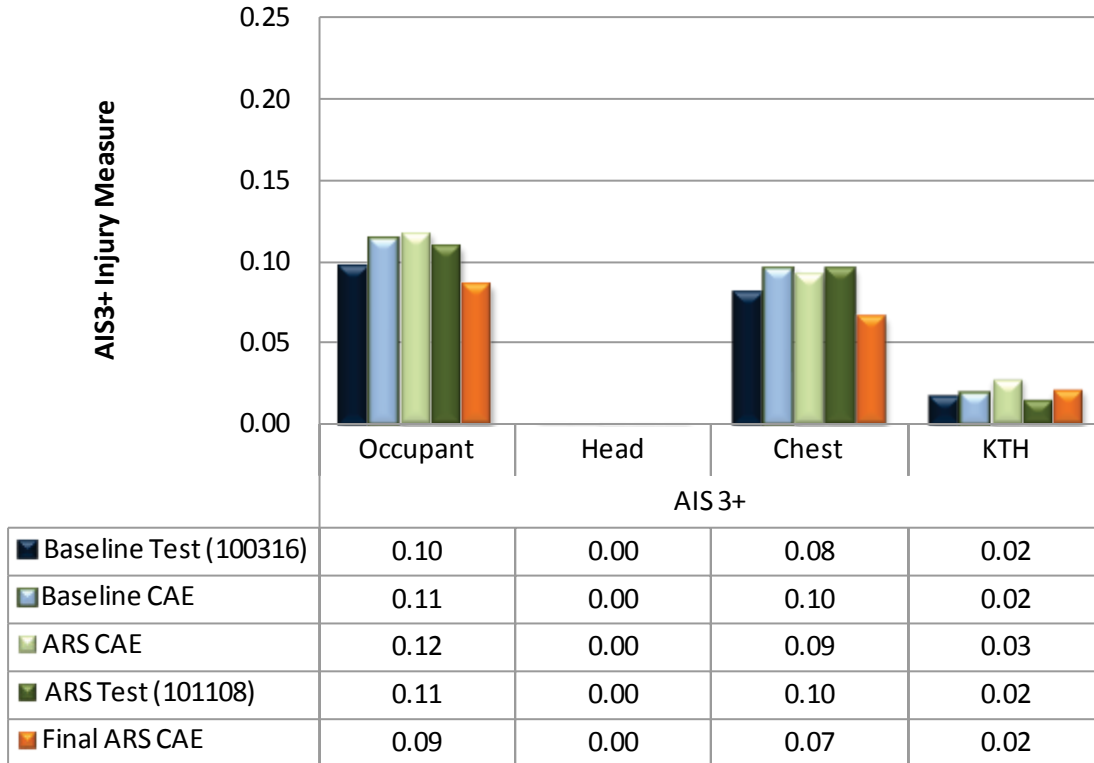


Figure B.3 – AIS3+ Injury Measure Summary for MDB25, HIII 50M Driver

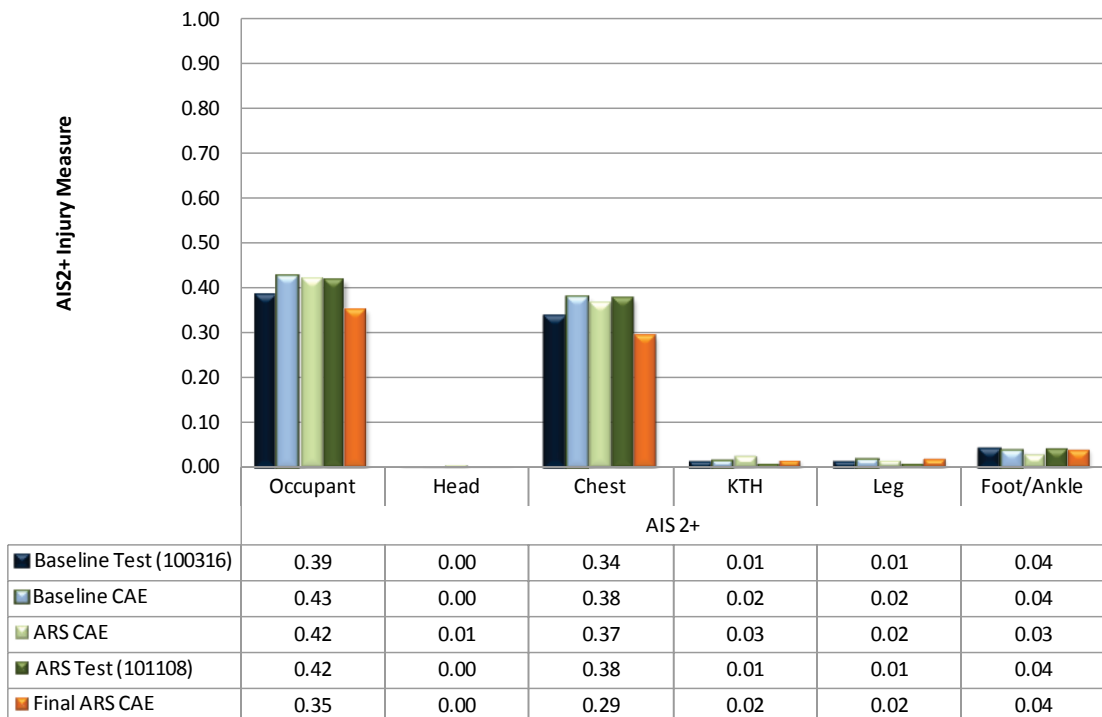


Figure B.4 – AIS2+ Injury Measure Summary for MDB25, HIII 50M Driver

## B.2.3 Pole35, Hill 50M

Table B.6 – ARS Configuration/Deployment Times for Pole35, Hill 50M Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	34
	Stage 2	44
	PVM Deploy Time	84
Knee Air Bag		34
Seat Belt System	Retractor PT	34
	Lap Anchor PT	40
	Retractor IEA Switch Time	74
Seat Ramp		ON

Table B.7 – Summary of Peak Injury Values for Pole35, Hill 50M Driver

Injury Criteria	Baseline Test (090922)	Baseline CAE	ARS CAE	ARS Test (101007)
HIC (15ms)	151	248	403	216
Neck NIJ	0.32	0.37	0.38	0.39
Chest Deflection (mm)	43	46	30	35
Chest Accel - 3ms (g)	45	44	41	37
Left Femur Fz (kN)	3.81	3.74	3.21	2.66
Right Femur Fz (kN)	3.28	1.1	3.52	2.86
Left Upper Tibia Fz (kN)	1.60	1.46	2.82	1.90
Right Upper Tibia Fz (kN)	0.45	1.81	3.18	1.22
Left Lower Tibia Fz (kN)	1.66	1.97	3.63	2.57
Right Lower Tibia Fz (kN)	2.32	2.69	3.67	2.96

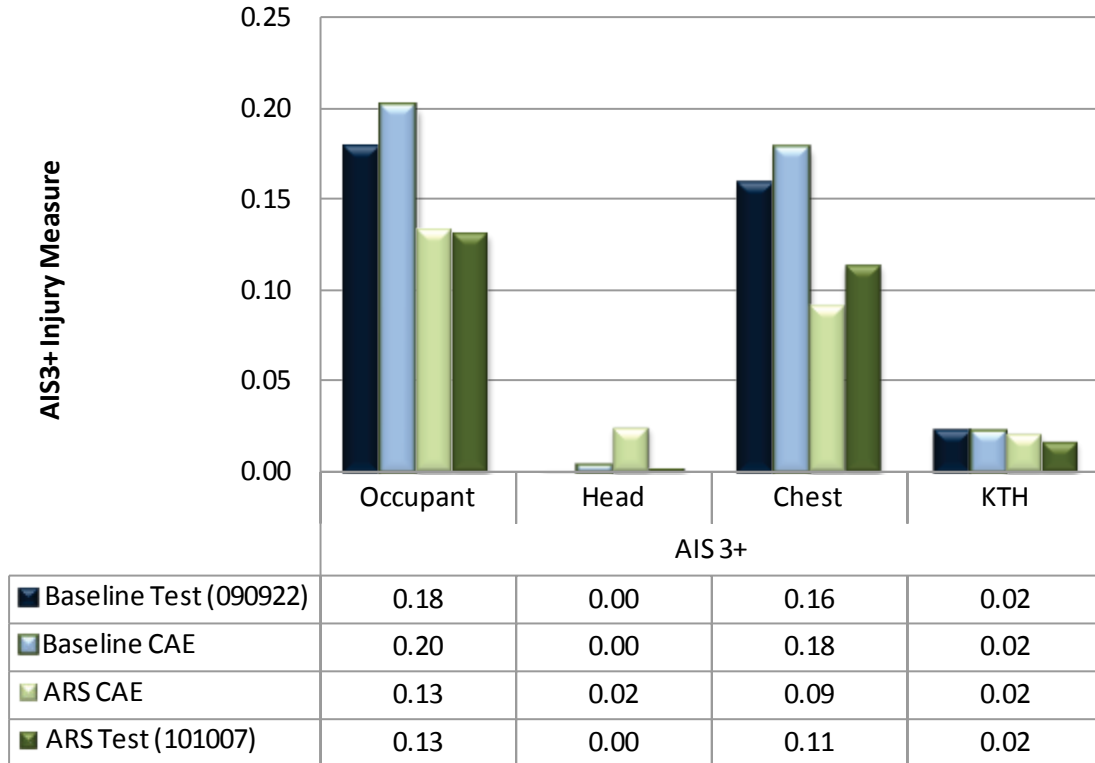


Figure B.5 – AIS3+ Injury Measure Summary for Pole35, Hill 50M Driver

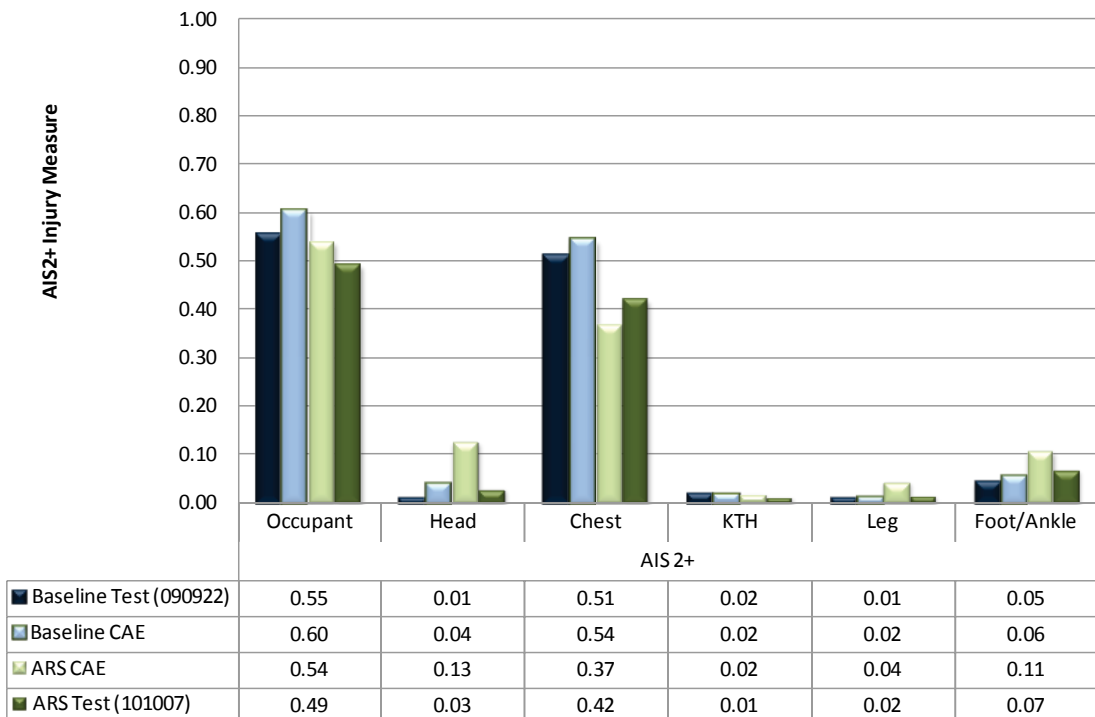


Figure B.6 – AIS2+ Injury Measure Summary for Pole35, Hill 50M Driver

## B.2.4 Pole25, HIII 50M

Table B.8 – ARS Configuration/Deployment Times for Pole25, HIII 50M Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	40
	Stage 2	50
	PVM Deploy Time	90
Knee Air Bag		40
Seat Belt System	Retractor PT	40
	Lap Anchor PT	46
	Retractor IEA Switch Time	70
Seat Ramp		ON

Table B.9 – Summary of Peak Injury Values for Pole25, HIII 50M Driver

Injury Criteria	Baseline Test (100322)	Baseline CAE	ARS CAE	ARS Test (100923)
HIC (15ms)	103	128	141	121
Neck NIJ	0.34	0.28	0.35	0.32
Chest Deflection (mm)	30	31	20	23
Chest Accel - 3ms (g)	36	35	29	27
Left Femur Fz (kN)	3.91	4.1	1.22	1.36
Right Femur Fz (kN)	3.52	3.5	1.08	1.91
Left Upper Tibia Fz (kN)	1.03	0.92	1.53	0.90
Right Upper Tibia Fz (kN)	1.02	0.92	1.32	1.38
Left Lower Tibia Fz (kN)	1.63	1.37	1.56	1.05
Right Lower Tibia Fz (kN)	1.95	1.9	1.95	2.05

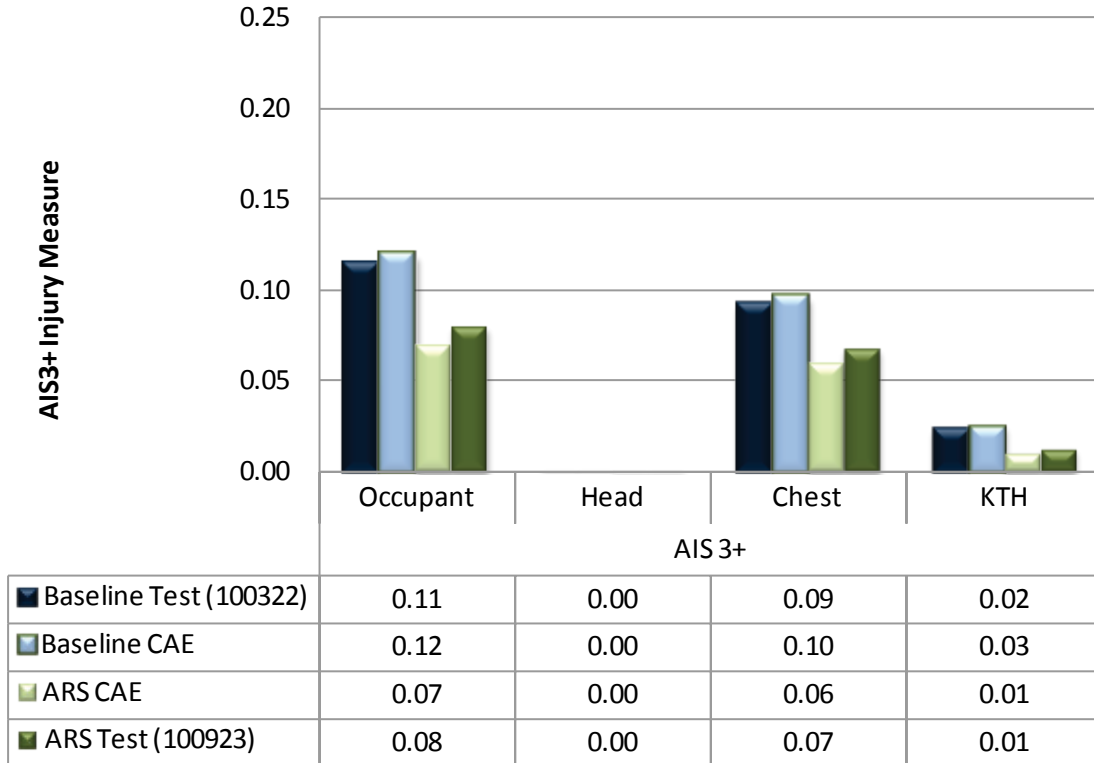


Figure B.7 – AIS3+ Injury Measure Summary for Pole25, Hill 50M Driver

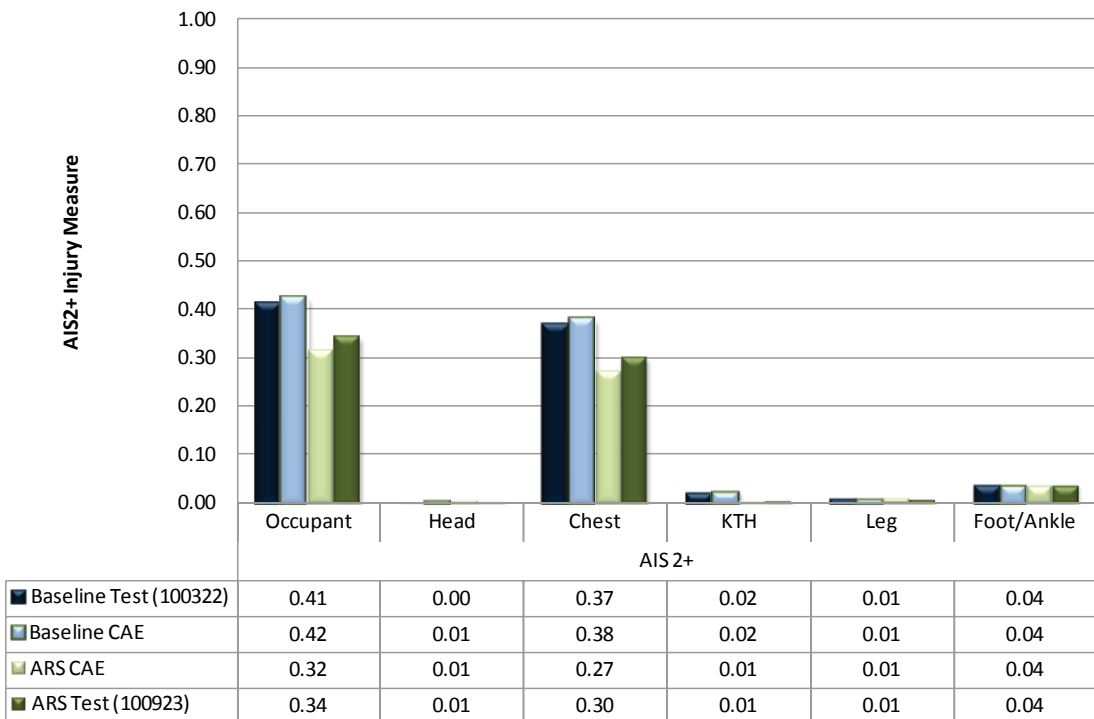


Figure B.8 – AIS2+ Injury Measure Summary for Pole25, Hill 50M Driver

### B.3 Passenger

#### B.3.1 MDB35, HIII 50M

**Table B.10 – ARS Configuration/Deployment Times for MDB35, HIII 50M Passenger**

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	12
	Stage 2	17
	PVM Deploy Time	66
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	12
	Retractor IEA Switch Time	55
Seat Ramp		ON

**Table B.11 – Summary of Peak Injury Values for MDB35, HIII 50M Passenger**

Injury Criteria	Baseline Test (101027)	Baseline CAE	ARS CAE	ARS Test (100916)
HIC (15ms)	630	343	213	219
Neck NIJ	0.36	0.31	0.24	0.26
Chest Deflection (mm)	29*	28	32	31
Chest Accel - 3ms (g)	42	40	42	39
Left Femur Fz (kN)	6.52	5.06	2.87	6.18
Right Femur Fz (kN)	3.74	4.16	1.34	2.53
Left Upper Tibia Fz (kN)	1.58	1.78	2.38	3.25
Right Upper Tibia Fz (kN)	3.03	3.70	3.22	3.31
Left Lower Tibia Fz (kN)	2.29	1.65	2.20	3.43
Right Lower Tibia Fz (kN)	4.09	4.27	2.04	3.83

\*In Test 101027, a peak chest deflection of 29 mm was recorded prior to instrumentation failure



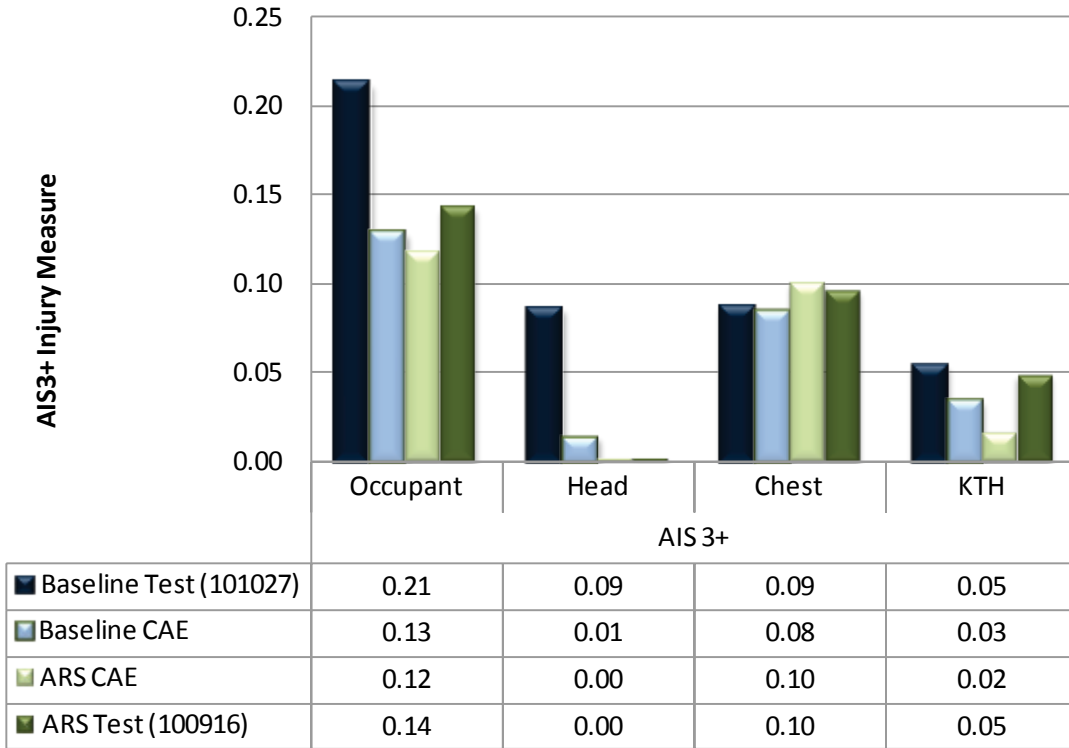


Figure B.9 – AIS3+ Injury Measure Summary for MDB35, Hill 50M Passenger

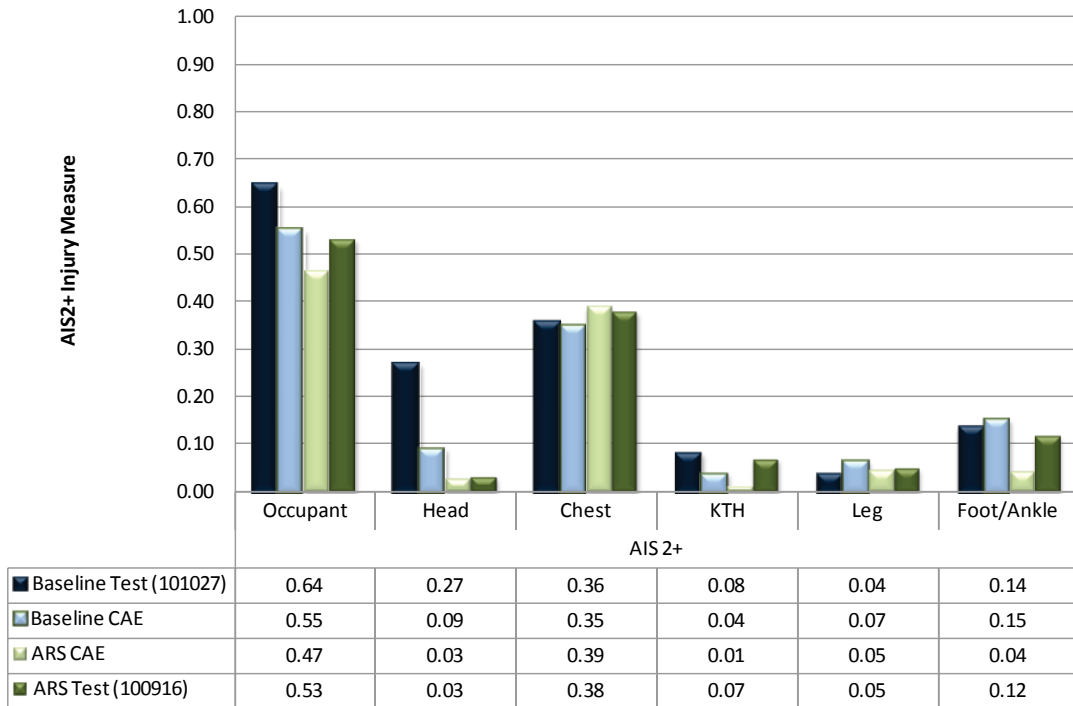


Figure B.10 – AIS2+ Injury Measure Summary for MDB35, Hill 50M Passenger

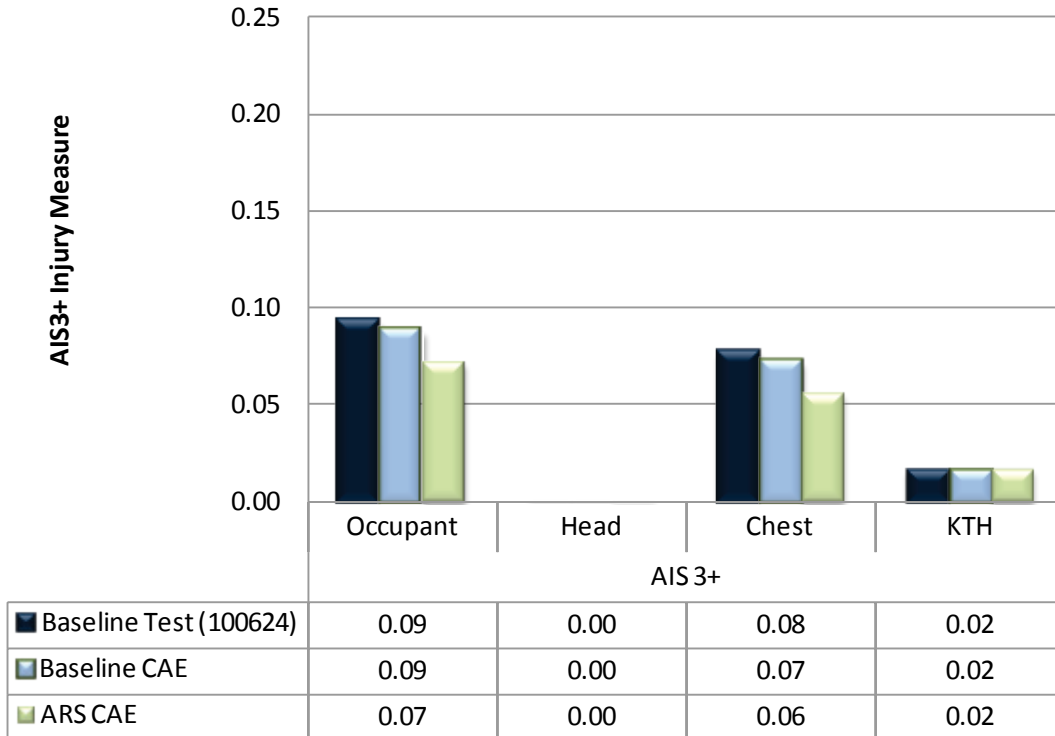
## B.3.2 MDB25, HIII 50M

Table B.12 – ARS Configuration/Deployment Times for MDB25, HIII 50M Passenger

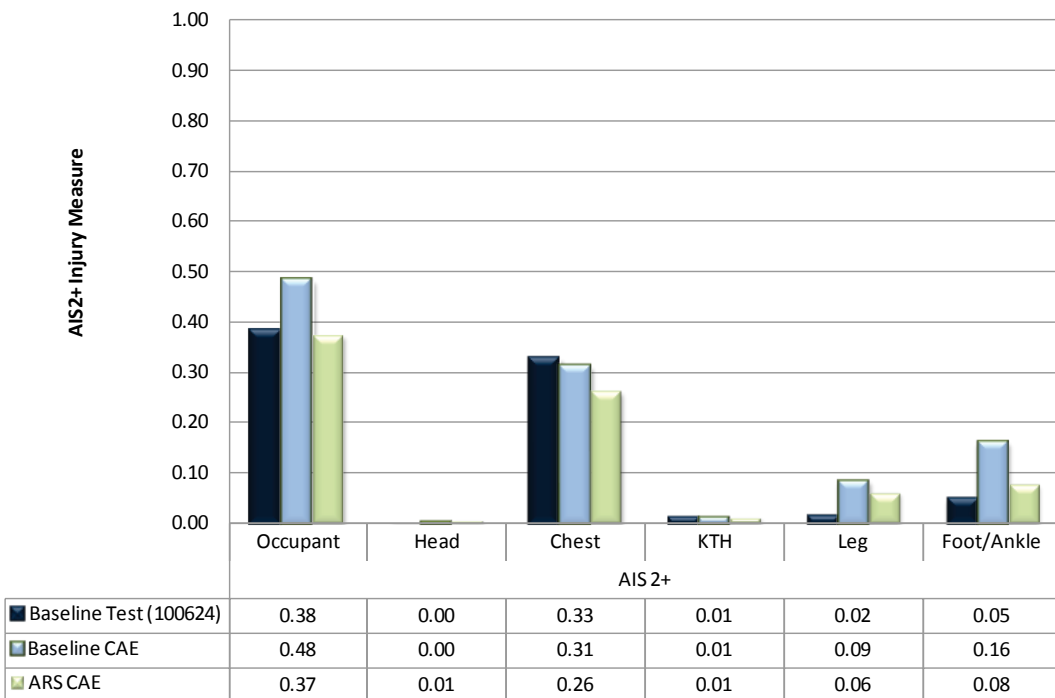
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	18
	Stage 2	23
	PVM Deploy Time	72
Knee Air Bag		OFF
Seat Belt System	Retractor PT	18
	Lap Anchor PT	18
	Retractor IEA Switch Time	51
Seat Ramp		ON

Table B.13 – Summary of Peak Injury Values for MDB25, HIII 50M Passenger

Injury Criteria	Baseline Test (100624)	Baseline CAE	ARS CAE
HIC (15ms)	107	118	125
Neck NIJ	0.22	0.29	0.19
Chest Deflection (mm)	26	24	19
Chest Accel - 3ms (g)	27	35	31
Left Femur Fz (kN)	2.81	2.79	2.77
Right Femur Fz (kN)	2.75	1.84	1.55
Left Upper Tibia Fz (kN)	1.75	4.03	3.60
Right Upper Tibia Fz (kN)	1.96	2.96	2.10
Left Lower Tibia Fz (kN)	1.86	4.38	3.14
Right Lower Tibia Fz (kN)	2.43	3.73	2.59



**Figure B.11 – AIS3+ Injury Measure Summary for MDB25, HIII 50M Passenger**



**Figure B.12 – AIS2+ Injury Measure Summary for MDB25, HIII 50M Passenger**

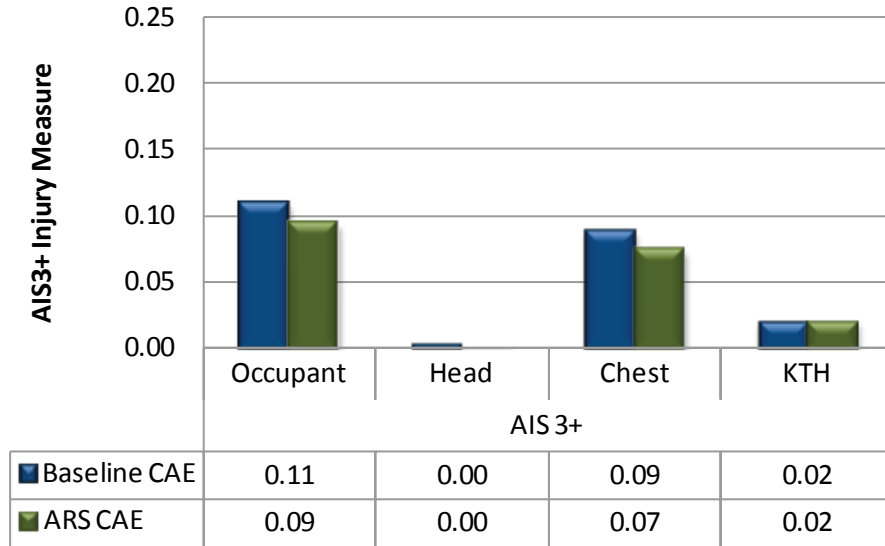
## B.3.3 Pole35, HIII 50M

Table B.14 – ARS Configuration/Deployment Times for Pole35, HIII 50M Passenger

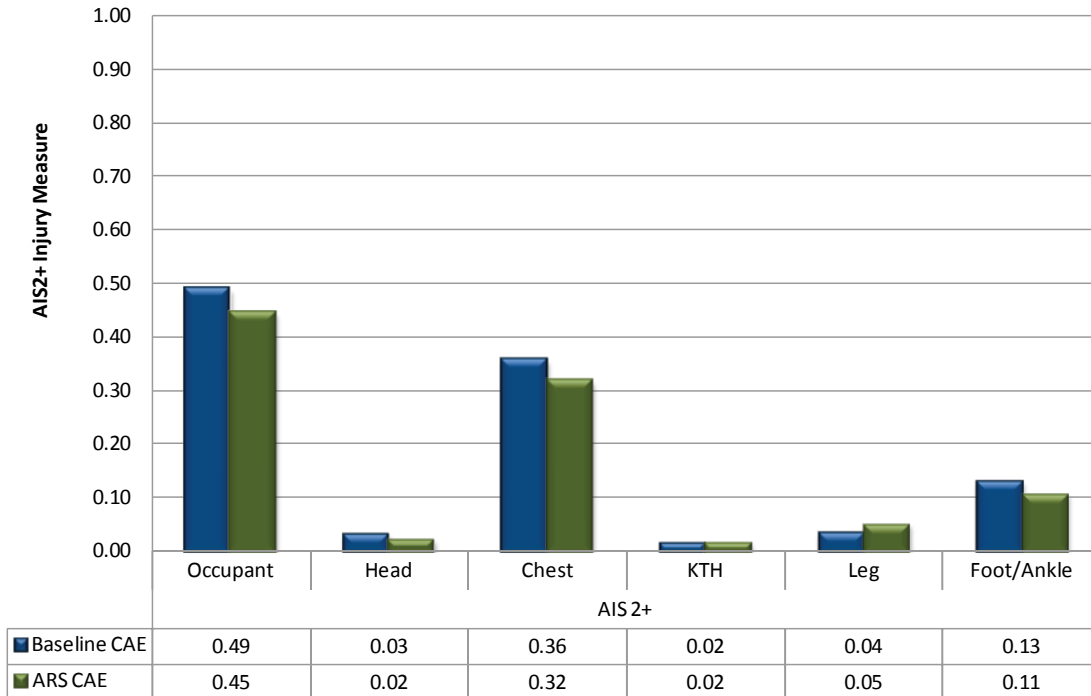
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	25
	Stage 2	30
	PVM Deploy Time	79
Knee Air Bag		25
Seat Belt System	Retractor PT	25
	Lap Anchor PT	25
	Retractor IEA Switch Time	60
Seat Ramp		ON

Table B.15 – Summary of Peak Injury Values for Pole35, HIII 50M Passenger

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	223	193
Neck NIJ	0.29	0.24
Chest Deflection (mm)	29	25
Chest Accel - 3ms (g)	40	51
Left Femur Fz (kN)	3.40	3.38
Right Femur Fz (kN)	2.60	3.30
Left Upper Tibia Fz (kN)	2.95	3.38
Right Upper Tibia Fz (kN)	2.47	2.90
Left Lower Tibia Fz (kN)	4.01	3.67
Right Lower Tibia Fz (kN)	3.44	3.38



**Figure B.13 – AIS3+ Injury Measure Summary for Pole35, Hill 50M Passenger**



**Figure B.14 – AIS2+ Injury Measure Summary for Pole35, Hill 50M Passenger**

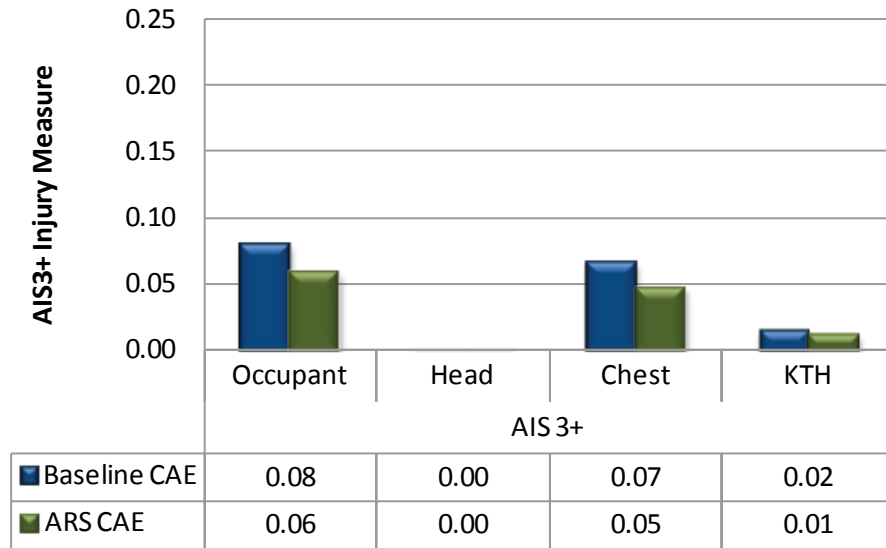
## B.3.4 Pole25, HIII 50M

Table B.16 – ARS Configuration/Deployment Times for Pole25, HIII 50M Passenger

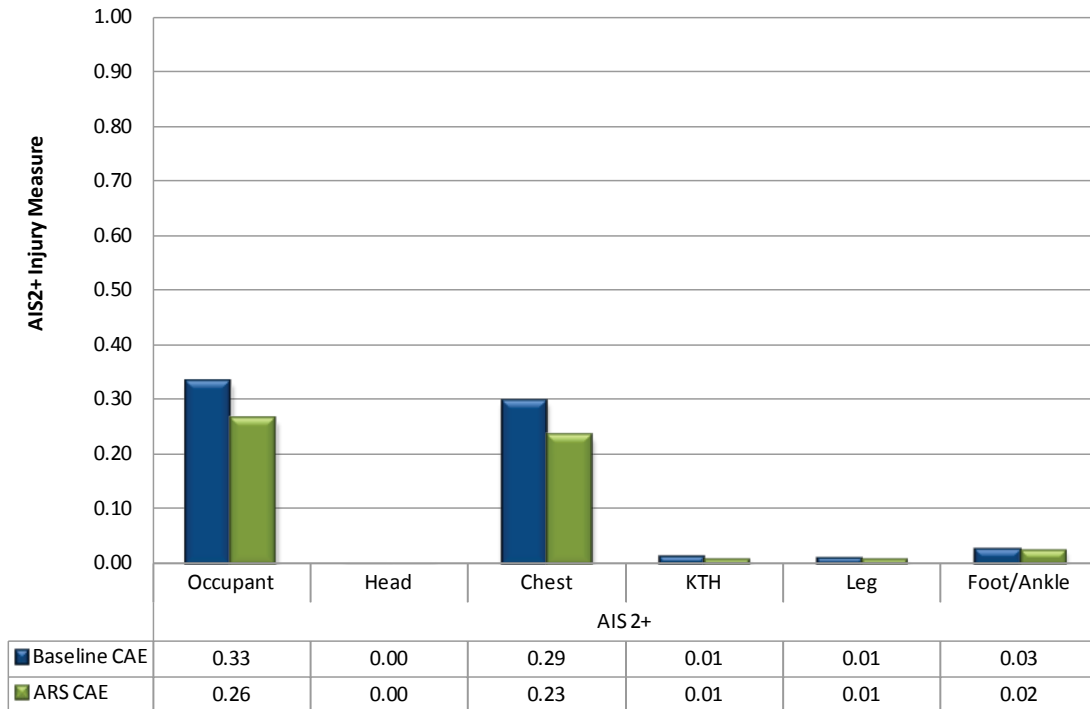
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	40
	Stage 2	45
	PVM Deploy Time	94
Knee Air Bag		40
Seat Belt System	Retractor PT	40
	Lap Anchor PT	40
	Retractor IEA Switch Time	65
Seat Ramp		ON

Table B.17 – Summary of Peak Injury Values for Pole25, HIII 50M Passenger

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	100	94
Neck NIJ	0.41	0.26
Chest Deflection (mm)	23	15
Chest Accel - 3ms (g)	36	29
Left Femur Fz (kN)	2.50	1.70
Right Femur Fz (kN)	2.40	1.29
Left Upper Tibia Fz (kN)	1.17	0.90
Right Upper Tibia Fz (kN)	1.26	0.56
Left Lower Tibia Fz (kN)	1.10	1.28
Right Lower Tibia Fz (kN)	1.46	0.79



**Figure B.15 – AIS3+ Injury Measure Summary for Pole25, HIII 50M Passenger**



**Figure B.16 – AIS2+ Injury Measure Summary for Pole25, HIII 50M Passenger**

## Appendix C 95<sup>th</sup> Percentile Male Occupant (HIII 95M)

### C.1 Background

There were no baseline PVP vehicle crash tests with the HIII 95M ATD, and so the assessment of the advanced restraint system relative to the baseline PVP restraint system was based solely on CAE analysis. The correlated MDB-to-vehicle and vehicle-to-pole models for the HIII 50M ATD were used, and the HIII 95M ATD CAE occupant model obtained from Humanetics (formerly First Technology Safety Systems) was swapped with the HIII 50M ATD. The occupant performance for the HIII 95M ATD in each of the load cases was established using the PVP restraint hardware, and then the models were run with the ARS components to determine the potential incremental benefit.

All CAE simulations with the HIII 95M ATD were conducted at a nominal 95<sup>th</sup> seating position identified for the PVP as the full-rear/full-down position. In addition, the D-ring was at the full-up position.

### C.2 Driver

#### C.2.1 MDB35, HIII 95M

**Table C.1 – ARS Configuration/Deployment Times for MDB35, HIII 95M Driver**

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	12
	Stage 2	22
	PVM Deploy Time	87
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	18
	Retractor IEA Switch Time	67
Seat Ramp		ON

**Table C.2 – Summary of Peak Injury Values for MDB35, HIII 95M Driver**

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	450	465
Neck NIJ	0.78	0.59
Chest Deflection (mm)	49	44
Chest Accel - 3ms (g)	52	46
Left Femur Fz (kN)	3.45	2.16
Right Femur Fz (kN)	3.50	6.15



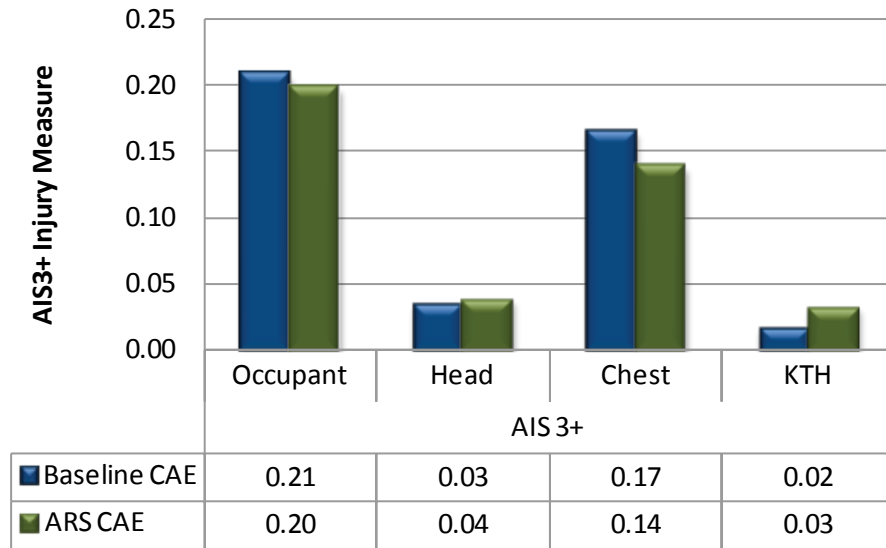


Figure C.1 – AIS3+ Injury Measure Summary for MDB35, HIII 95M Driver

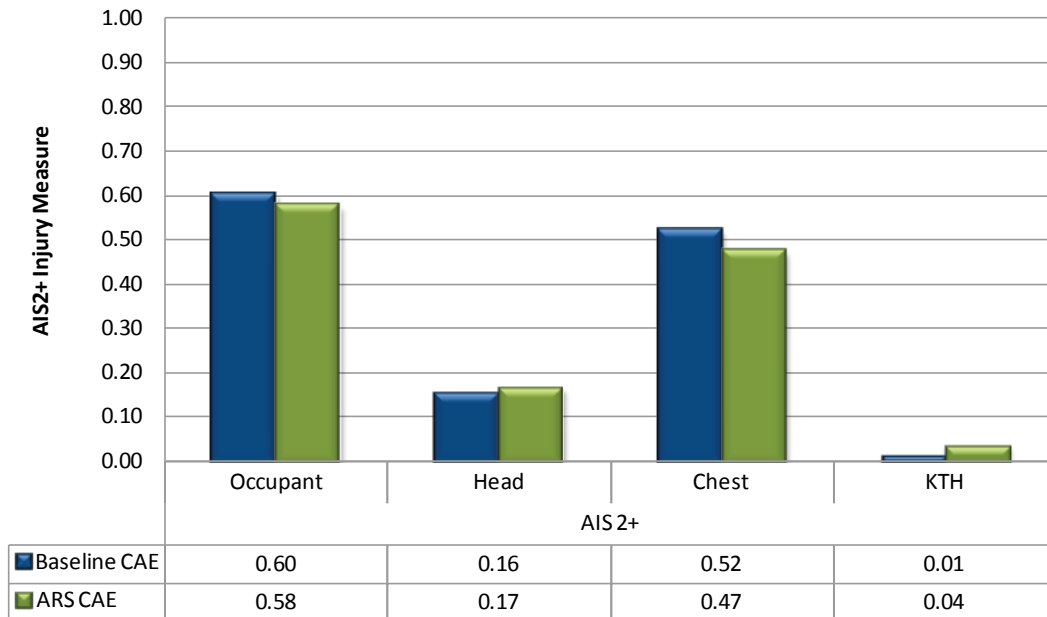


Figure C.2 – AIS2+ Injury Measure Summary for MDB35, HIII 95M Driver

## C.2.2 MDB25, HIII 95M

Table C.3 – ARS Configuration/Deployment Times for MDB25, HIII 95M Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	18
	Stage 2	28
	PVM Deploy Time	83
Knee Air Bag		OFF
Seat Belt System	Retractor PT	18
	Lap Anchor PT	18
	Retractor IEA Switch Time	63
Seat Ramp		ON

Table C.4 – Summary of Peak Injury Values for MDB25, HIII 95M Driver

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	250	204
Neck NIJ	0.53	0.42
Chest Deflection (mm)	47	43
Chest Accel - 3ms (g)	32	36
Left Femur Fz (kN)	1.96	1.78
Right Femur Fz (kN)	1.29	1.41

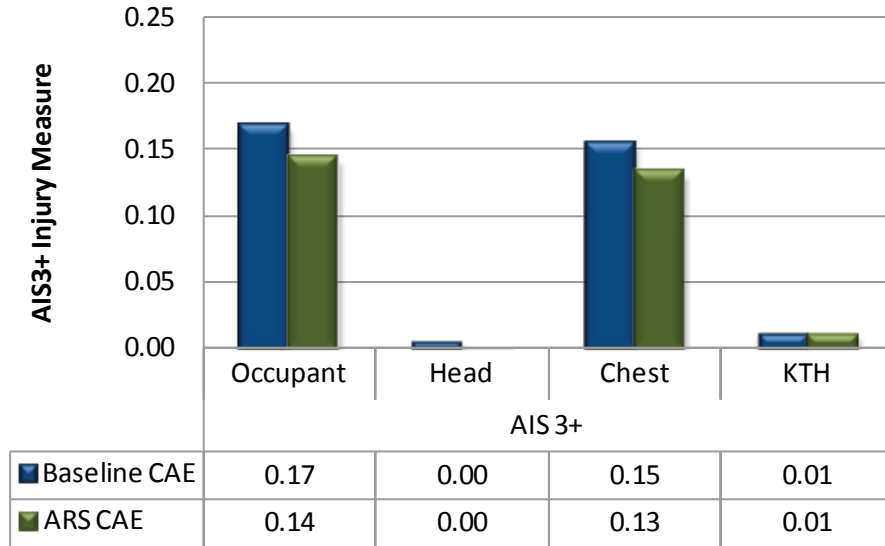


Figure C.3 – AIS3+ Injury Measure Summary for MDB25, HIII 95M Driver

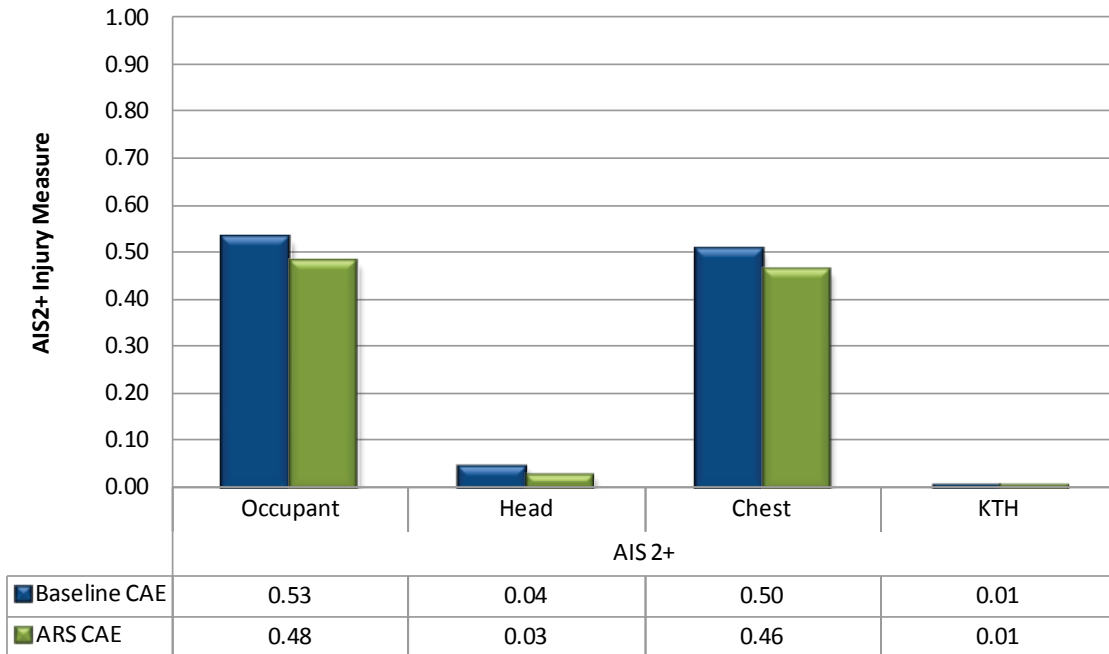


Figure C.4 – AIS2+ Injury Measure Summary for MDB25, HIII 95M Driver

## C.2.3 Pole35, HIII 95M

Table C.5 – ARS Configuration/Deployment Times for Pole35, HIII 95M Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	34
	Stage 2	44
	PVM Deploy Time	84
Knee Air Bag		34
Seat Belt System	Retractor PT	34
	Lap Anchor PT	34
	Retractor IEA Switch Time	89
Seat Ramp		ON

Table C.6 – Summary of Peak Injury Values for Pole35, HIII 95M Driver

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	545	429
Neck NIJ	0.69	0.52
Chest Deflection (mm)	53	47
Chest Accel - 3ms (g)	49	42
Left Femur Fz (kN)	3.06	2.52
Right Femur Fz (kN)	2.17	2.25

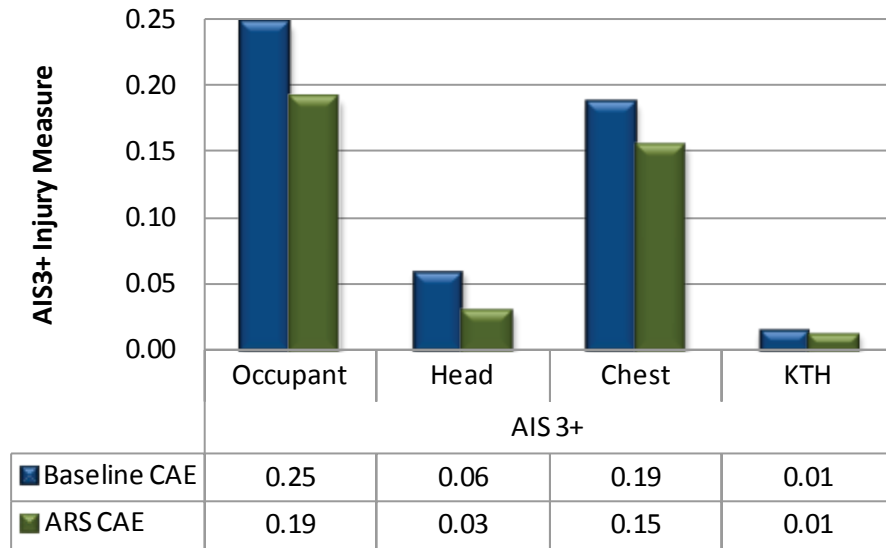


Figure C.5 – AIS3+ Injury Measure Summary for Pole35, Hill 95M Driver

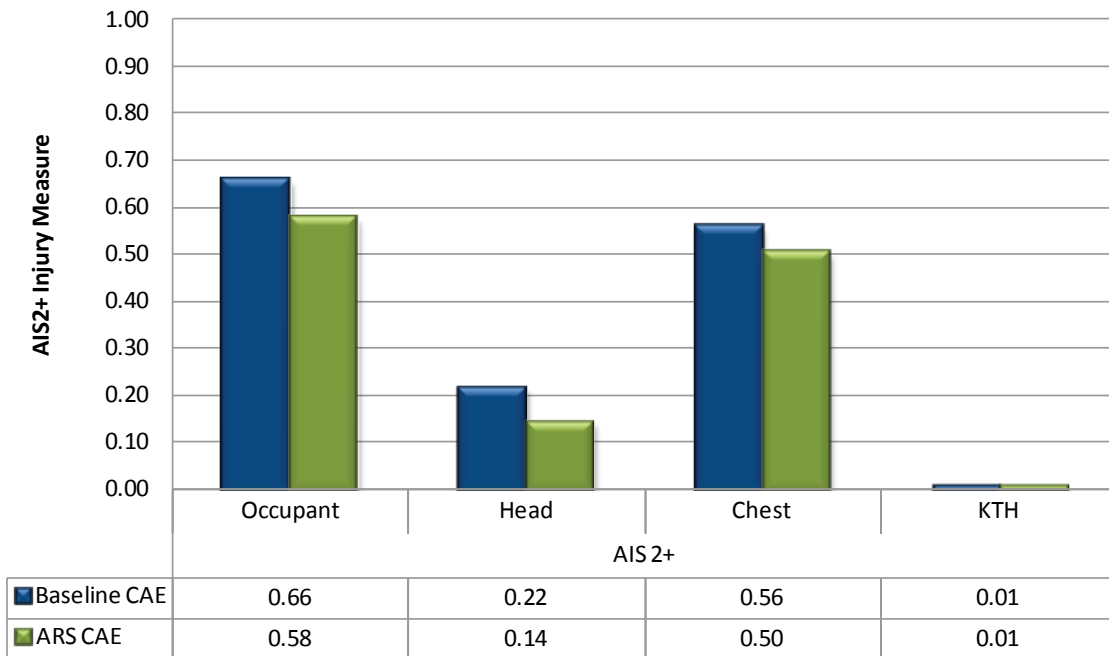


Figure C.6 – AIS2+ Injury Measure Summary for Pole35, Hill 95M Driver

## C.2.4 Pole25, HIII 95M

Table C.7 – ARS Configuration/Deployment Times for Pole25, HIII 95M Driver

ARS Component		Deployment Times (ms)
Driver Air Bag	Stage 1	40
	Stage 2	50
	PVM Deploy Time	90
Knee Air Bag		40
Seat Belt System	Retractor PT	40
	Lap Anchor PT	40
	Retractor IEA Switch Time	95
Seat Ramp		ON

Table C.8 – Summary of Peak Injury Values for Pole25, HIII 95M Driver

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	200	235
Neck NIJ	0.43	0.49
Chest Deflection (mm)	54	43
Chest Accel - 3ms (g)	37	31
Left Femur Fz (kN)	0.96	1.87
Right Femur Fz (kN)	3.20	2.14

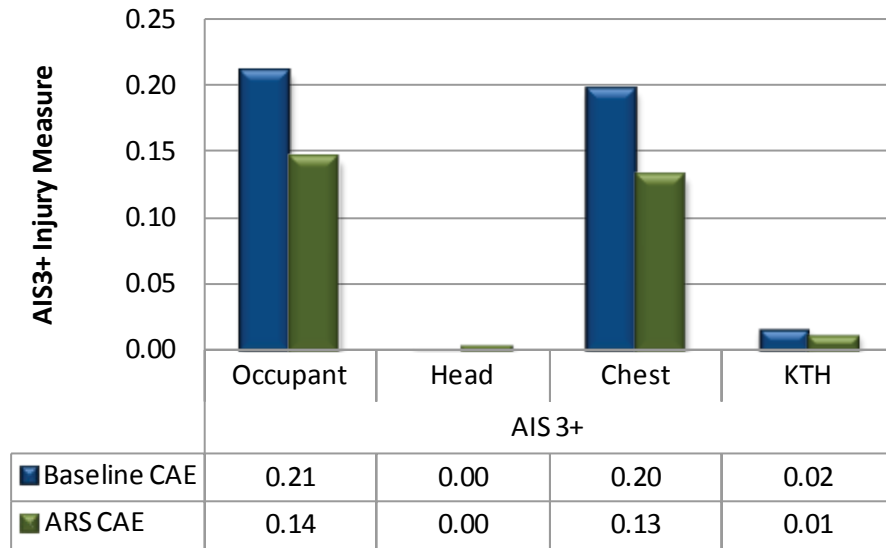


Figure C.7 – AIS3+ Injury Measure Summary for Pole25, Hill 95M Driver

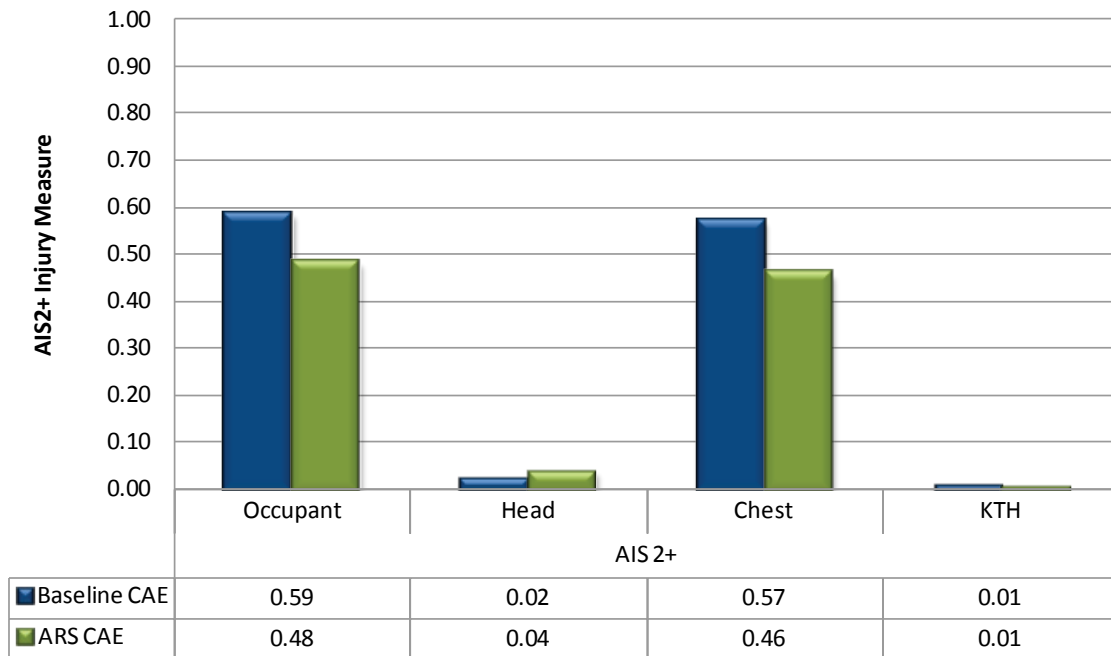


Figure C.8 – AIS2+ Injury Measure Summary for Pole25, Hill 95M Driver

### C.3 Passenger

#### C.3.1 MDB35, HIII 95M

**Table C.9 – ARS Configuration/Deployment Times for MDB35, HIII 95M Passenger**

ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	12
	Stage 2	17
	PVM Deploy Time	82
Knee Air Bag		12
Seat Belt System	Retractor PT	12
	Lap Anchor PT	12
	Retractor IEA Switch Time	72
Seat Ramp		ON

**Table C.10 – Summary of Peak Injury Values for MDB35, HIII 95M Passenger**

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	404	374
Neck NIJ	0.64	0.80
Chest Deflection (mm)	35	35
Chest Accel - 3ms (g)	50	43
Left Femur Fz (kN)	4.81	3.37
Right Femur Fz (kN)	5.32	5.10



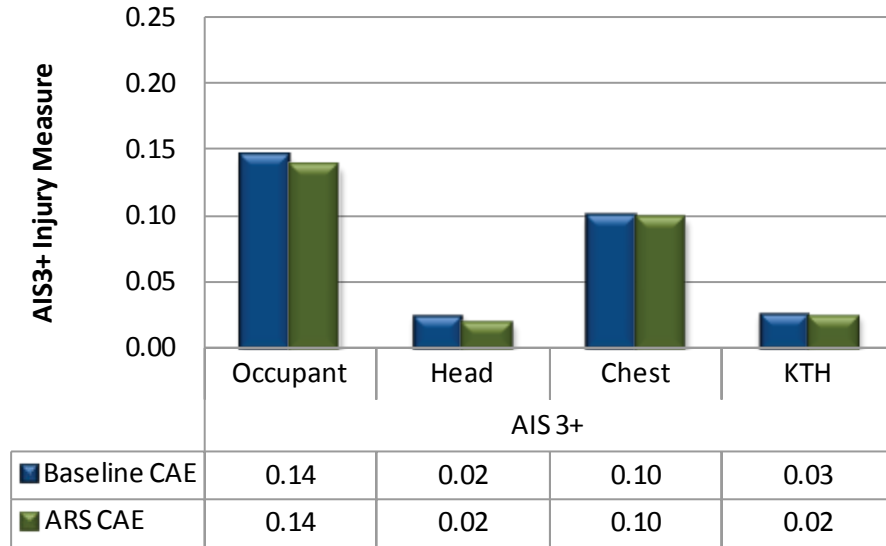


Figure C.9 – AIS3+ Injury Measure Summary for MDB35, Hill 95M Passenger

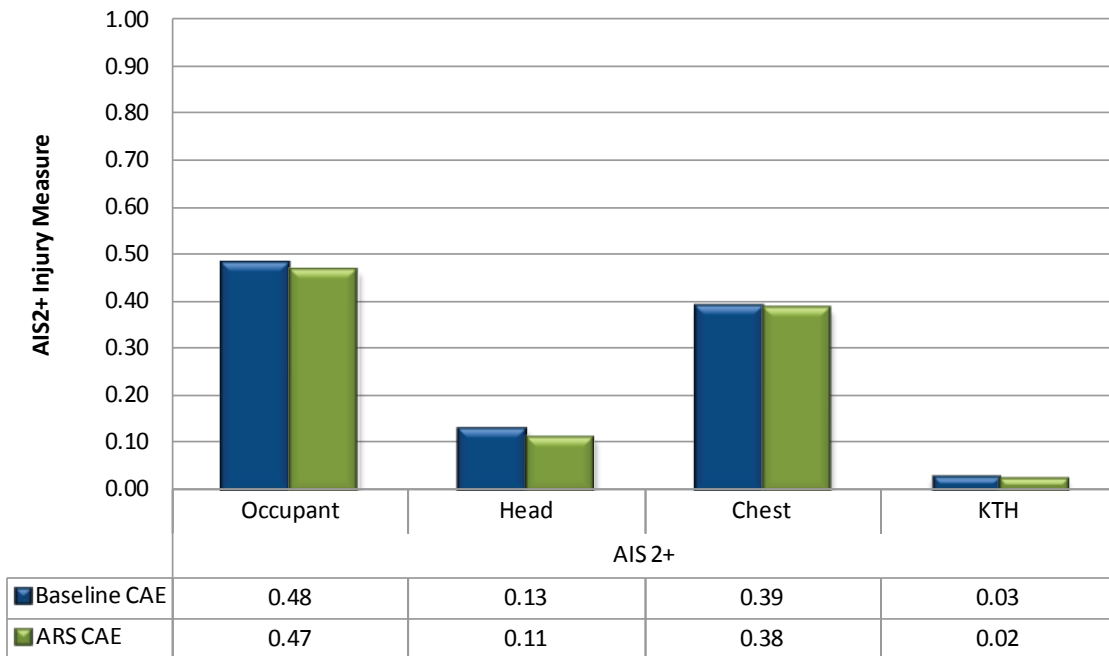


Figure C.10 – AIS2+ Injury Measure Summary for MDB35, Hill 95M Passenger

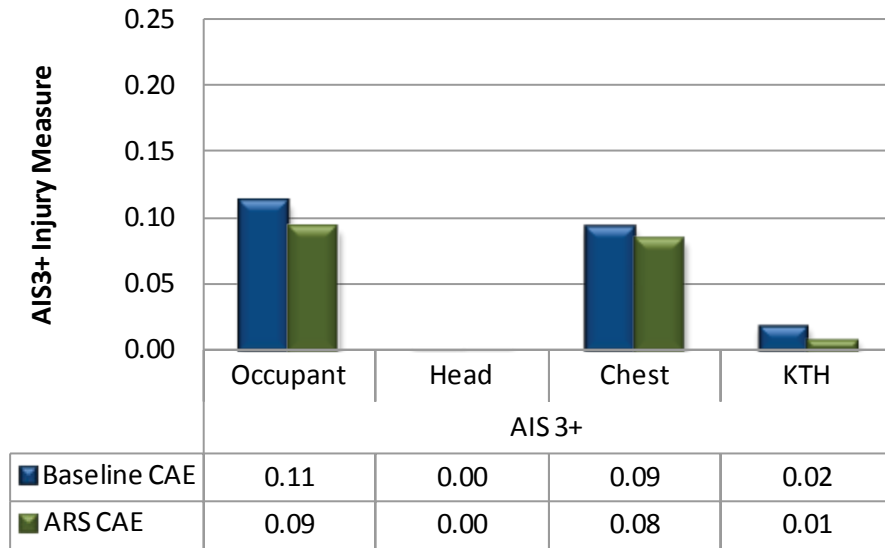
## C.3.2 MDB25, HIII 95M

Table C.11 – ARS Configuration/Deployment Times for MDB25, HIII 95M Passenger

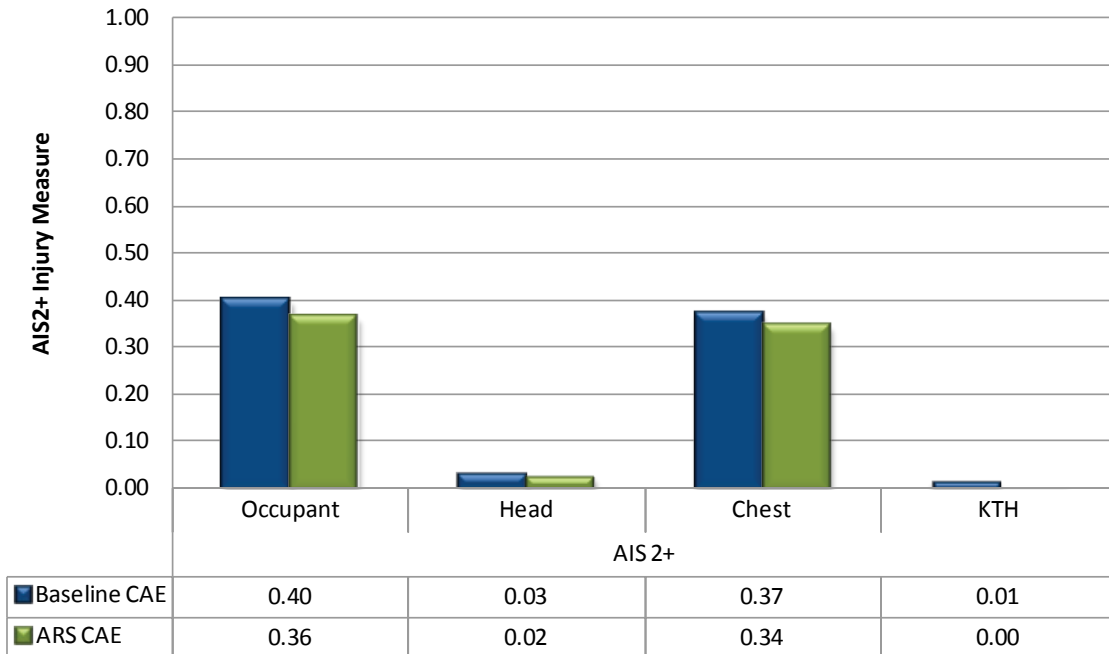
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	18
	Stage 2	23
	PVM Deploy Time	93
Knee Air Bag		OFF
Seat Belt System	Retractor PT	18
	Lap Anchor PT	18
	Retractor IEA Switch Time	68
Seat Ramp		ON

Table C.12 – Summary of Peak Injury Values for MDB25, HIII 95M Passenger

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	214	196
Neck NIJ	0.57	0.43
Chest Deflection (mm)	34	31
Chest Accel - 3ms (g)	45	45
Left Femur Fz (kN)	2.00	0.53
Right Femur Fz (kN)	3.81	0.58



**Figure C.11 – AIS3+ Injury Measure Summary for MDB25, HIII 95M Passenger**



**Figure C.12 – AIS2+ Injury Measure Summary for MDB25, HIII 5F Passenger**

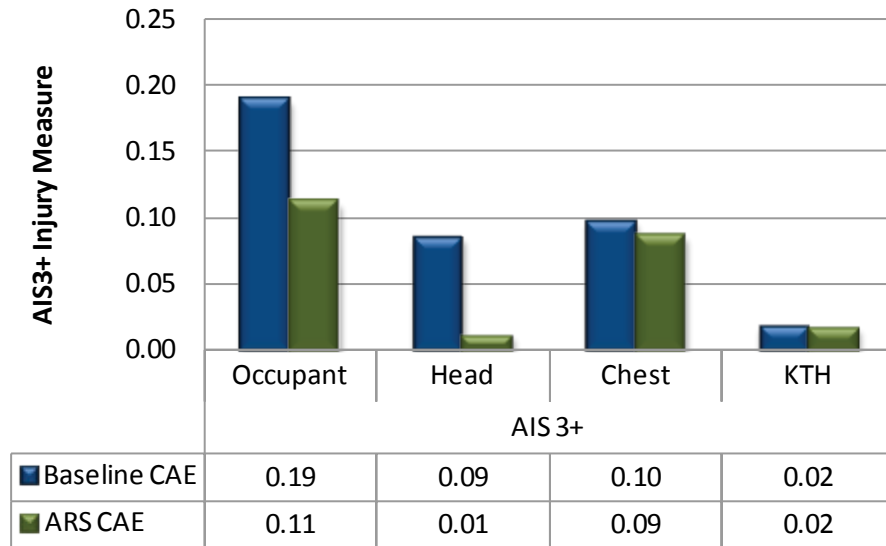
## C.3.3 Pole35, HIII 95M

Table C.13 – ARS Configuration/Deployment Times for Pole35, HIII 95M Passenger

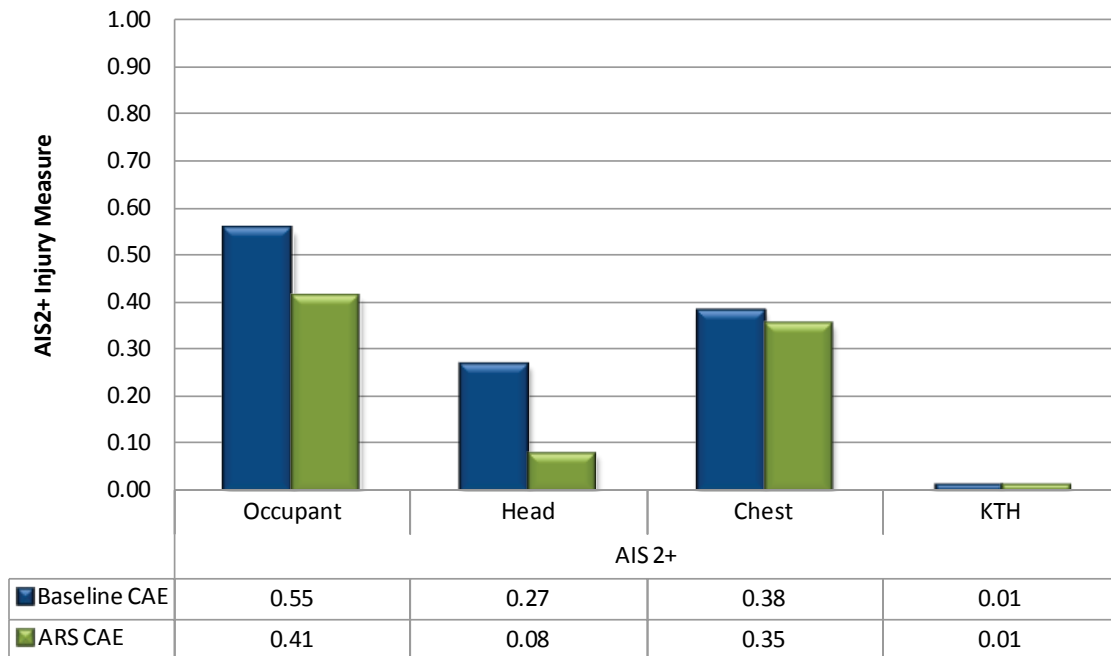
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	25
	Stage 2	30
	PVM Deploy Time	90
Knee Air Bag		25
Seat Belt System	Retractor PT	25
	Lap Anchor PT	25
	Retractor IEA Switch Time	80
Seat Ramp		ON

Table C.14 – Summary of Peak Injury Values for Pole35, HIII 95M Passenger

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	625	318
Neck NIJ	0.94	0.56
Chest Deflection (mm)	35	32
Chest Accel - 3ms (g)	55	30
Left Femur Fz (kN)	3.85	3.51
Right Femur Fz (kN)	2.33	1.90



**Figure C.13 – AIS3+ Injury Measure Summary for Pole35, HIII 95M Passenger**



**Figure C.14 – AIS2+ Injury Measure Summary for Pole35, HIII 95M Passenger**

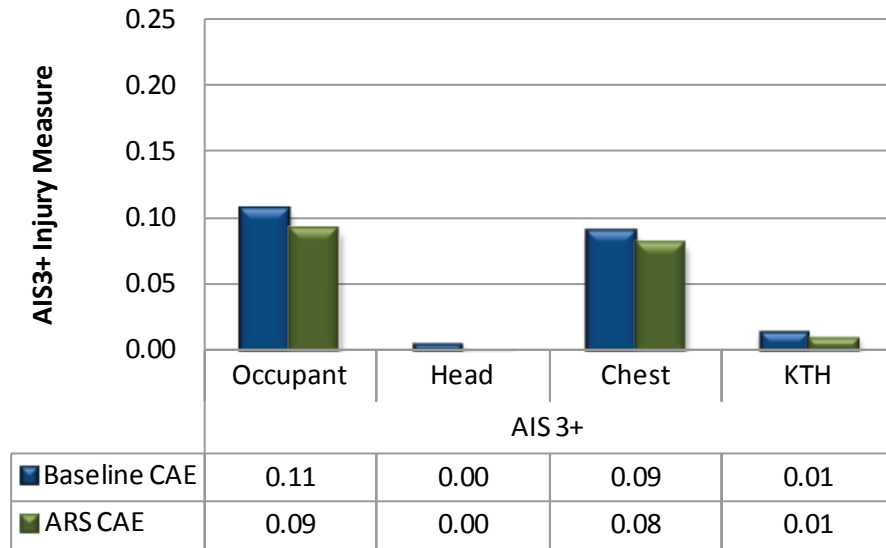
## C.3.4 Pole25, HIII 95M

Table C.15 – ARS Configuration/Deployment Times for Pole25, HIII 5F Passenger

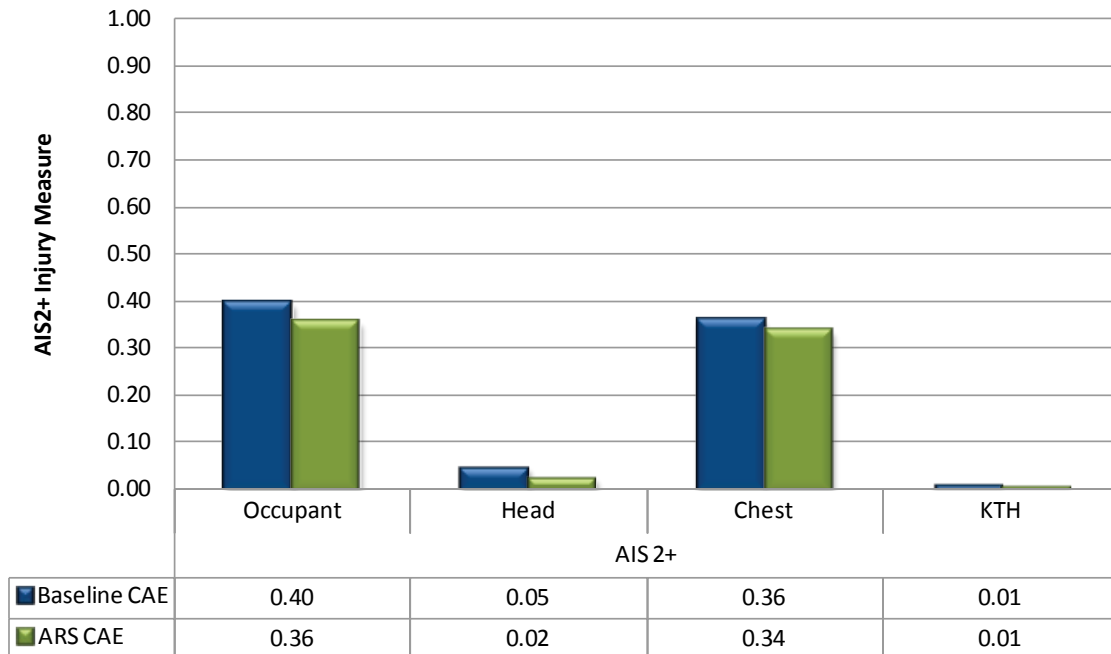
ARS Component		Deployment Times (ms)
Passenger Air Bag	Stage 1	40
	Stage 2	45
	PVM Deploy Time	105
Knee Air Bag		40
Seat Belt System	Retractor PT	40
	Lap Anchor PT	46
	Retractor IEA Switch Time	95
Seat Ramp		ON

Table C.16 – Summary of Peak Injury Values for Pole25, HIII 95M Passenger

Injury Criteria	Baseline CAE	ARS CAE
HIC (15ms)	255	197
Neck NIJ	0.72	0.37
Chest Deflection (mm)	32	30
Chest Accel - 3ms (g)	46	40
Left Femur Fz (kN)	1.80	1.35
Right Femur Fz (kN)	2.70	1.43



**Figure C.15 – AIS3+ Injury Measure Summary for Pole25, HIII 95M Passenger**



**Figure C.16 – AIS2+ Injury Measure Summary for Pole25, HIII 95M Passenger**

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