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SAE Aircraft SEAT Committee

ARP5765 : Analytical Methods for Aircraft Seat Design and Evaluation

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

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

Background

AC 20-146: Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, and 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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ARP5765
Analytical Methods for Aircraft Seat Design and Evaluation

ARP 5765 : Analytical Methods for Aircraft Seat Design and Evaluation

Objectives

- The primary objective of the ARP is to provide a quantitative method to measure and evaluate the degree of correlation between a model and a physical test, and to provide best modeling practices to improve the accuracy and predictability of seat analyses
- Use Analytical methods not only in design phase but also in certification.
- Guide / help analyst step by step to reach the ultimate goal of "Certification By Analysis"

Participants

Technical Specialist from

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

A/C Manufacturers
- Airbus
- Cessna
- Embraer

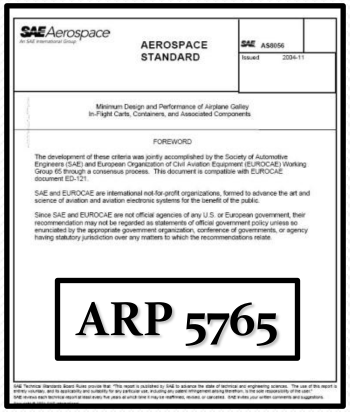
Software
- FTSS
- TASS
- ESI-Pamcrash
- Altair

Regulatory
- FAA
- EASA

Academic
- NIAR

ARP 5765 : Analytical Methods for Aircraft Seat Design and Evaluation

SAE ARP 5765 Outline


SAE Aerospace
An SAE International Group
AEROSPACE STANDARD
SAE 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.

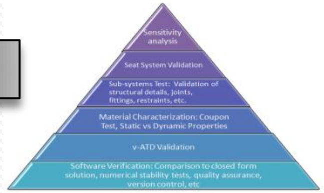
ARP 5765

Section 4: V-ATD Calibration

Validity of V-ATDs based on 2pt, 3pt, 4pt (Test condition 1 & 2)

- Mass and Geometry
- Pelvis Shape
- Dynamic response
- Defines compliance criteria
- Provides specifications and performance criteria

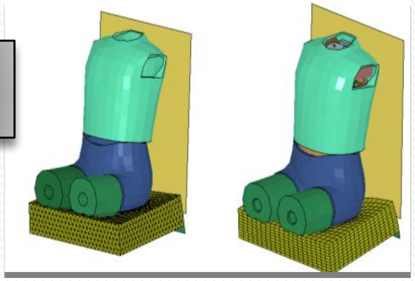
Section 5: System Validation



How to evaluate the accuracy of seat models ?

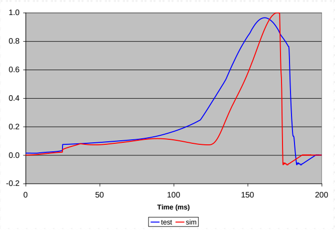
- Defines min set of test parameters and data needed to evaluate the degree of correlation between the model and the physical test,
- provides procedures for quantitative comparison of test and modeling results.

Section 6: Testing & Modeling Best Practice



Provides current best test & modeling practices that have been found to improve the efficiency and validity of computer models

Appendix:



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

4.0 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
  - Test Condition 2 (14 CFR XX.562) 2pt, FF 3pt, FF 4pt,
  - Test Condition 1 (14 CFR XX.562)

Dynamic Response

- Original component tests specified considering an automotive interior
- Need to evaluate the ATD performance for conditions likely in aircraft seat tests
  - FF 2pt belt: extreme flail envelope
  - FF 3pt belt: torso twist
  - FF 4pt belt: submarining
  - Download: vertical crash vector

Data set Example

TABLE 4.3 – Dynamic Calibration Data Set – Forward Facing ATD

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

5.0 System Verification & Validation

Ensure that the system (v-ATD, restraints, seat, etc.) is an accurate representation of the real world

- **Verification**
  - Code
  - Calculation
- **Validation**
  - Materials
  - Component Test
  - Sensitivity Analysis
- **Documentation**

6.1 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.**

- **Consistent ATD Pre-Test Position**
    - Test Documentation
    - Seat and Interior Mockup Measurements
    - ATD Position
- **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
- **Additional Data Considerations**
    - FAA-Hybrid III
    - Seat pan/cushion
    - ATDs used for ballast
    - Seat instrumentation

6.1 Testing Best Practices – Examples from CAMI Ref.

Proposed 1-G Seating Method

- Adjust friction in ATD joints
- Position dummy above seat
- Lower dummy while applying 20 lb. of pressure to sternum while holding knees up
- Rock dummy side to side to settle the pelvis in the seat
- Position arms and feet
- Measure position and angle of pelvis, position of head, knee and ankle, and torso angle*

*Torso angle estimated from H-pt and Head CG positions

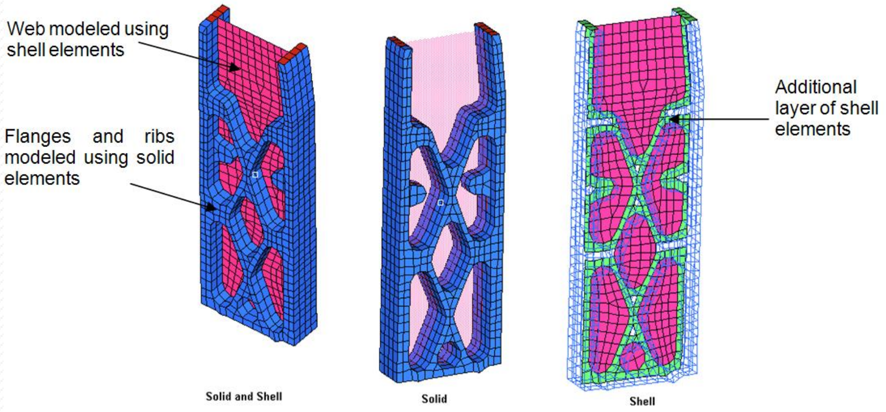
60° Seating Technique (Iterative)

- Position back shims as necessary
- Lower dummy into the seat
- Attach lap belt and tighten while pushing down on the shoulders to match H-point goal (x,y,z)
- Position feet and knees
- Adjust pelvic angle as necessary
- Verify torso angle and ankle position
- Position arms
- Document final position

6.2 Modeling Best Practices

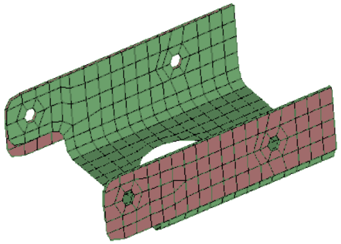
- **Global Parameters**
  - Units
  - Integration Methods
  - Time step
  - Mass scaling
  - Damping
  - Element Quality Criteria
- **Physical Discretization**
  - Modeling structural elements
  - Modeling of non structural elements
- **Material Definition**
  - Data: Structural Non-structural Testing methods,
  - 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

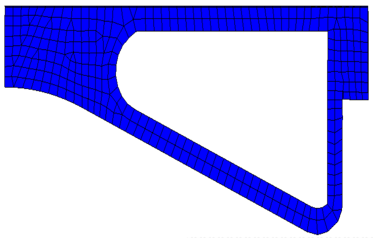
Physical Discretization



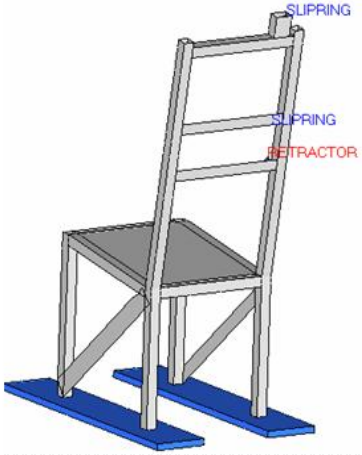
FE Modeling - Structural Seat Components

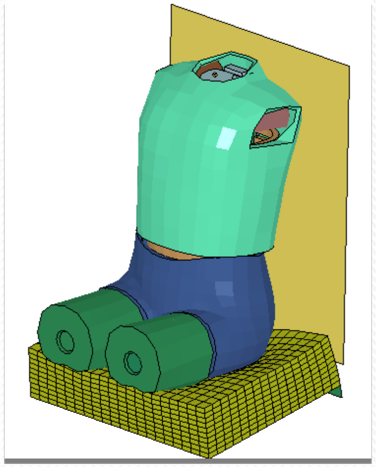
- Based on type of Analysis : Structural Stress Analysis or Occupant Injury Evaluation
- Combination of Shell, solid and beam elements.
- FE model is checked for element quality criteria,
- Maintaining the *connectivity, compatibility, and continuity* in the entire FE Model ensures a continual load path from occupant to the aircraft floor.

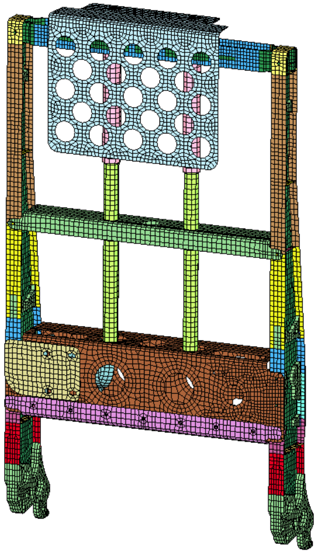




FE Modeling - Non Structural Seat Components







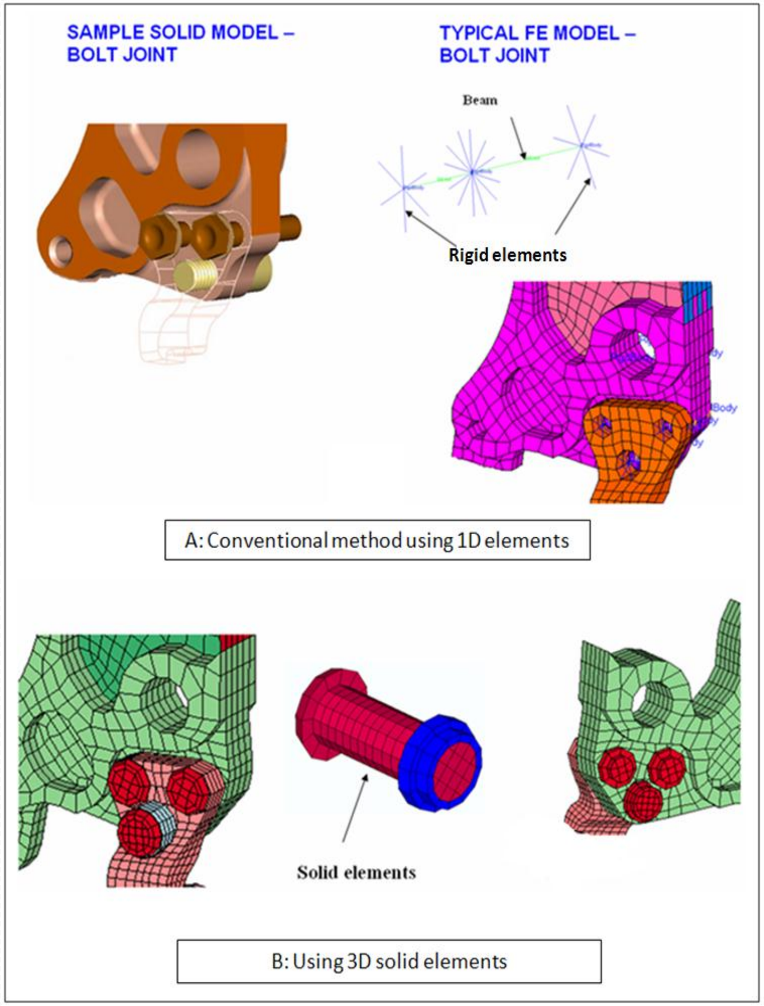
Element Quality Criterion

To ensure quality in Finite Element Model

- It is recommended that minimum and maximum quadrilateral element angle should be 45 and 135° and for triangular element it should be 20 and 120°.
- The use of 3 node triangular elements or 4 node tetrahedron or 6 node pentahedron (wedge) elements should be as minimal as possible near critical structural areas.
- No duplicate elements and have proper connectivity between nodes.

Items	Quadrilateral or Shell Elements		Hexahedron or Solid (Brick) Elements	
	95 % of Elements	5% of Elements	95 % of Elements	5% of Elements
Aspect Ratio	<=5	<=10	<=5	<=10
Face Skew	<=45°	<=60°	<=45°	<=60°
Face Warpage	<=10°	<=21°	<=10°	<=21°
Jacobian	>= 0.7	>= 0.5	>= 0.7	>= 0.5

Modeling of Joints



- Majority of failures in dynamic structural seat tests are observed in the assembly joints. These joints may be a nut-bolt joint or a screw connection.
- Figure shows a typical FE model of a bolted joint, modeled using the more traditional method of rigid elements and equivalent strength beam elements.
- This technique is lack the simulation of bearing stresses and pretensions.
- By providing actual nut and bolt surfaces, bearing stresses are introduced in the joint modeling.
- This modeling method also provides better representation of shearing and bending phenomena in the joint. Instead of modeling bolt threads, nodes on common surfaces of the nuts and bolts are merged.

Modeling of belt webbing

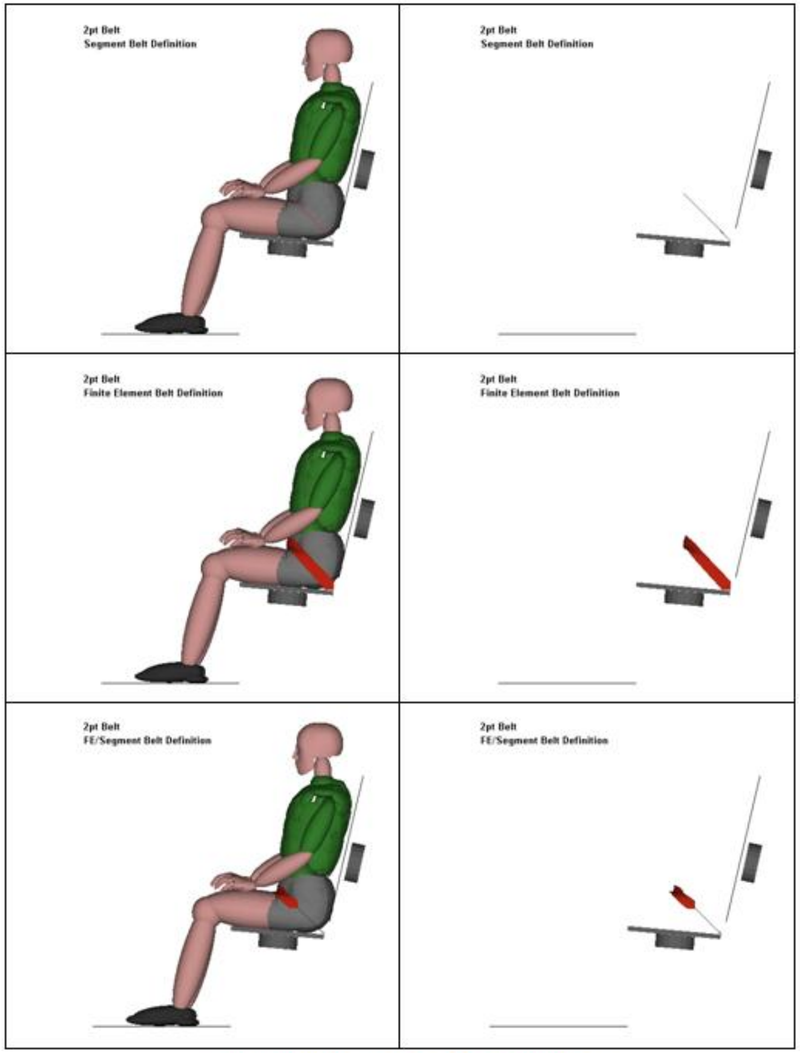


FIGURE 6.6 - Belt Modeling Techniques

- Segment Belt: This belt consists of a chain of 1-D straight belt segments.
- Finite Element Belt: Belt components can be modeled with 2-D membrane finite elements in order to predict complex behavior such as multi-directional belt slip, submarining, and roll-out.
- Hybrid Belt: For this modeling approach a hybrid of Finite Element and segment belts are used to define the belt system

Floor deformations

- Two-Stage Analysis
- Single Dynamic Event Analysis

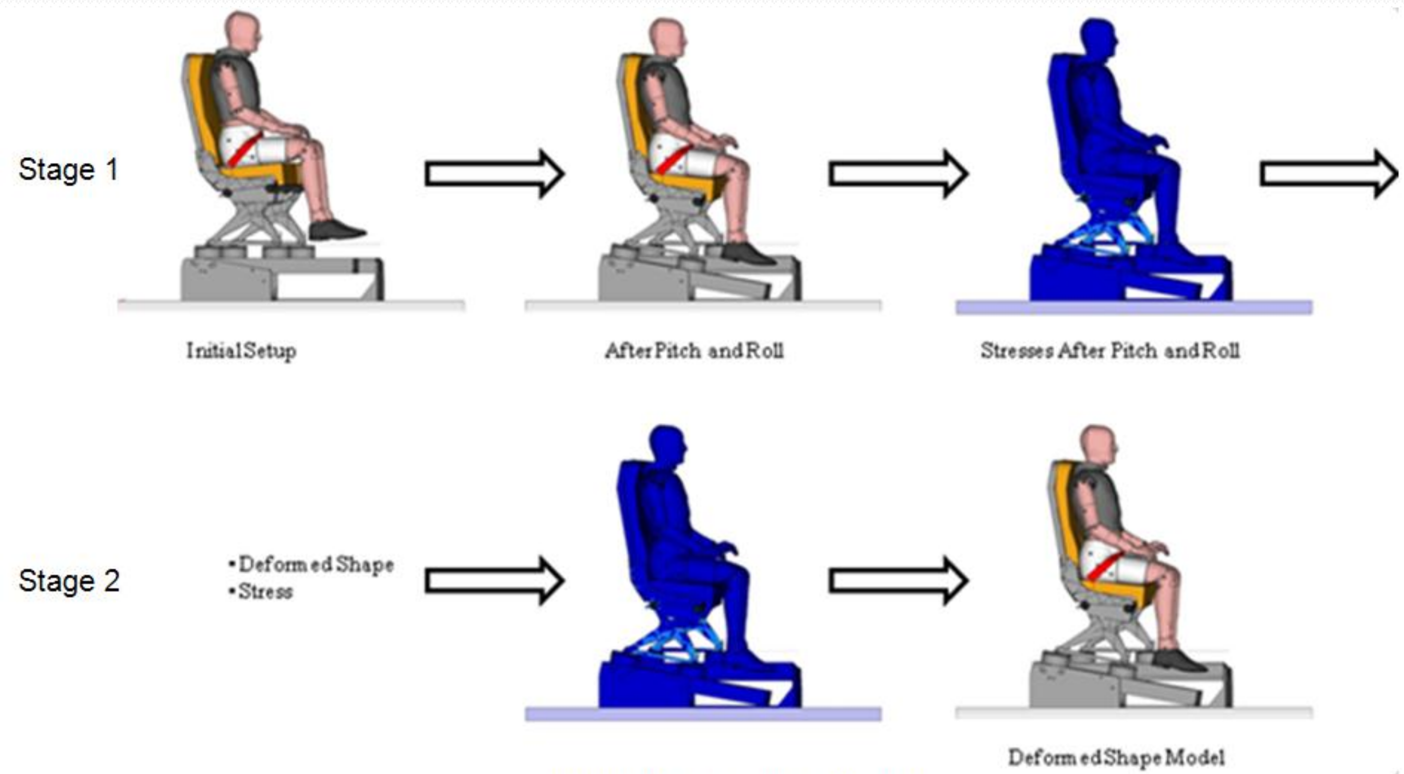


FIGURE 6.10 - Pre-Simulation

Material Definition

Material characterization data must be selected from sources that conform to accepted industry practices such as published ASTM, MMPDS or equivalent standards

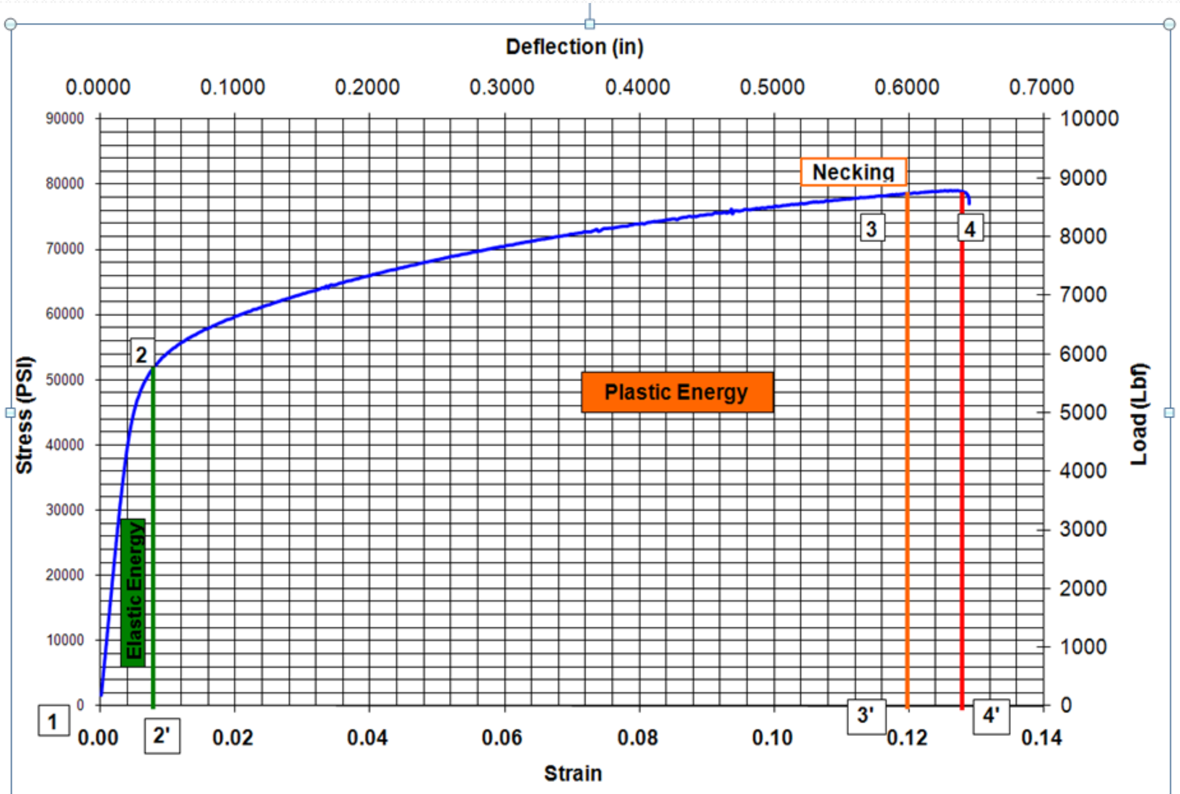


FIGURE 6.7 - Elastic and Plastic Energy in Ductile Material (AL 2024)

Tensile tests per ASTM E8/E8M

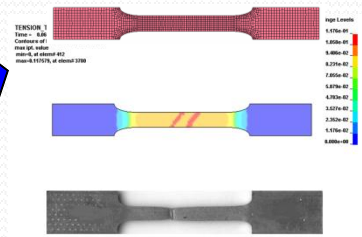
1. Start point of stress-strain or load-deflection curve
2. Yield stress if yield point is not defined
3. Necking point
4. Ultimate tensile stress

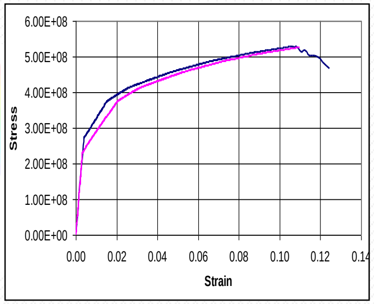
This data is then used in the numerical model to predict structural failure.
For a ductile material such as aluminum or steel, it is recommended to use necking point

Material Testing

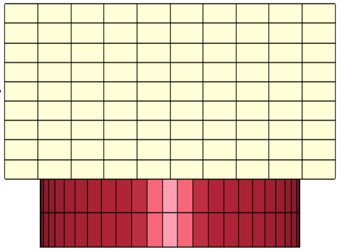
Material characterization data must be selected from sources that conform to accepted industry practices such as published ASTM, MMPDS or equivalent standards

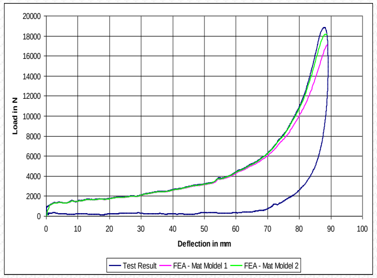
Metallic Material



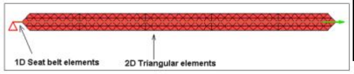


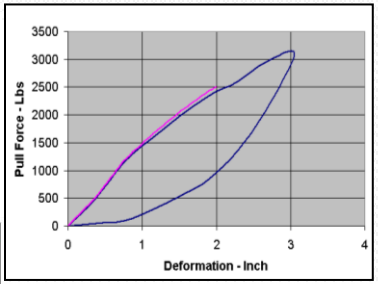
Cushion Material

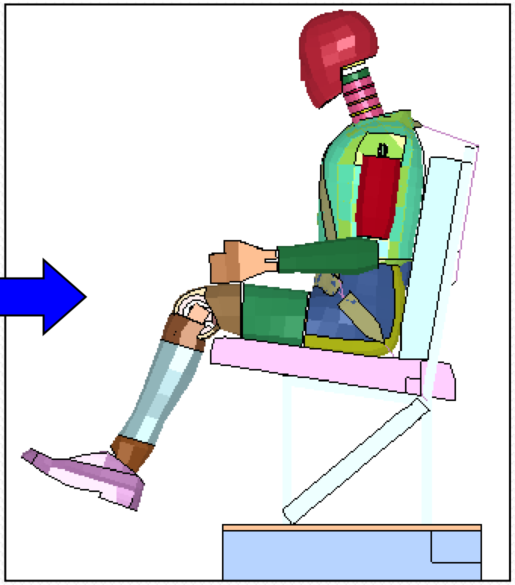




Restraint Material







Output control

- **Output request : SAE J211-1 provides detailed information on instrumentation polarity, sampling rate, and filtering methods.**
- **The database definitions are incorporated in the deck for time interval of 0.001 sec to generate the plot files or graphics files and a time interval of 0.0001 sec to generate the occupant output data, floor load data and belt load data. The SAE document J211/1 can be referred for the test instrumentation information.**
- **Output definition : In order to properly compare test and simulation results, it is important to select the appropriate output location.**

Output control

Time Step

Critical Time Step

The Critical time step (Δtcr) for a given model is given by

$\Delta tcr = L / C$

where C is sound speed = Sqrt (E/ρ).

E is Material Young's modulus and ρ is Material density

Time Step Scale Factor

0.9 or 0.67 (for soft materials like Foam)

If the minimum of an element length in the entire FE model is 5mm, the computed time step size would be approximately 1e-6 seconds

Initial Penetration –

are not accepted Because of improper Contact

Allowable Mass scaling

Ideal condition

Why mass scaling

Globally

Individual component

Conservative approach for the components in main load path, larger deformation or plastic strain.

Hourglassing

Reduced Integration Element formulation – zero energy modes

coarse mesh or poor element quality

Inappropriate contact definition

Incorrect modeling definition

poor boundary conditions

Energy Balance

- After completion of an analysis, it is recommended to look into the overall energy balance.
- That allows analyzing the overall response of the system for given inputs and hence understanding the accuracy of the solution.
- **In ideal condition, total energy = initial total energy + external work**
- or in other words if the **energy ratio is equal to 1.0.**

Plot the energy profile from output files.

$$W = \Delta E$$

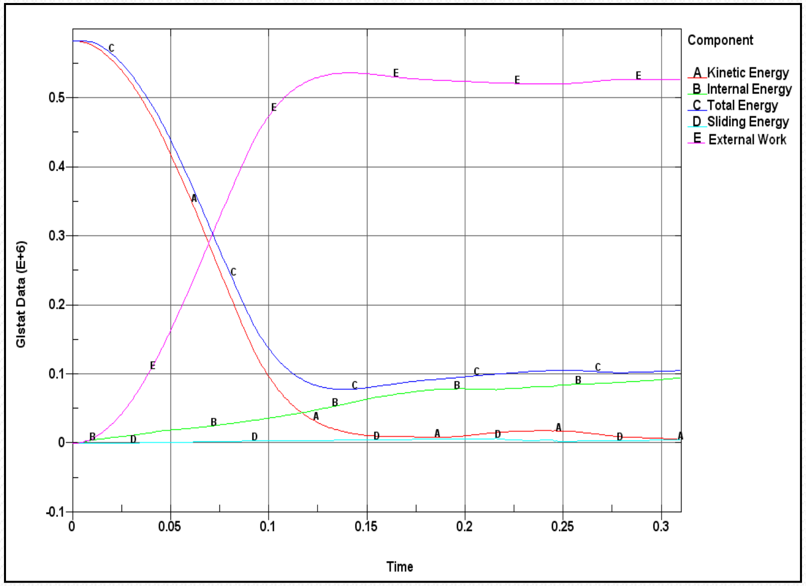
$$E = KE + IE + HE + SE$$

Where W = External Work
E = Total Energy
KE = Kinetic Energy
IE = Internal Energy
HE = Hourglass Energy
SE = Sliding Energy

$W \sim \Delta E$

$HE < 5\% \, IE$

$SE < 5\% \, IE$



Appendix

Future Plan: ARP 5765 Rev. 1

By end of 2014

- Complete Section 5: System Verification and Validation
- Case Studies

Please join us tomorrow from 1.30 pm onwards for ARP 5765 Rev 1 discussion

Questions ?