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ARP5765 Rev. A :
Analytical Methods for Aircraft Seat Design and Evaluation

Prasanna Bhonge

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Background

AC 20-146: Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, & 29 Airplanes and Rotorcrafts

- **Signed in May 2003; allows simulation results to be used in support of seat certification**
- **Provides high-level guidance on the validation of seat models**
- **Defines the conditions under which computer modeling can be used in support of certification**

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ARP 5765

Analytical Methods for Aircraft Seat Design and Evaluation

Objectives

The primary objectives of the ARP is to provide

- **Quantitative method to measure and evaluate the degree of correlation between a model and a physical test**
- **Best modeling practices to improve the accuracy and predictability of seat analyses**

Technical Specialist from

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

A/C Manufacturers
- Airbus
- Cessna
- Embraer
- Bombardier

Software
- FTSS
- TASS
- ESI
- Altair
- LSTC

Regulatory
- FAA
- EASA

Academic
- NIAR

SAE ARP 5765 Rev A – Published in Nov. 2015.

1. SCOPE
2. REFERENCES

3. V-ATD CALIBRATION
4. SYSTEM VERIFICATION AND VALIDATION (REV A)
5. MODEL USE (REV A)
6. DOCUMENTATION (REV A)
7. BEST PRACTICES

APPENDIX

A: METHODOLOGY FOR THE COMPARISON OF TEST AND SIMULATION WAVEFORMS

B: FAA - NIAR DATA SET FOR THE HYBRID II ATD

C: FAA - NIAR DATA SET FOR THE FAA HYBRID III ATD

D: SAMPLE HYBRID II V-ATD CALIBRATION REPORT

E: SYSTEM VERIFICATION AND VALIDATION EXAMPLES **(REV A)**

3.0 v-ATD Calibration

Goal: **define the process for ensuring that v-ATDs match the anthropometry and kinematic performance of a physical ATD for aviation- specific applications**

- **Mass and Geometry**
- **Component Response (head, chest, knee, etc.)**
- **Pelvic Shape Evaluation (cushion interaction)**
- **Dynamic Response : evaluate ATD performance for aircraft conditions**

FF 2pt belt: extreme flail envelope
FF 3pt belt: torso twist
FF 4pt belt: submarining

Test Condition 2 (14 CFR XX.562)
2pt, 3pt, 4pt restraint system

Download: vertical crash vector

Test Condition 1 (14 CFR XX.562)

Dynamic Calibration Data Set – Forward Facing ATD

Data set Example

Channel Description	Forward Facing 2-Point Belt	Forward Facing 60 Deg 2-Point Belt	Forward Facing 3-Point Belt	Forward Facing 4-Point Belt
Sled Ax	X	X	X	X
Upper Neck Fx *			X	X
Upper Neck Fy *			X	
Upper Neck Fz *			X	X
Upper Neck Mx *			X	
Upper Neck My *			X	X
Chest Ax (CFC 180)			X	X
Lumbar Fz		X		
Lumbar My		X		
Right Lap Belt Load	X		X	X
Left Lap Belt Load	X		X	X
Right Shoulder Belt Load				X
Left Shoulder Belt Load			X	X
Seat Pan Fx	X	X	X	X
Seat Pan Fz	X	X	X	X
Seat Pan My	X	X	X	X
Head CG X Position	X	X	X	X
Head CG Z Position	X	X	X	X
H-point X Position	X		X	X
H-point Z Position	X	X		
Knee X Position	X			X
Knee Z Position	X			X
Ankle X Position	X			
Ankle Z Position	X			
Shoulder X Position			X	X
Shoulder Z Position			X	X
Opposite Shoulder X Position			X	
Opposite Shoulder Z Position			X	
Head Angle	X			X
Pelvis Angle	X	X		X

* FAA Hybrid III only

Dynamic Calibration Data Set – Forward Facing ATD

Table 4 - Maximum allowable peak error for forward facing v-ATD**

Channel Description	Forward Facing 2-Point Belt		Forward Facing 60 degree 2-Point Belt		Forward Facing 3-Point Belt		Forward Facing 4-Point Belt	
Upper Neck Fx *					10%	-	20%	-
Upper Neck Fy *					30%	-		
Upper Neck Fz *					15%	+	30%	+
Upper Neck Mx *					25%	-		
Upper Neck My *					10%	+	20%	+
Chest Ax (CFC 180)					10%	-	10%	-
Lumbar Fz			10%	-				
Lumbar My								
Right Lap Belt Load	10%	+			10%	+	10%	+
Left Lap Belt Load	10%	+			10%	+	10%	+
Right Shoulder Belt Load							10%	+
Left Shoulder Belt Load					10%	+	10%	+
Seat Pan Fx								
Seat Pan Fz	25%	-	10%	-	25%	-	10%	-
Seat Pan My	20%	-	10%	-	10%	-	20%	-
Head CG X Position	0.5 inches (12.7 mm)	+			1.75 inches (44.45 mm)	+	0.25 inches (6.35 mm)	+
Head CG Z Position							0.3 inches (7.62 mm)	-
H-point X Position	0.25 inches (6.35 mm)	+			1.25 inches (31.75 mm)	+	0.5 inches (12.7 mm)	+
H-point Z Position	0.2 inches (5.08 mm)	+	0.1 inches (2.54 mm)	-				
Knee X Position	0.5 inches (12.7 mm)	+					0.5 inches (12.7 mm)	+
Knee Z Position								
Ankle X Position								
Ankle Z Position								
Shoulder X Position					2.0 inches (50.8 mm)	+	0.5 inches (12.7 mm)	+
Shoulder Z Position							0.5 inches (12.7 mm)	-
Opposite Shoulder X Position					0.5 inches (12.7 mm)	+		
Opposite Shoulder Z Position								
Head Angle							8 degree	-
Pelvis Angle	7 degree	-	3 degree	+			5 degree	+

* FAA Hybrid III only

** Column with plus or minus denotes peak of interest is either a global maxima or minima

Dynamic Calibration Data Set – Forward Facing ATD

Table 5 - Maximum allowable curve shape error for forward facing v-ATD

Channel Description	Forward Facing 2-Point Belt	Forward Facing 60 degree 2-Point Belt	Forward Facing 3-Point Belt	Forward Facing 4-Point Belt
Upper Neck Fx *			10%	10%
Upper Neck Fy *			30%	
Upper Neck Fz *			20%	25%
Upper Neck Mx *			40%	
Upper Neck My *			10%	40%
Chest Ax (CFC 180)			10%	15%
Lumbar Fz		15%		
Lumbar My		25%		
Right Lap Belt Load	15%		10%	10%
Left Lap Belt Load	15%		10%	10%
Right Shoulder Belt Load				10%
Left Shoulder Belt Load			10%	10%
Seat Pan Fx	20%	5%	15%	10%
Seat Pan Fz	20%	5%	15%	10%
Seat Pan My	20%	10%	10%	15%
Head CG X Position	10%	10%	10%	10%
Head CG Z Position	10%	15%	30%	10%
H-point X Position	10%		20%	10%
H-point Z Position	10%	15%		
Knee X Position	10%			10%
Knee Z Position	10%			10%
Ankle X Position	15%			
Ankle Z Position	20%			
Shoulder X Position			15%	15%
Shoulder Z Position			40%	15%
Opposite Shoulder X Position			10%	
Opposite Shoulder Z Position			75%	
Head Angle	10%			10%
Pelvis Angle	10%	20%		10%

* FAA Hybrid III only

4.0 Seat System Verification and Validation

V&V Plan

Plan, Reality of Interest, Intended Use, and SRQs

Verification

Code Verification

Calculation Verification

Validation

Material Properties

- **Handbook**
- **ASTM / accepted test method**
- **Constitutive model/ material model**

Component tests /models

- **Novel materials /rate sensitive**
- **Novel structures**
- **Joints**
- **Test Method / Model**

System Validation

- **Test Condition/s**
- **Structure and Occupant**
- **Initial condition**
- **Input/ output checks**
- **SRQ**

Sensitivity Analysis

- **Critical Components**
- **Input parameters**
- **Output parameters**
- **Geometry and etc.**

Goal is to Ensure that the system (v-ATD, seat structure, restraints, and other sub systems and their connections) is an accurate representation of the test.

Building Block Approach

Material Characterization

What

- Source of the data
- Reliability & Repeatability of data
- Strength values for temperature and other condition (hot/wet/dry) if required
- A basis/ B basis allowables
- Failure criteria

Where

- MMPDS
- NIAR FAA test data ?
- Plastic Deformation and Ductile Fracture of 2024-T351 – by Jeremy Daniel (OSU Dissertation 2010)
- Allowables - Based Flow Curves for Nonlinear Finite-Element Analysis – J.D. Pratt

How

- ASTM E8, ASTM D-3039 – Tensile test
- ASTM E9, ASTM D-3410, ASTM D-6641, ASTM D-5467 – Compression test
- ASTM D-3518 – Lamina shear testing
- ASTM D-7078 – V-notch Shear Test
- SAE AS 8043 - Seat belt pull test
- ASTM D3574-03 - High speed cushion compression test

System Validation

Initial conditions

- **Talks about initial position and condition checks:**
- **Precision:** Improving Test Repeatability and Methods
- **Documentation**

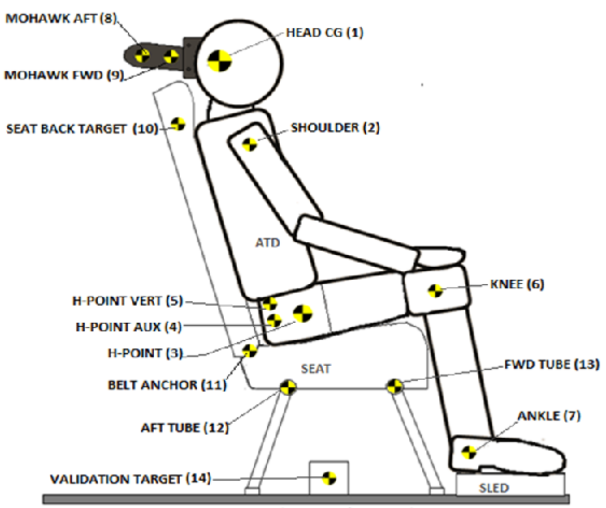
Initial position seat and occupant parameters check

Typical Channels for Structural Forward Test Condition (Part 25 PAX seat)

#	LOCATION	Measured Dimensions		
		X*	Y*	Z*
1	Head CG	□	•	□
2	Shoulder	□	•	□
3	H-Point	□	•	□
4	H-Point Aux	□	•	□
5	H-Point Vert	□	•	□
6	Knee	□	•	□
7	Ankle	□	•	□
8	Mohawk Aft	□	•	□
9	Mohawk Fwd	□	•	□
10	Seat Back Target	□	•	□
11	Belt Anchor	□	•	□
12	Aft Tube	□	•	□
13	Fwd Tube	□	•	□
14	Validation Target	□	•	□
15	Belt Webbing Middle		□	
16	Buckle Right		□	
17	Buckle Left		□	

* Location measured with respect to fixed reference point that can be used to correlate with numerical model

□	Minimum required dimension to be measured
•	Optional dimension to be measured



Approximate location of targets shown.

Post processing pre-requisite checks

- Test pulse,
- Kinematics,
- Mass scaling,
- Hour-Glassing,
- Energy balance,
- Initial penetration
- Etc.

Seat System Response Quantities

Typical Channels for Combined Horizontal-Vertical Test Condition

Primary	Support	Threshold
Lumbar Fz	Occupant Trajectory	Belt Loads
Floor Reaction Fz	Lumbar moment	

Acceptable Limit for Primary Channel is 10% (AC 20-146)

Typical Channels for Structural Test Condition (Forward Facing)

Primary	Support	Threshold
Floor Reaction Fx and Fz	Occupant Trajectory	Floor Reaction Fy
Belt Loads		strain in the primary load path structural members

Typical Channels for Injury Criteria Test Condition

Primary	Support	Threshold
Head Resultant Acceleration and HIC	Floor Reaction Fx and Fz	Floor Reaction Fy
Head Path	Pelvic and/or Knee Motion	
Belt Loads	Target Seatback Motion	
Femur Fz	Head Impact Velocity and Angle	
Impact Location		

5. Model Use

Limitation

Table 9 - AS8049 compliance requirements

Compliance Requirement SAE #	Requirements	Can be Demonstrated by Numerical Analysis	Comments
5.3.9.13	Live vest retrieval	Not Practical	
5.4.1	Seat structure remain attached	Possible	The model will have to demonstrate that it properly predicts failure
	Prediction of primary structural damage	Possible	Damage prediction may be possible by comparing maximum stress/strain data with accepted values, however, this is just predicting damage and not failure, would need to determine acceptability
	Deformation, crippling, shear buckling	Possible	
5.4.2	Occupant restraint system remains attached	Possible	Belt path and location should be evident when reviewing the occupant kinematics
	Damage prediction: fraying, tears	Not Practical	These would require a very fine mesh and other techniques to simulate fiber layup and typically beyond the capability of most restraint system models
	Buckle release and damage to components affecting buckle release	Not Practical	This would require detailed modeling of the buckle and its operation/mechanism and is generally beyond most dynamic models
	Seat Belt Payout	Not Practical	While the payout itself is not a requirement, it can be important to measure this quantity to aid in the assessment of the belt performance. Since the buckle and ring connectors are not modeled at this time, belt slippage and payout cannot be determined.
5.4.3	Seat permanent deformation within quantitative limits (C/B ratio, seat pan rotation, seat permanent deformation). Reference 3.5 of AS8049B.	Not Practical	The final resting portion of the seat can be determined, but a subsequent analysis would need to be conducted to apply the restoring force. Because this restoring force cannot be readily applied or the floor unwarped, the final permanent deformation point cannot be determined. However, a conservative approach may be to use the maximum dynamic displacement and compare that with the warped configuration to determine an estimate of the permanent deformation. Consideration must be given here if the permanent deformation cannot be determined as this will severely limit the application of the model for structural evaluations.
	Deployable Items affecting egress (tray tables, leg rests, video monitor, etc.)	Possible	As long as the action is modeled appropriately
	Stowable seats near exits or exit path	Possible	The seats would be modeled and validated as regular seats
5.4.4	HIC not to exceed 1,000	Possible	Part of the kinematic determination of the v-ATD
	Post-test delethalization, sharp edge evaluation	Not Practical	This would require a significantly small mesh in all areas, or running the model many times increasing mesh density in areas were failure was predicted. A better alternative would be to determine areas of where damage occurs and conduct specific testing on those objects for evaluation
5.4.5	Upper torso restraint loads not to exceed 1,750 pounds	Possible	Part of the loads determination
5.4.6	Lumbar load not to exceed 1,500 pounds	Possible	Part of the loads determination
5.4.7	Upper torso restraint remains on ATD during impact	Possible	Belt path and location should be evident when reviewing the occupant kinematics
5.4.8	Pelvic restraint remains on ATD pelvis during impact	Possible	Belt path and location should be evident when reviewing the occupant kinematics
	Submarining	Possible	Belt path and location should be evident when reviewing the occupant kinematics
5.4.9	Femur load not to exceed 2,250 pounds	Possible	Part of the loads determination
5.4.10	Retention of items of mass	Not Practical	While the items of mass will be included, the details regarding how they are attached and the fitting mechanisms with their associated strengths to the seat are not included

Factor Of Safety

5.8 Factor of Safety

To account for the testing uncertainty, conservatism can be incorporated into validation and model use via a factor of safety. For example, repeated testing of seat cushions show a typical variance about ±125 pounds when testing parameters are tightly controlled. Assuming the uncertainty is normally distributed, the standard deviation is 41.67 pounds (6 standard deviations within the 250 pound range). Based on this standard deviation, there is a 95% confidence that the true load is below the regulatory limit of 1,500 pounds if the measured or simulated load is no greater than 1,430 pounds. Therefore, it is recommended that only seat configurations with dynamic test data that yield spine loads below 1,430 pounds should be used for validation. Likewise, for model use, it is recommended that only models that produce a lumbar load below 1,430 pounds be used. Note that models can exceed 1,430 pounds in the validation phase.

Table 10 - Example peak lumbar loads

	Validation	Model Use
Model under predicts	Test = 1,400 pounds, Model = 1,350 pounds	Model = 1,380 pounds or less
Model over predicts	Test = 1,400 pounds, Model = 1,450 pounds	Model = 1,430 pounds or less

Given two dynamic tests with the same desired deceleration profile, the maximum HIC values will likely vary. Therefore, a precise match between the test derived HIC and the analytical HIC is not realistic. However, the maximum analytical HIC value should correlate to within 100 HIC units of the maximum test derived HIC value. The applicant is encouraged to generate conservative HIC prediction models. One method to add conservatism to the process is to incorporate test uncertainty as a factor of safety in validation and model use. Using the same process as above and assuming a typical variance of ±200 HIC units, the 95% confidence HIC value is 890. Therefore, it is recommended that only seat configurations with dynamic test data that produce a HIC value below 890 should be used for validation. Likewise, for model use, it is recommended that only models that produce a HIC value below 890 be used. Note that models can exceed 890 in the validation phase.

Table 11 - Example HIC values

	Validation	Model Use
Model under predicts	Test = 850, Model = 800	Model = 840 or less
Model over predicts	Test = 850, Model = 900	Model = 890 or less

6. Documentation

- Software/ Hardware
- M&S assumptions, capabilities, limitations, risks, and impacts
- Units
- Description and Results of V&V tasks
- Identifying unresolved issues associated V&V implementation
- Documenting recommendations in support of accreditation decision

7. Best Practices

7.1 Testing Best Practices

In addition to the basic requirements in SAE AS8049B

- Improving Test Repeatability and Methods
- To provide optimal data for the purposes of modeling a dynamic sled test.
- Documentation
- Early and good communication between the test engineer and engineering analyst
- Plan collecting additional information such as strain gauges, load cells, additional cameras, etc.

- **General Documentation**
  - Specific ATD dimensions
  - Sitting height
  - H-point location
- **Motion Analysis**

  Target Point Placement Considerations
  - Head
  - Shoulder
  - H-point
  - Knee and Ankle Pivots
  - Restraint system
  - Target Obscurities
  - Overhead Cameras
- **Consistent ATD Pre-Test Position**
  - ATD Position
  - Seat and Interior Mockup Measurements
- **Additional Data Considerations**
  - FAA-Hybrid III
  - Seat pan/cushion
  - ATDs used for ballast
  - Seat instrumentation

7.2 Modeling Best Practices

- **Global Parameters**
  - Units
  - Integration Methods
  - Time step
  - Mass scaling
  - Element Quality Criteria
- **Physical Discretization**
  - Modeling structural elements
  - Modeling of non structural elements
- **Material Definition**
  - Material model verification
  - Failure mode definition
  - Strain rate sensitivity
- **Contact Definition**
- **Load Application**
- **Initial Conditions**
  - ATD positioning
  - Establishing equilibrium position
  - Pitch and Roll
- **Output Control**
  - Energy Balance
  - Output request
  - Negative volume
  - Hourglass Energy

Appendix

A: METHODOLOGY FOR THE COMPARISON OF TEST AND
SIMULATION WAVEFORMS

B: FAA - NIAR DATA SET FOR THE HYBRID II ATD

C: FAA - NIAR DATA SET FOR THE FAA HYBRID III ATD

D: SAMPLE HYBRID II V-ATD CALIBRATION REPORT

E: SYSTEM VERIFICATION AND VALIDATION EXAMPLES **(REV A)**

SAE ARP 5765 Rev B ?