Evaluation of a Rigid Seat Test Methodology for Replacement of Seat Cushions on Transport Category Aircraft

Testing Variability

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Background

- Current aircraft seat bottom cushion replacement policy (ANM-115-05-005) for Transport Category seats is only applicable to monolithic cushions and uses a component test which evaluates only the foam.
- Most Transport Category cushions combine multiple foam types, have complex shapes, and are covered with a variety of materials. A test method that can evaluate the performance of typical replacement cushions would help operators ensure that the original level of safety provided by the seat system is maintained when crucial safety components are replaced.

Background

- **Since rigid seat tests results were used to validate the component test method used in the current policy, it was postulated that a rigid seat test could also be used to directly compare entire cushion assemblies.**
- **A replacement methodology using rigid seats would need to:**
  - be repeatable and reproducible,
  - be validated to ensure that cushion test results produce the same trends as when the same cushions are tested in real seats.

Replacement Procedure Evaluation

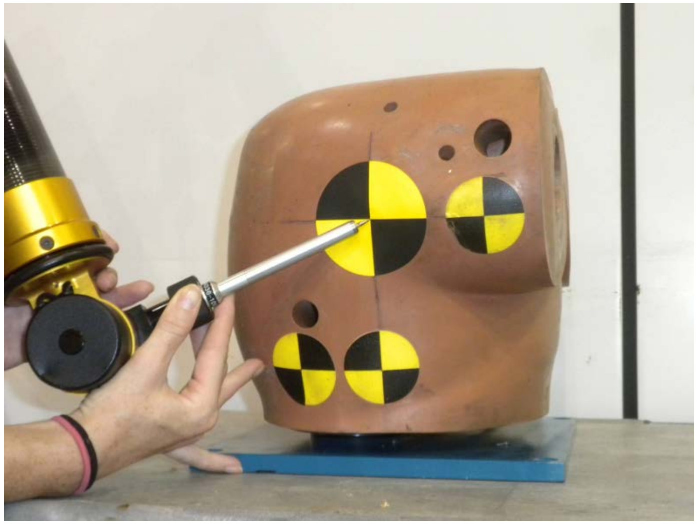
- **Test Methods**
  - Rigid seat
    - Seat pan shape matches the real seat shape to support cushion in a realistic fashion. Shape of flexible seat pans are measured when occupied at 1 G of load. Flat pan used for rectangular cushions or monolithic foam block comparisons.
    - Seat back angle was 13 degrees from vertical and seat pan angle was 5 degrees from horizontal.

Replacement Procedure Evaluation

- **Test Methods (cont.)**
  - Rigid seat
    - Simulated floor was adjusted to the appropriate relative height with respect to the seat cushion. This was done to maintain the ATD h-point to ankle vertical distance.
    - Lap belt anchor location
      - For complete cushion assemblies, they were located at the same position relative to the bottom cushion as in the real seat.
      - For the monolithic foam block comparisons, they were located about 4 inches forward of the seat pan/back intersection to facilitate observation of the pelvis motion.

Replacement Procedure Evaluation

- **Test Methods (cont.)**
  - Hybrid-II ATD
    - Two dummies used for all tests (ATD 1 and ATD 2).
    - Pelvises marked to facilitate measurement of initial position.

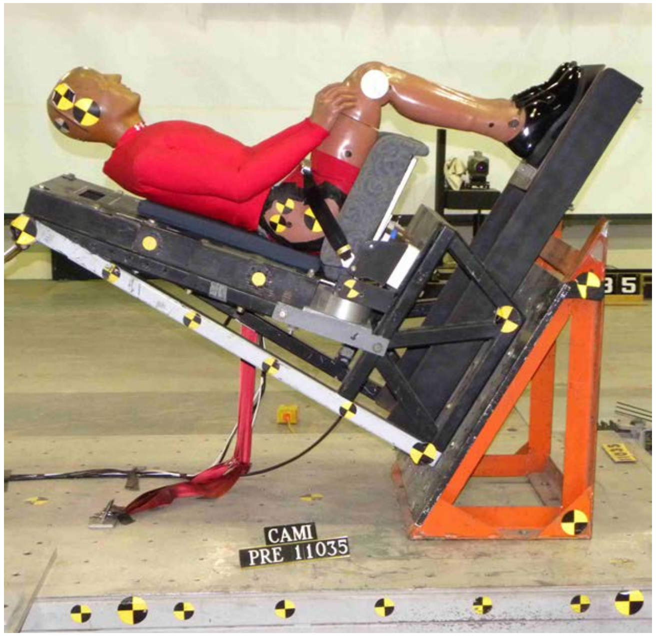


Replacement Procedure Evaluation

- **Test Methods (cont.)**
  - Initial position
    - ATD nominal position relative to the seat cushion measured when seated at 1 G for each cushion type.
    - ATD pre-test position was matched to the measured nominal position. Pre-test position controlled within: ± 0.1 inch for pelvis hip point, ± 1 degrees for pelvis angle, and ± 2 degree for torso.
    - The same ATD was used for both the nominal measurement and dynamic tests to ensure correct cushion pre-load.

Replacement Procedure Evaluation

- **Test Methods (cont.)**
  - Test Conditions:
    - 14g, 35 ft/s, triangular pulse defined in 14 CFR 25.562.



Replacement Procedure Evaluation

- **Validation Tests**
  - The original plan for validating the replacement procedure was to test cushion assemblies built from a range of typical aircraft foams and compare their performance in a variety of real seats and in a rigid seat configured to match the real seat's geometry.
  - Conflicting results made an investigation of lumbar load repeatability and reproducibility necessary to interpret data gathered during this project. The concern is that testing variation may be confounding direct comparison of cushion response data (the signal could be buried in the noise).

Test Uncertainty Quantification

- **Reducible Uncertainty Sources**
  - Occupant initial position
  - Arm rest interaction
  - Cushion configuration
- **Irreducible Uncertainty Sources**
  - ATD to ATD vertical response variation
  - Test method variability
  - Foam material variability

Reducible Uncertainty

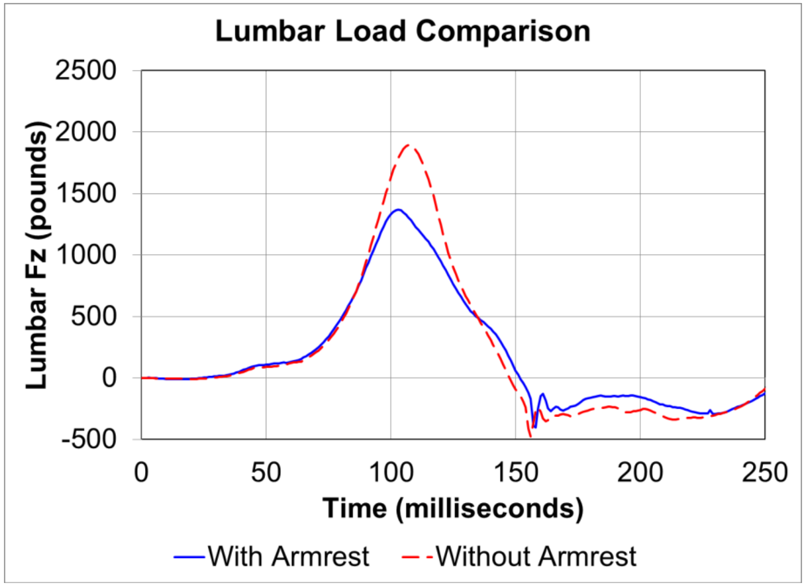
- **Occupant initial position**
  - Seating the ATD 1 inch higher than nominal increased average lumbar load on a rigid seat by 344 lb.   All tests used the same ATD and cushions made from 4 inch thick, low density, low initial stiffness foam (with no dress cover).

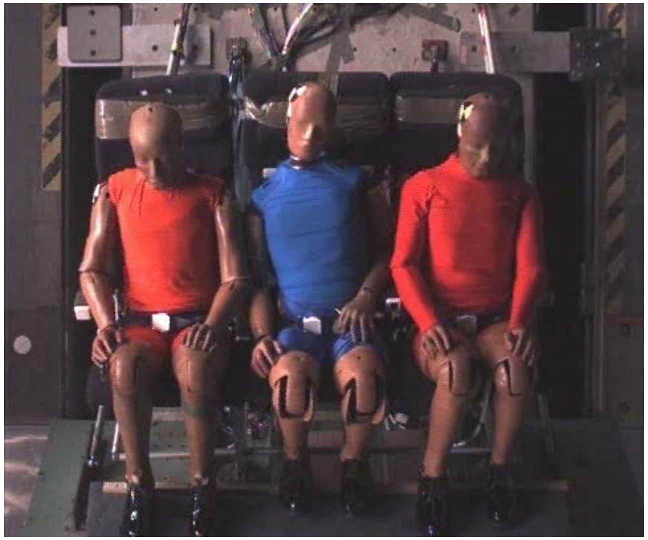
# of Tests	H-pt Z Height	Average Lumbar Load (Lb.)	Range (Lb.)
3	Nominal 1-G	1221	26
3	Nominal + 1”	1565	156

  - These results indicate the importance of controlling ATD pre-test position carefully.

Reducible Uncertainty

- **ATD arm interaction**
  - ATD arms resting on seat armrests can become a secondary load path, artificially reducing the lumbar load.





Reducible Uncertainty

- **ATD arm interaction (cont.)**
  - The amount of force reduction was higher in cantilevered seat places that permitted more occupant vertical motion and therefore, more opportunity to offload force to the stationary armrest.

Test	Armrest Config	Seat Position	ATD #	Lumbar Fz Normalized (Lb.)	Fz Difference (Lb.)
A11020	Down	Cantilevered	2	1179	-336
A11021	Up	Cantilevered	2	1515	
A11020	Down	Supported	1	1589	-107
A11021	Up	Supported	1	1696	

Reducible Uncertainty

- **ATD arm interaction (cont.)**
  - These results indicate the importance of avoiding arm interaction by:
    - Armrest removal or folding (if feasible)
    - Selecting an ATD arm initial position to minimize contact with armrests.

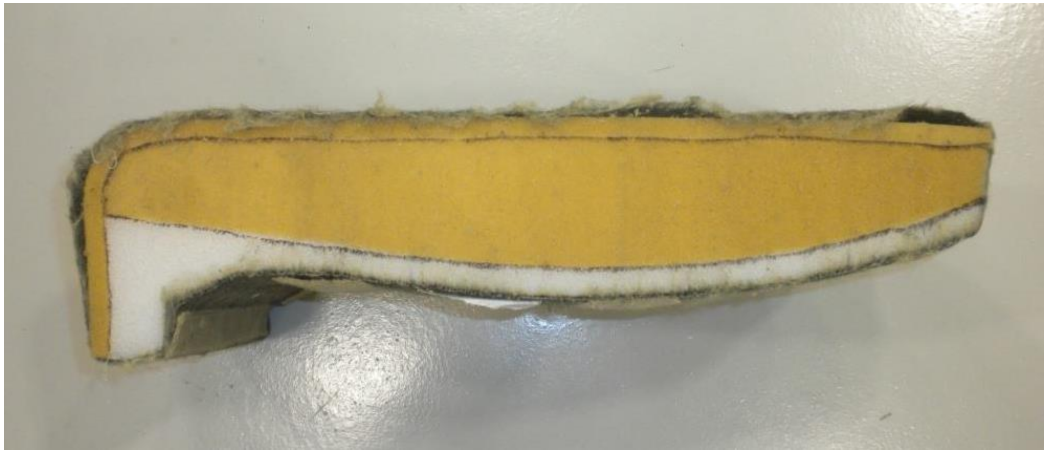
Reducible Uncertainty

- **Cushion configuration**
  - The cover can affect stiffness since it acts as a barrier to airflow out of the cushion as it is compressed. Air flow is one reason that cushion static F/D characteristics differ from dynamic F/D. Rigid seat tests with and without a cover produced a 145 lb. difference in average lumbar load.

# of Tests	Cushion Covering	Average Lumbar Load (Lb.)	Range (Lb.)
3	Uncovered (medium density, low initial stiffness foam)	1347	30
3	Covered (medium density, low initial stiffness foam)	1202	59

Reducible Uncertainty

- **Cushion configuration (cont.)**
  - Contoured cushions often have varying material type and thickness over the span and breath of the cushion. Testing the entire cushion permits direct evaluation of the effect of the cushion shape and material combinations.



Irreducible Uncertainty

- **ATD differences in vertical response**
  - The response of two ATDs was compared in rigid seat tests with three types of cushion assemblies. The lumbar loads produced by each ATD was significantly different for each cushion type.

Cushion Designation	Cushion Construction	ATD 1 (Lb.)	ATD 2 (Lb.)	Delta (Lb.)
B	2 inch, med density, open cell foam	1771	1355	417
	2 inch, high density, low initial stiffness, open cell foam			
C	3 inch, med density, open cell foam	2007	1618	389
	0.5 inch, closed cell, flotation			
D	2 inch, med density, high initial stiffness, open cell foam	1829	1628	201
	2 inch, closed cell, flotation foam			

Irreducible Uncertainty

- **ATD differences in vertical response (cont.)**
  - The ATDs used for these tests have an H-point height difference of about 0.4 to 0.5 inches, depending on the type of cushion.

Cushion	ATD	H-Point Height (inches)	Difference (inches)
No Cushion	1	3.94	0.47
No Cushion	2	3.47	
Cushion B	1	8.23	0.43
Cushion B	2	7.80	
Cushion C	1	8.13	0.53
Cushion C	2	7.60	
Cushion D	1	8.40	0.41
Cushion D	2	7.99	

Irreducible Uncertainty

- **ATD differences in vertical response (cont.)**
  - ATD 1, which had the greater H-point height, produced higher lumbar loads than ATD 2 for all three cushion types. The additional height indicates that ATD 1 had an additional 0.5 inches of rubber skin/foam on the bottom of the pelvis.

Irreducible Uncertainty

- **ATD differences in vertical response (cont.)**
  - Since the foam material used in the pelvis is soft, this additional thickness could have a similar effect as was observed in the tests with insufficient preload (where 1 inch less preload resulted in 344 lb more lumbar load).
  - The additional foam thickness could be one cause of the higher lumbar loads produced by ATD 1.

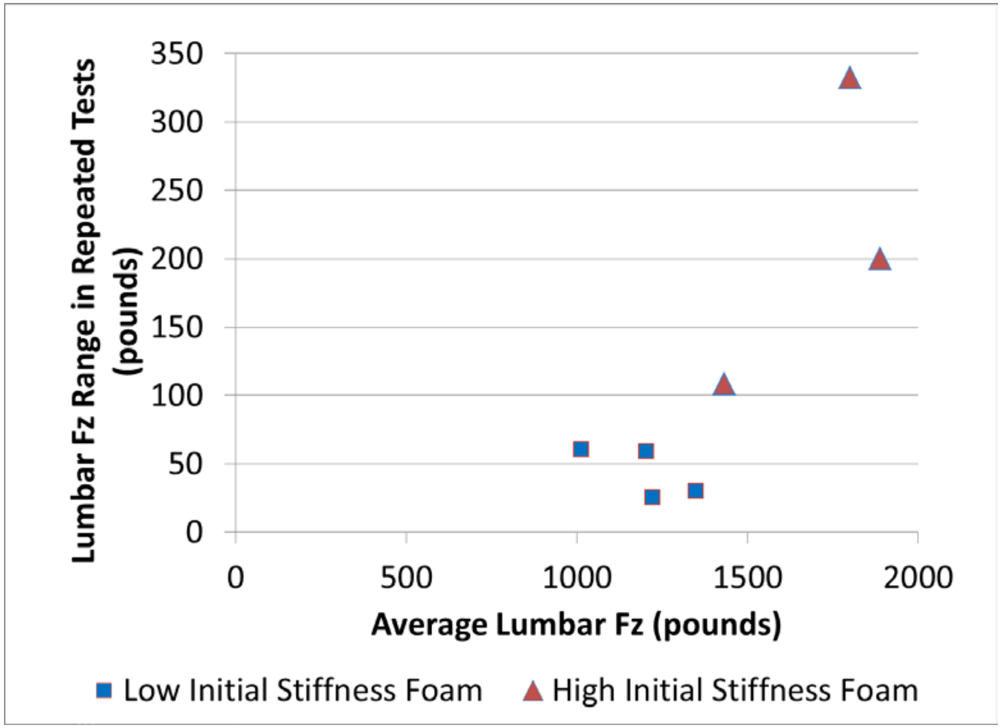
Irreducible Uncertainty

- **Inherent variability**
  - To investigate the inherent variability of the rigid seat test method, repeated tests of several types, stiffness, and thickness of foam materials were conducted. Test variability was minimized by:
    - using the same ATD for all tests,
    - controlling ATD initial position,
    - using the same specimen,*
    - normalizing the lumbar load to the G-peak goal of 14 G. (by scaling the lumbar load by the ratio of G-peak goal to G-peak actual).

**The specimen was rotated before each test to provide a different area for loading by the pelvis bone.*

Irreducible Uncertainty

- **Inherent variability (cont.)**
  - The range of results is still significant even when variables are well controlled



Irreducible Uncertainty

- **The lumbar load range for each group of repeated tests varied from 30 to 332 lb.**
- **For this group of tests, the magnitude of variance is related to foam type.**
  - The low density, open cell foam with low initial stiffness (which had more initial pre-test compression) produced less variability than the medium density, open cell foam with high initial stiffness (which had less initial pre-test compression).
  - The mechanism causing the variance is not apparent.

Irreducible Uncertainty

- **Foam variability**
  - The foam manufacturing process can result in density and stiffness variations in the product.
  - Foam specifications typically cite several testing standards that must be met by the product. The results of those standard tests, however, are not necessarily indicative of the dynamic performance in an aircraft seat cushion application.
  - This means that the permitted variation in foam product characteristics results in an unquantified level of dynamic performance variation between seat cushion articles.

Irreducible Uncertainty

- **Foam variability (cont.)**
  - A comparison of tests with the same cushion construction (but different articles) yielded a lumbar load range for each cushion type that varied from 25 to 200 lb. However, it is not clear what portion of the variability is due to actual cushion differences versus inherent test variability.

Observations

- **There is a potential for significant variability in vertical dynamic test results for a variety of reasons.**
  - Some sources of error can be controlled by careful attention to test setup and test article construction.
  - Other sources are inherent to the test dummy, test method, or material being tested.

Observations

- Significant test variability can interfere with the product development process since the actual performance differences between designs may be masked by the test variability.
- Significant test variability also reduces confidence in the robustness of the seat dynamic performance.
- Variability quantification is a necessary part of any cushion performance comparison test.

Observations: Minimizing Variation

- **Careful control of occupant initial position.**
- **Avoid arm interaction with surroundings.**
- **Use the FAA Hybrid-III or at least the Hybrid-III pelvis.**
  - The thickness of foam on the bottom of the Hybrid-III pelvis tightly controlled during production. This should improve dynamic performance consistency between ATDs.
  - The Hybrid-III pelvis can be installed on a Hybrid-II ATD with no modifications.
- **Use the same ATD for all development tests of a new product. Use the same ATD for 1g nominal position measurements and the tests.**
  - Minimizing one source of variability can help when evaluating design changes.

Conclusions

- **ATD vertical calibration**
  - The data indicating that ATD construction variation has a significant affect on lumbar load highlights the need to tightly bound vertical ATD response.
  - Must quantify the range of vertical response for currently produced ATDs.
  - Work with ATD manufacturers to implement a vertical calibration standard to ensure consistent performance between articles and manufacturers.
  - Quantify effect of wear and tear to determine appropriate calibration intervals.

Replacement Method Development

- **Quantifying ATD vertical performance is the first step in validating any replacement method since the full scale test produces the reference values used for comparison.**
- **While test variability prevented a straightforward validation of the rigid seat test method, a study of the underlying physics using component testing and computer modeling may provide the information necessary to validate this method or assist in development of a different one.**

Future Work

A New Hope….

- **Accurate characterization of ATD pelvis/lumbar dynamic force/deflection characteristics.**
- **Accurate characterization of rate sensitive cushion materials.**
- **Mathematical models of cushion/ATD interaction.**

CAMI's New High-Rate Material Test Stand

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Questions?