Seventh Triennial International
Aircraft Fire & Cabin Safety Research Conference
Dec 2-5 2013

Aircraft Seat Performance Evaluation for Larger (95 Percentile Passenger) Population using Analytical Methods

- Background
- Base Model Validation (AC 20.146 & ARP 5765)
- Evaluation of 95th Percentile Passenger
- Case 1 – Typical Business Jet Seat
- Case 2 – Typical Commercial Aircraft Seat
- ~~Conclusion~~ Discussions

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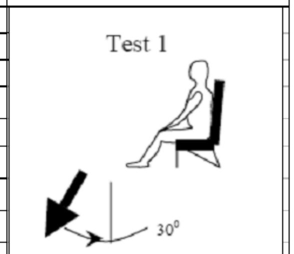
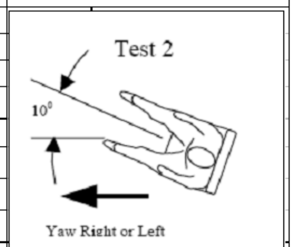
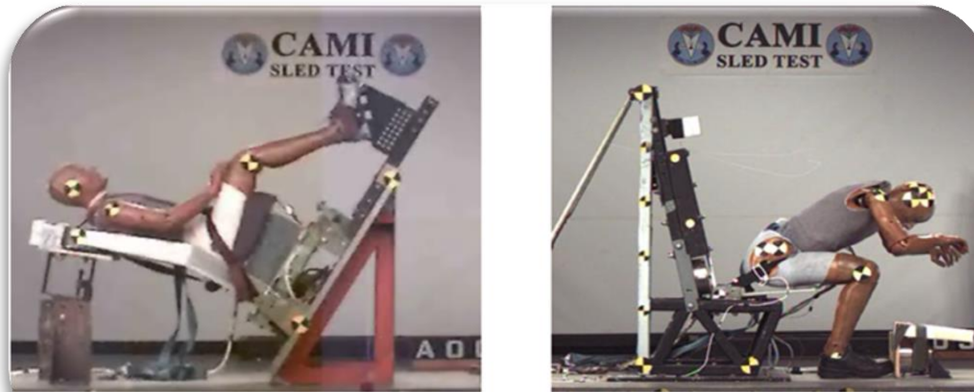
Background

- **Civil Aircraft Dynamic Seat Regulations; 25.562**

Aircraft Type	Part 23	Part 25	
	FAR 23.562	FAR 25.562	
Test 1 Combined vertical / longitudinal condition			
Test Velocity (in ft / sec)	31	35	
Peak Deceleration (in G's)	19 /15	14	
Time to Peak (in sec)	0.05 / 0.06	0.08	
Seat Yaw angle	0^{0}	0^{0}	
Initial conditions			
Seat Pitch angle	0^{0}	0^{0}	
Seat Roll angle	0^{0}	0^{0}	
Fixture angle	60^{0} Fixture	60^{0} Fixture	
Test 2 Longitudinal condition			
Test Velocity (in ft / sec)	42	44	
Peak Deceleration (in G's)	26 / 21	16	
Time to Peak (in sec)	0.05 / 0.06	0.09	
Seat Yaw angle	10^{0}	10^{0}	
Initial conditions			
Seat Pitch angle	10^{0}	10^{0}	
Seat Roll angle	10^{0}	10^{0}	
Fixture angle	0^{0}	0^{0}	
Compliance Criteria			
Deformation Limit - inch			
HIC	1000	1000	
Lumbar Load - lb	1500	1500	
Strap Load - lb	1750	1750	
Femur Load - lb	NA	2250	

Dynamic test conditions 1 and 2



Test condition 1 Test condition 2

- **Not only Structural Integrity but also Passenger Safety**
- **Both tests must be conducted with an occupant simulated by a 170-pound (ATDs)**

Facts

- Structural evaluation of Civil Aircrafts is based on 50th percentile male ATDs (Ref. 14CFR 25.562)
- Structural Integrity comes first and then Passenger Safety
- Automotive Seat testing involves both 50th and 95th percentile ATDs (Ref. FMVSS)
- Military aircraft seat testing involves both 50th and 95th percentile ATDs

Purpose of this Study

- In house, additional evaluation of seating systems beyond regulatory requirements
  - To determine seat loads for 95 Percentile passenger
  - To determine injuries for 95 Percentile passenger
  - Ultimate aim is to determine "how much extra structural weight to seat" for 95 Percentile passenger (Not covered in this study)

Procedure

Base FEA seat model was validated with test results (AC 20.146)

Methodology was then utilized to demonstrate or to compare the effect of using the 95th percentile e-ATDs on the important test parameters such as:

- Restraint loads,
- Floor reactions

- Head paths and Acceleration
- Lumbar load

For Comparison, a few seat scenarios were studied:

- Rigid Seat (not attached)
- Typical Business Aircraft Jet Seat
- Typical Commercial Aircraft Seat

No testing was done on 95th percentile ATDs

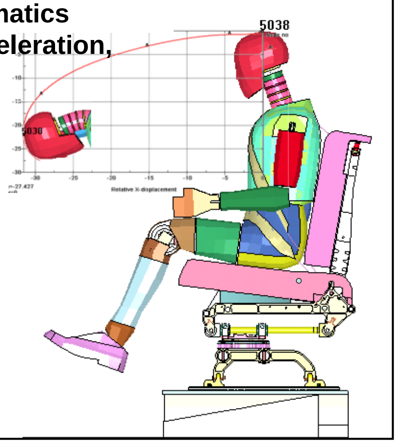
- Occupant kinematics and Head path
- Energy balance
- Restraint loads
- Seat deformations
- Floor reaction
- HIC
- Lumbar load

Validation Process for Base Model As per AC 20.146

- Material Testing : Coupons
- Component Testing
- Cushion: DAX 55
- Restraint: Polyester
- Material Model Verifications

- E-ATDs: from LSTC
- Solver: LSDYNA

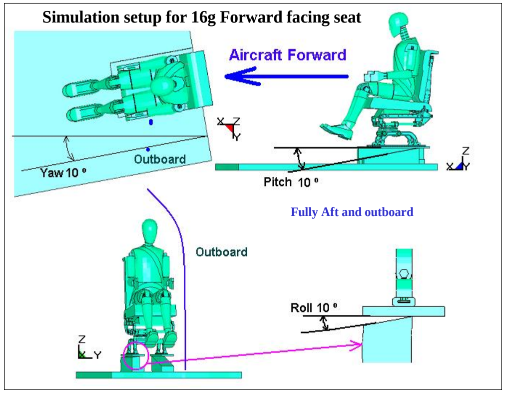
Occupant kinematics
Head Path, Acceleration, etc.



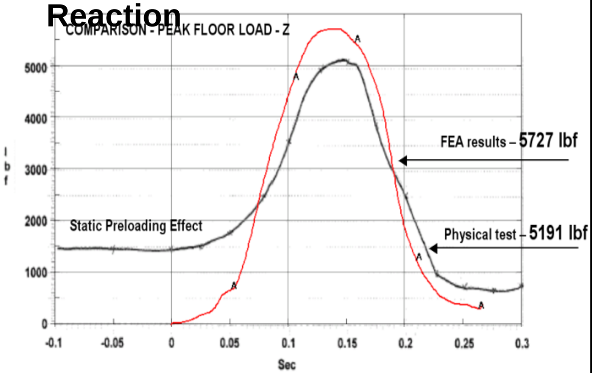
Ultimately, the goal is to satisfactorily answer the question "How well does the FE model simulate the physical certification test?"

+- 10 %

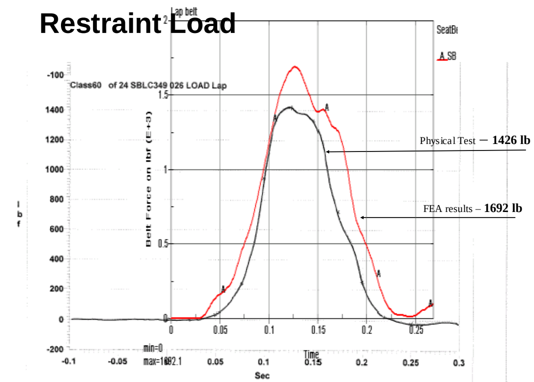
Initial Setup



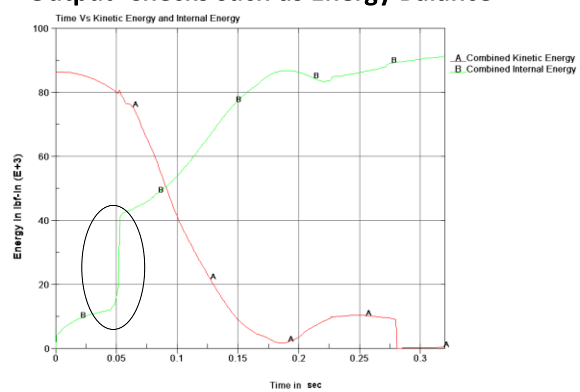
Floor Reaction



Restraint Load



Output Checks such as Energy Balance



Summary Validation

Sr. No	Items		Results			Comparison		Remarks
	Loads at peak Magnitude and Time	**Units**	**FEA**	**Test**	**Compliance Limit**	**% Magnitude**	**% Phase**	
Test Condition 2 - Longitudinal velocity change dynamic test condition								
1	Sled peak acceleration	g's	16.20	16.20				
2	Floor reactions							Loads below 25% of the peak are not cosidered for validation
a	Maximum tension	Lbs	5522.66	5191		6.39		
	Time		0.138	0.145			-4.83	
b	Maximum compression	Lbs	-4611	-4595		0.36		
	Time		0.114	0.130			-12.31	
3	Belt loads							
a	Shoulder	Lbs	963	876	1750	9.97		
	Time		0.115	0.120			-4.17	
b	Lap	Lbs	1514	1426		6.17		
	Time		0.123	0.122			0.82	
4	Head Trajectory	inch	32.00	28.00		14.29		
5	Head Acceleration	g's	No head strike		1000			Only in case of Head striking
6	Backrest Deformations	inch	1.12	1.32		-15.45		
7	Seat Pan Angle	degree	6.00	5.20		15.38		

AC 20.146 & ARP 5765

AC 20.146: Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, and 29 Airplanes and Rotorcraft

ARP5765 : Analytical Methods for Aircraft Seat Design and Evaluation

SAE Aircraft SEAT Committee

Industry group (including the FAA, EASA and Research Institutes) defines industry best practices

- Aviation Standard (AS)
- Aviation Recommended Practice (ARP)
- Aviation Information Reports (AIR)

SAE ARP 5765

Objectives

- Support AC 20.146
- Quantitative method to measure and evaluate the degree of correlation between an analytical model and a test
- Best modeling practices to improve the accuracy and predictability of seat analyses

Participants: Technical Specialist from

Seat Suppliers
- Weber / Zodiac
- IPECO
- Recaro
- Sicma
- B/E Aerospace
- Contour

A/C Manufacturers
- Airbus
- Cessna
- Embraer

Software
- FTSS
- TASS
- ESI
- Altair

Regulatory
- FAA
- EASA

Academic
- NIAR

SAE ARP 5765

Outline

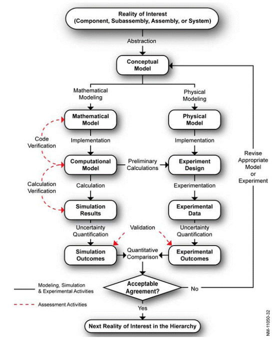
Section 3: V-ATD Calibration

Validation of V-ATDs based on test data

- Physical Properties and Geometry
- Kinematics
- Dynamic response
- Defines compliance criteria


SAE Aerospace
AEROSPACE STANDARD
AS8056
Issued 2004-11
Minimum Design and Performance of Airplane Galley In-Flight Carts, Containers, and Associated Components
FOREWORD
The development of these criteria was jointly accomplished by the Society of Automotive Engineers (SAE) and European Organization of Civil Aviation Equipment (EUROCAE) Working Group 65 through a consensus process. This document is compatible with EUROCAE document ED-121.
SAE and EUROCAE are international not-for-profit organizations, formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public.
Since SAE and EUROCAE are not official agencies of any U.S. or European government, their recommendation may not be regarded as statements of official government policy unless so enunciated by the appropriate government organization, conference of governments, or agency having statutory jurisdiction over any matters to which the recommendations relate.

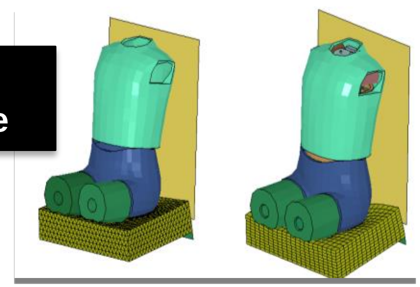
Section 4: System Validation



How to evaluate accuracy of seat model?

- Defines set of test parameters & data to evaluate the degree of correlation between the model & the test,
- Define process map & provides procedures for quantitative comparison of test and modeling results.

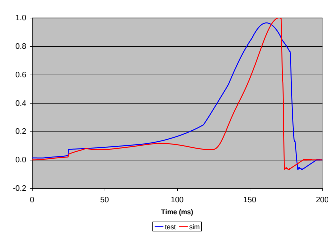
Section 5: Testing & Modeling Best Practice



Best practice guidelines

- Provides best practices for test & modeling that help improving accuracy and validity of computer models

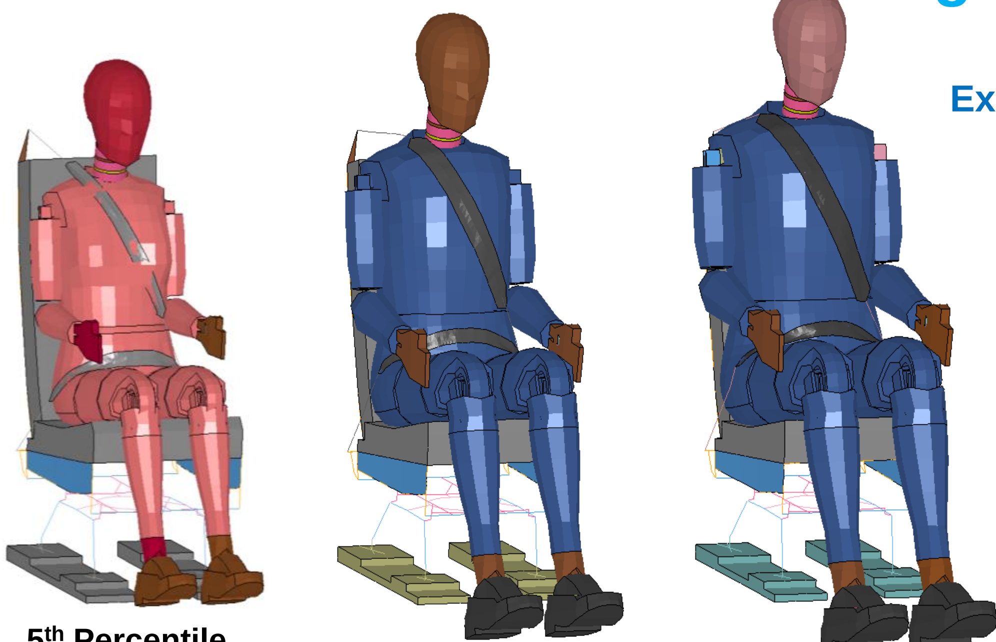
Appendix:



Appendix

- A: Methodology for comparison of Test and Simulation Waveforms
- B & C: Data set for Hybrid II & FAA Hybrid III
- D: Sample V-ATD calibration report

Evaluation of 95 Percentile Passenger



5th Percentile Female | 50th Percentile M | 95th Percentile M

Examples of Passenger Populations

Methodology was then utilized to demonstrate or to compare the effect of using the 95th percentile e-ATDs on the important test parameters such as:

- Restraint loads,
- Floor reactions

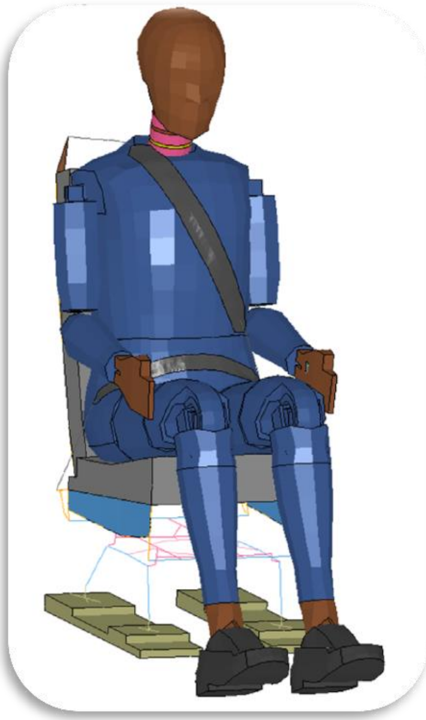
- Head paths and Acceleration
- Lumbar load

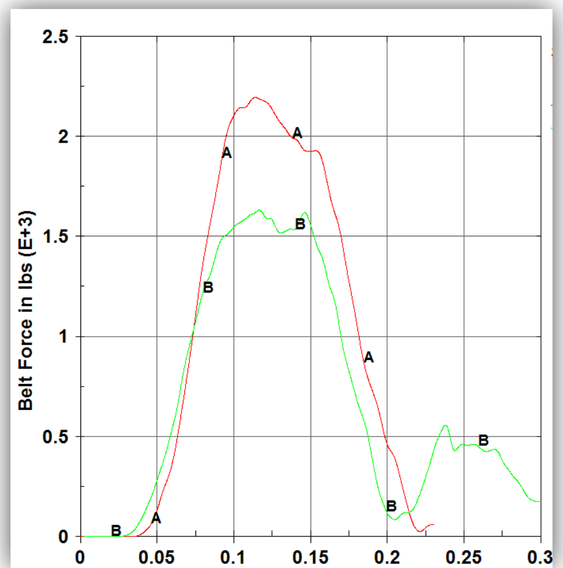
5th percentile female e-ATD was also analyzed for reference.

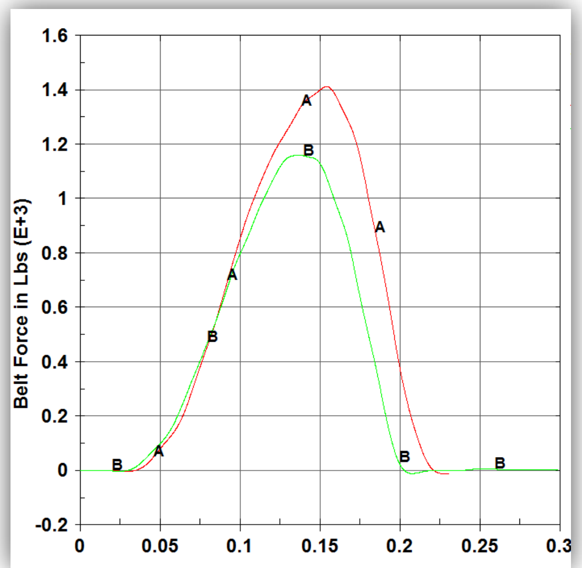
Comparison – 5th, 50th and 95th e-ATD						
Sr No	**Loads at peak Magnitude and Time**	**Units**	**5th Percentile Female e-ATD**	**50th Percentile Male e-ATD**	**95th Percentile Male e-ATD**	**% Increase 95th to 50th**
						% Magnitude
1	**Weight**					
	Seat Weight	Lbs	45	45	45	
	Occupant weight	Lbs	108	170	225	32.35
	Total Weight	Lbs	153	215	270	25.58
2	**Height**					
	Occupant Sitting Height	in	31	34.8	36.8	5.75
	Occupant Sitting CG (from H- point)	in		3.7	4.4	18.92

Case 1 – Typical Business Jet Seat

Belt Loads



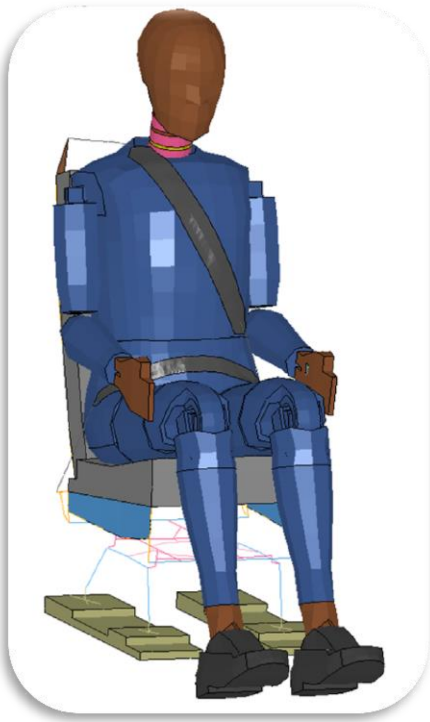


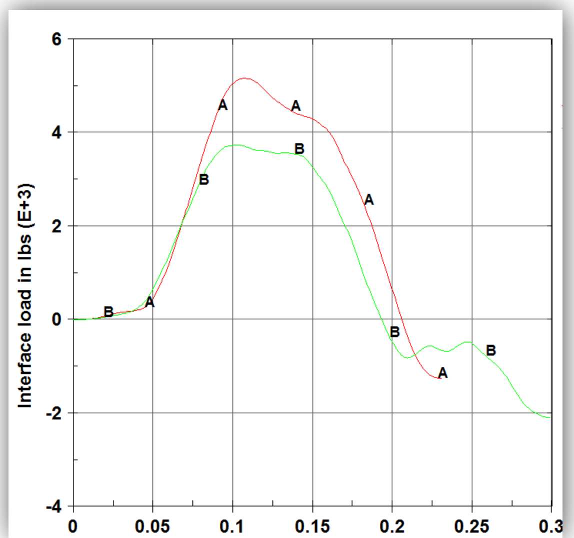


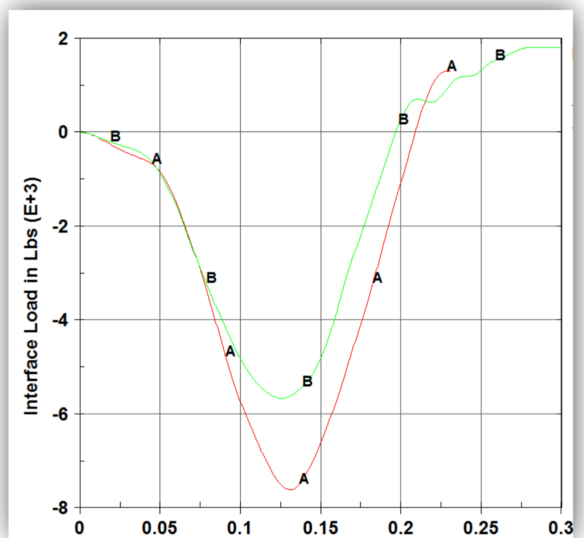
Comparison - 50th and 95th e-ATD Results						
Sr No	**Loads at peak Magnitude and Time**	**Units**	**50th Percentile e-ATD**	**95th Percentile e-ATD**	**% Increase**	
					% Magnitude	**% Phase**
1	Sled peak deceleration	g's	16	16		
3	Belt loads					
a	Shoulder	Lbs	1186	1446	**21.9**	
	Time	Seconds	0.138	0.156		**13.0**
b	Lap	Lbs	1633	2196	**34.5**	
	Time	Seconds	0.117	0.113		**-3.4**

Case 1 – Typical Business Jet Seat

Interface load or Floor Reaction



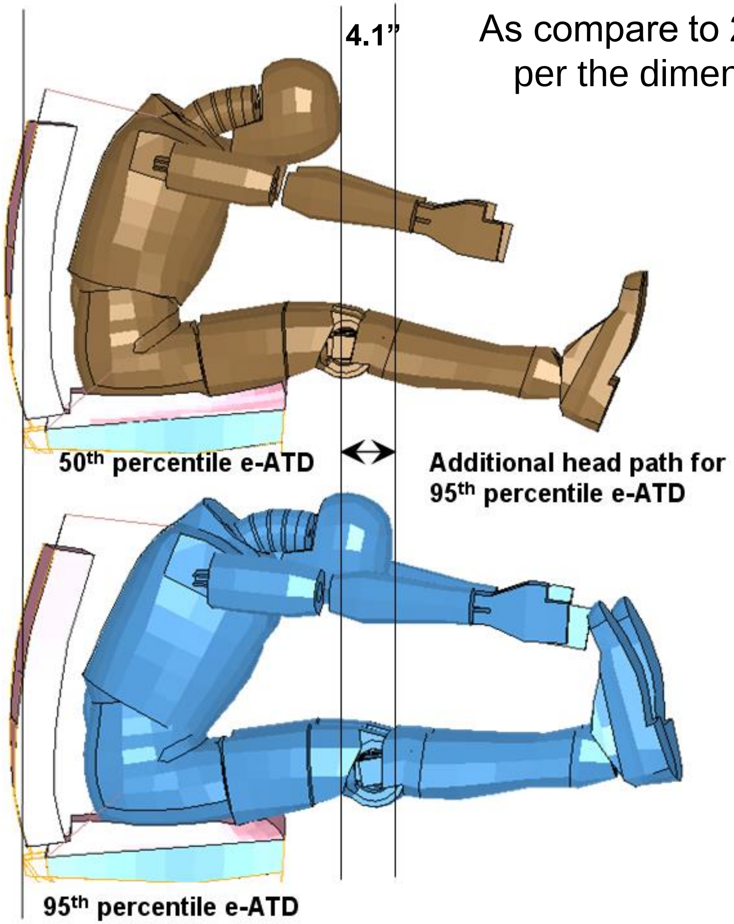




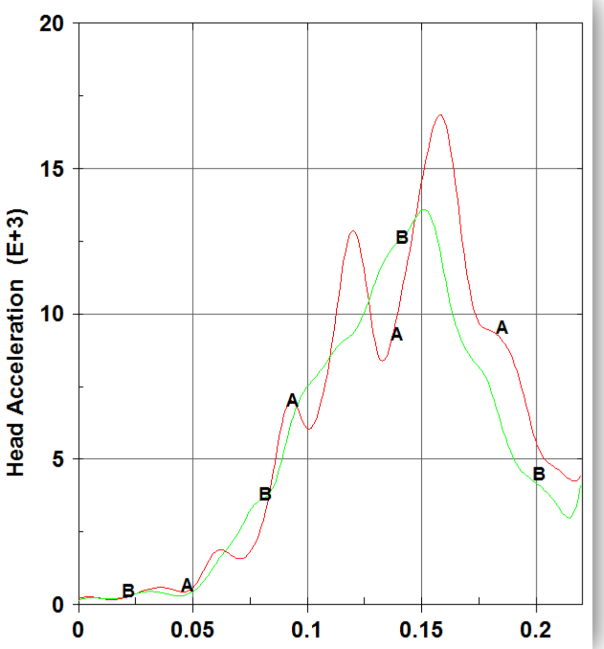
Comparison - 50th and 95th e-ATD Results						
Sr No	Loads at peak Magnitude and Time	Units	50th Percentile e-ATD	95th Percentile e-ATD	% Increase	
					% Magnitude	% Phase
1	Sled peak deceleration	g's	16	16		
2	Floor reactions					
a	Maximum compression	Lbs	5717	7594	32.8	
	Time	Seconds	0.126	0.131		4.0
b	Maximum tension	Lbs	3841	5126	33.5	
	Time	Seconds	0.106	0.112		5.7

Case 1 – Typical Business Jet Seat

Head Path and Head Accelerations



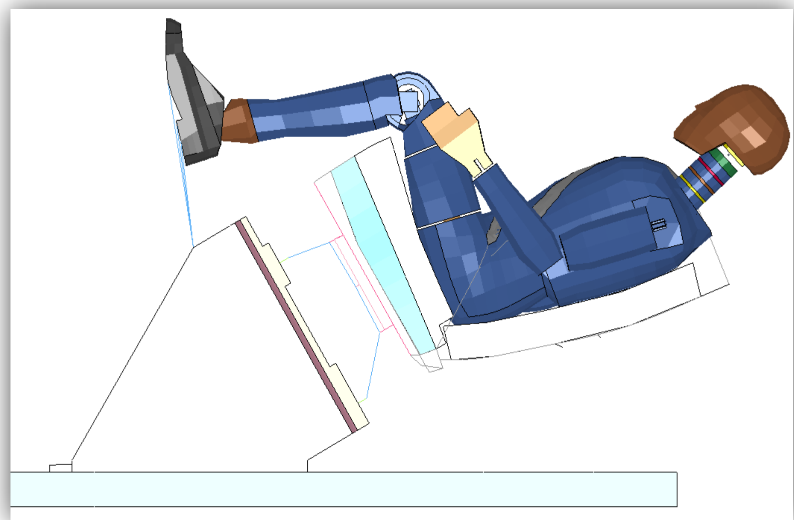
As compare to 2.3” as per the dimension

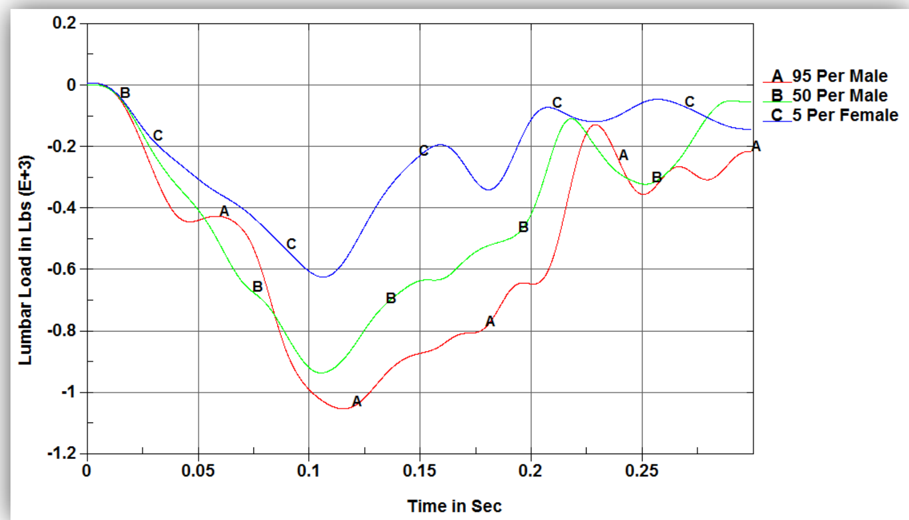


Comparison - 50th and 95th e-ATD Results						
Sr No	Item	Units	50th Percentile e-ATD	95th Percentile e-ATD	% Increase	
					% Magnitude	% Phase
1	Sled peak deceleration	g's	16	16		
4	Head Path	inch	17.9	22.0	23.2	

Case 1 – Typical Business Jet Seat

Lumbar Load with leg support

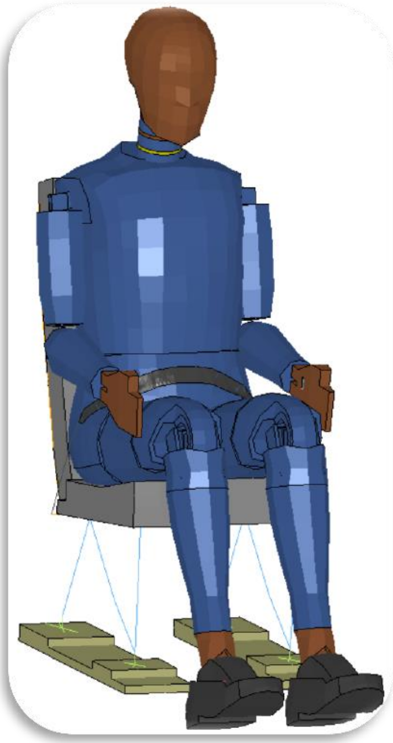


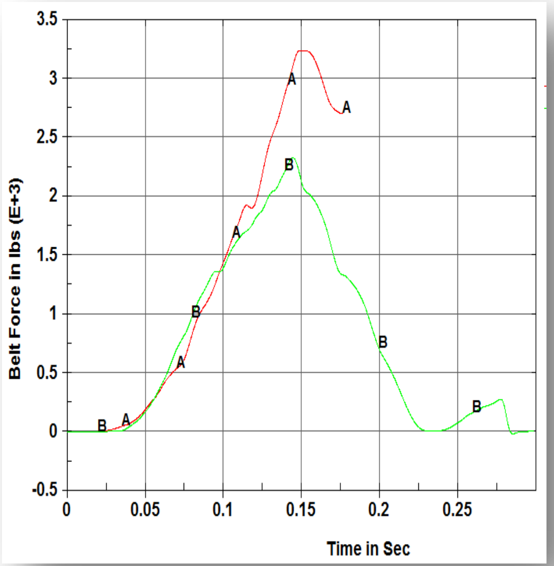


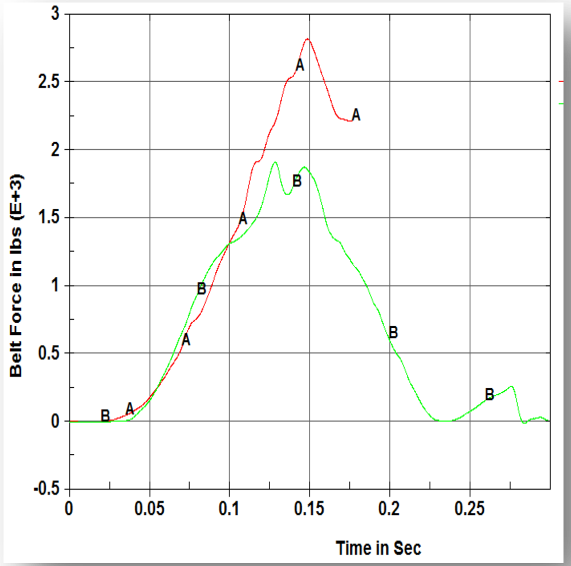
Comparison - 50th and 95th e-ATD Results							
Sr No	Loads at peak Magnitude and Time	Units	5th Percentile Female e-ATD	50th Percentile Male e-ATD	95th Percentile Male e-ATD	% Increase	
						% Magnitude	% Phase
1	Sled peak deceleration	g's	14	14	14		
2	Lumbar Load	Lbs	619	921	1045		
	Time	Seconds	0.105	0.105	0.116		

Case 2 – Typical Commercial Aircraft Seat

Belt Loads





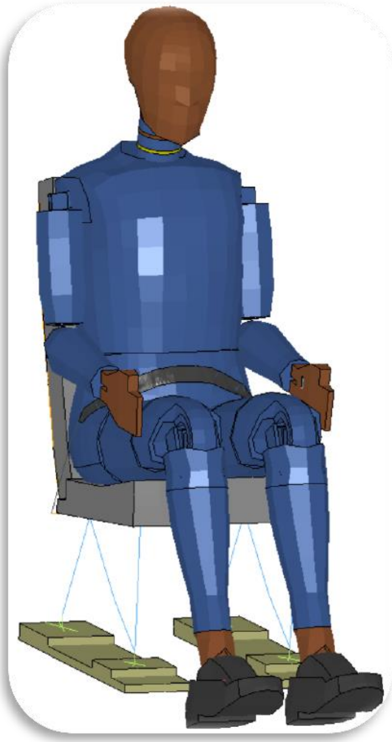


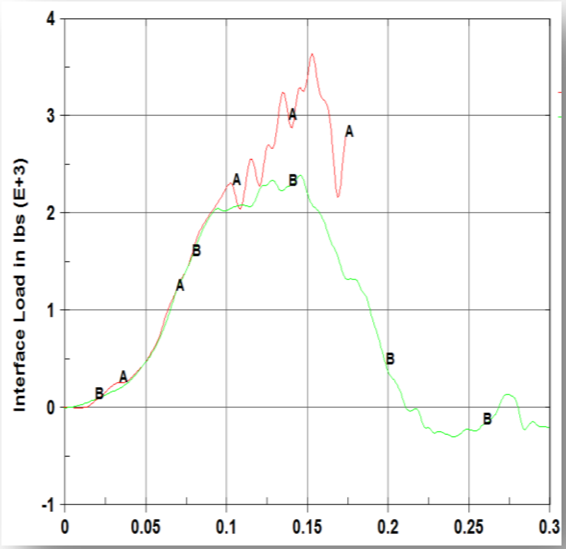
Comparison - 50th and 95th e-ATD Results

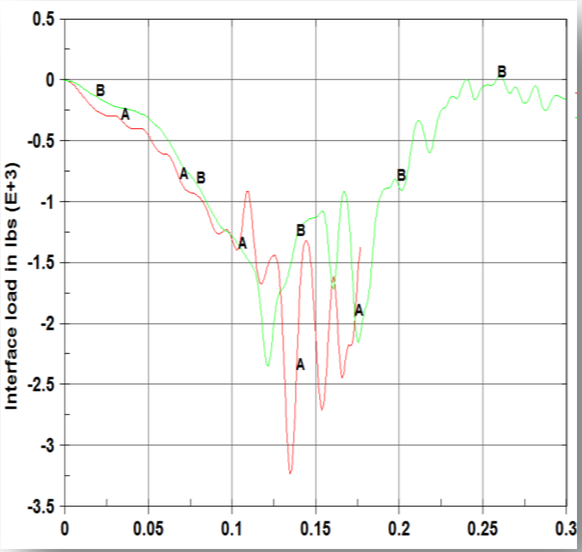
Sr No	Loads at peak Magnitude and Time	Units	5th Percentile Female e-ATD	50th Percentile Male e-ATD	95th Percentile Male e-ATD	% Increase	
						% Magnitude	% Phase
1	Sled peak deceleration	g's	16	16	16		
3	Belt loads						
b	Lap	Lbs	1673	2328	3237	39.0	
	Time	Seconds	0.145	0.144	0.148		2.8

Case 2 – Typical Commercial Aircraft Seat

Interface load or Floor Reaction



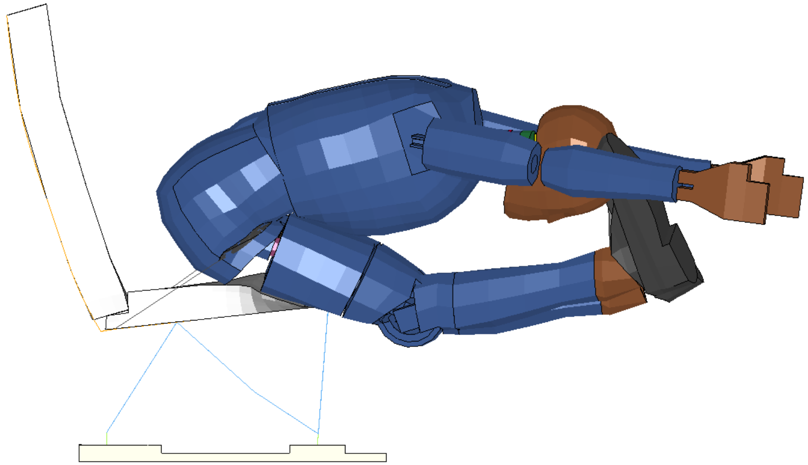




Comparison - 50th and 95th e-ATD Results							
Sr No	Loads at peak Magnitude and Time	Units	5th Percentile Female e-ATD	50th Percentile Male e-ATD	95th Percentile Male e-ATD	% Increase	
						% Magnitude	% Phase
1	Sled peak deceleration	g's	16	16	16		
2	Floor reactions						
a	Maximum compression	Lbs	1350	2305	3213	39.4	
	Time	Seconds	0.173				
b	Maximum tension	Lbs	1745	2423	3727	53.8	
	Time	Seconds	0.145	0.147	0.153		4.1

Case 2 – Typical Commercial Aircraft Seat

Head Path and Head Accelerations



Comparison - 50th and 95th e-ATD Results							
Sr No	**Loads at peak Magnitude and Time**	**Units**	**5th Percentile Female e-ATD**	**50th Percentile Male e-ATD**	**95th Percentile Male e-ATD**	**% Increase**	
						% Magnitude	**% Phase**
1	Sled peak deceleration	g's	16	**16**	**16**		
4	Head Path	inch	27.92	**30.8**	**34.6**	12.3	

Result Discussion

Case 1 – Typical Business Aircraft Jet Seat							
Sr No	Loads at peak Magnitude and Time	Units	5th Per Female e-ATD	50th Percentile Male e-ATD	95th Percentile Male e-ATD	% Increase 95th over 50th	
						% Magn.	% Ph
1	Sled peak deceleration	g's		16	16		
2	Floor reactions						
a	Maximum compression	Lbs		5717	7594	32.8	
	Time	Seconds		0.126	0.131		4.0
b	Maximum tension	Lbs		3841	5126	33.5	
	Time	Seconds		0.106	0.112		5.7
3	Belt loads						
a	Shoulder	Lbs		1186	1446	21.9	
	Time	Seconds		0.138	0.156		13.0
b	Lap	Lbs		1633	2196	34.5	
	Time	Seconds		0.117	0.113		-3.4
4	Head Path	inch		17.9	22.0	23.2	
1	Sled peak deceleration	g's	14	14	14		
2	Lumbar Load	Lbs	619	921	1045	13.5	
	Time	Seconds	0.105	0.105	0.116		10.5

- % Increase in floor reaction
- % Increase in belt loads

Result Discussion

Case 2 – Typical Commercial Aircraft Seat							
Sr No	**Loads at peak Magnitude and Time**	**Units**	**5th Percentile Fe e-ATD**	**50th Percentile M e-ATD**	**95th Percentile M e-ATD**	**% Increase 95th over 50th**	
						% Magnitude	**% Phase**
1	Sled peak deceleration	g's	16	**16**	**16**		
2	Floor reactions						
a	Maximum compression	Lbs	1350	**2305**	**3213**	39.4	
	Time	Seconds	0.173				#DIV/0!
b	Maximum tension	Lbs	1745	**2423**	**3727**	53.8	
	Time	Seconds	0.145	**0.147**	**0.153**		4.1
3	Belt loads						
a	Shoulder	Lbs					
	Time	Seconds					
b	Lap	Lbs	1673	**2328**	**3237**	39.0	
	Time	Seconds	0.145	**0.144**	**0.148**		2.8
4	Head Path	inch	27.92	**30.8**	**34.6**	12.3	

- **% Increase in floor reaction**
- **% Increase in belt loads**

Result Discussion

A validated FEA methodology was presented, 5th percentile Female, 50th and 95th percentile male e-ATDs were analyzed

95th p ATDs are found ~ 25% increase in weight, 20% increase of height compared with the 50th percentile occupants.

Belt loads and Floor reactions went up ~ 33% when 95th P ATDs was analyzed using typical business jet seat with 3pt restraint. These values went up to 40% for typical commercial aircraft seat with 2 pt restraint.

Head path went up ~ 4 to 5” in both cases.

Lumbar load went up 13 to 16% (Rigid Seat).

More research and testing need to be done to determine effect on the seat weight when designed for the range of occupant population sizes studied herein.

Comfort or Ergonomics Design should be based on : 50th percentile ATDs

Injury criteria development should be based on : 50th percentile ATDs

Structural development of seat should be based on : 95th percentile ATDs

Acknowledgement