M&S Issues in the FAA

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TSO Workshop

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Federal Aviation Administration

STEP SENIOR TECHNICAL EXPERTS PROGRAM
ADVANCING SAFETY THROUGH SCIENCE

Topics

- Certification in the FAA
- Seat certification and analysis
- Guidance overview
- Examples of concerns

Acknowledgement/Disclaimer

- The views expressed in this presentation are those of the authors and do not necessarily reflect the view of the Agency
- FAA research may advise regulatory decisions, however, certification approvals are based on published federal regulations and policy

- No company proprietary data will be shown; pictures/data are from research tests with similar outcomes

- The examples are from ongoing projects where additional work is needed for final approval; no unsafe designs were approved based on these activities

Certification of Aircraft Articles

How do you certify an article?

- Demonstrate compliance with the applicable regulations with an accepted means of compliance (MOC)
- An Applicant can propose alternate MOC via an Issue Paper
  - Applicant and FAA negotiate the contents of the AMOC and applicability
- Sometimes in a single step and can be part of certification at aircraft level
- Oftentimes, articles approved to an industry standard, then compliance to the applicable regulation is later demonstrated
  - Technical Standard Order (TSO)
- **Generally compliance through physical testing!**

Certification by Analysis

The FAA approves the data, not the analytical technique

The FAA holds no list of acceptable analyses, approved computer codes, or standard formulas

- Use of a well-established analysis technique is not enough to guarantee the validity of the result
- The applicant must show the data are valid
- The FAA or our designees must find the data accurate and applicable, and that the analysis does not violate the assumptions of the problem

(Refer to FAA Order 8110.4C Type Certification, Paragraph 2-6g)

P/F Criteria for Aircraft Seats (Simplified)

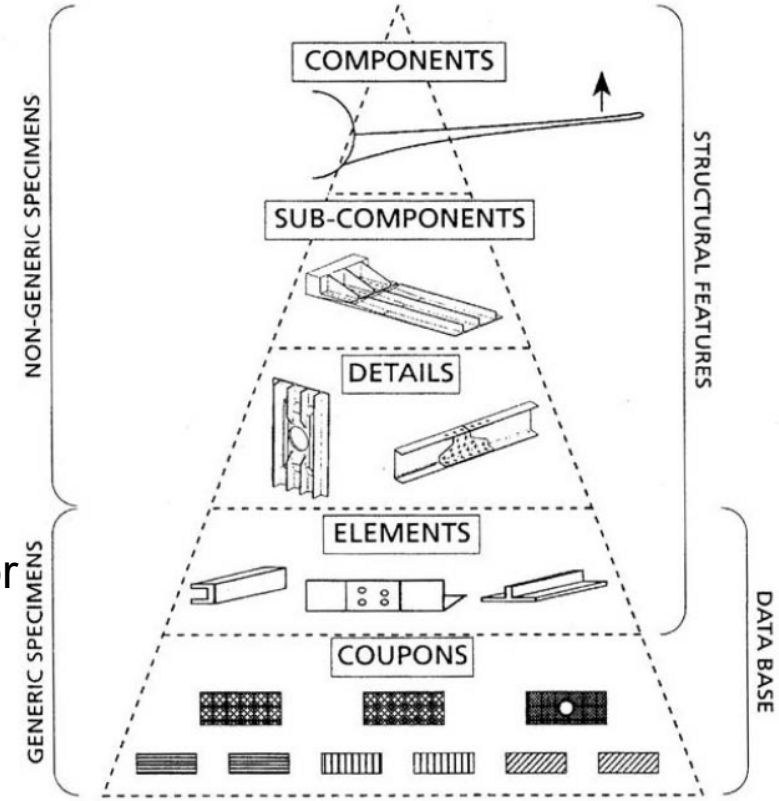
- Aircraft seats must be designed to protect occupants from serious injury under specific conditions detailed in the Code of Federal Regulations
  - Seat must stay attached to aircraft floor
  - Occupant injury risk is below defined thresholds (multiple system response quantities)
  - A representative seat is tested to show compliance
    - Tested seat must be conformed to the design
  - Manufacture of the seats must meet design specifications

AC 20-146A

- Methodology for Dynamic Seat Certification by Analysis for Use in Part 23, 25, 27, and 29 Airplanes and Rotorcraft
- The advisory circular (AC) sets forth an acceptable means, but not the only means, for demonstrating compliance with Title 14, Code of Federal Regulations (14 CFR) 23.562, 25.562, 27.562, and 29.562, as well as Technical Standard Order (TSO) TSO-C127a, and TSO-C127b
- AC 20-146 was signed on May 19, 2003 and is superseded
- Revision A was signed on 29 June, 2018 and is available for use
- Revision A change 1 is awaiting publication after public comment

AC 20-146A

- Virtual ATD (v-ATD) defined by SAE ARP 5765B
  - Calibration specifics contained within
- Newer version provides detail on other parameters
- Relies heavily on a building block approach
- Two error metrics defined
  - Magnitude error $$Error = \frac{|Peak_{test} - Peak_{sim}|}{|Peak_{test}|} * 100\%$$
  - Curve Shape error – Based upon Sprague and Geers comprehensive error



8.3 Application-Specific Validation Criteria

- The applicant should validate relevant parameters to the application of the model. The applicant and the ACO should identify and agree on the validation criteria specific to the application, and the certification plan should list those criteria. The applicant and the ACO should negotiate any additional validation criteria not listed in this AC. The following paragraphs provide guidance on the validation parameters to consider; however, the final levels should be coordinated with the ACO. If no acceptable rationale is available to make this determination, then the details listed in the following paragraphs may be followed:
- 8.3.2.1 Structural Response – Internal Loads
  - The peak critical floor reaction loads between the analysis and test data should correlate to within 10 percent unless a different level of correlation was determined prior to the initiation of any program.

Model Conservatism

- "Conservative simulation results are encouraged, but not required"
- Can use conservative inputs
  - More stringent sled pulse
  - Conservative material properties
    - May need to run more than one simulation
- Can use conservative limits model use
  - Similar to HIC and lumbar load "factor of safety"
- Only model predictions of HIC ≤ 890 eligible or lumbar load of ≤ 1430 lb
- Extrapolation limit a function of the degree of conservatism seen in validation

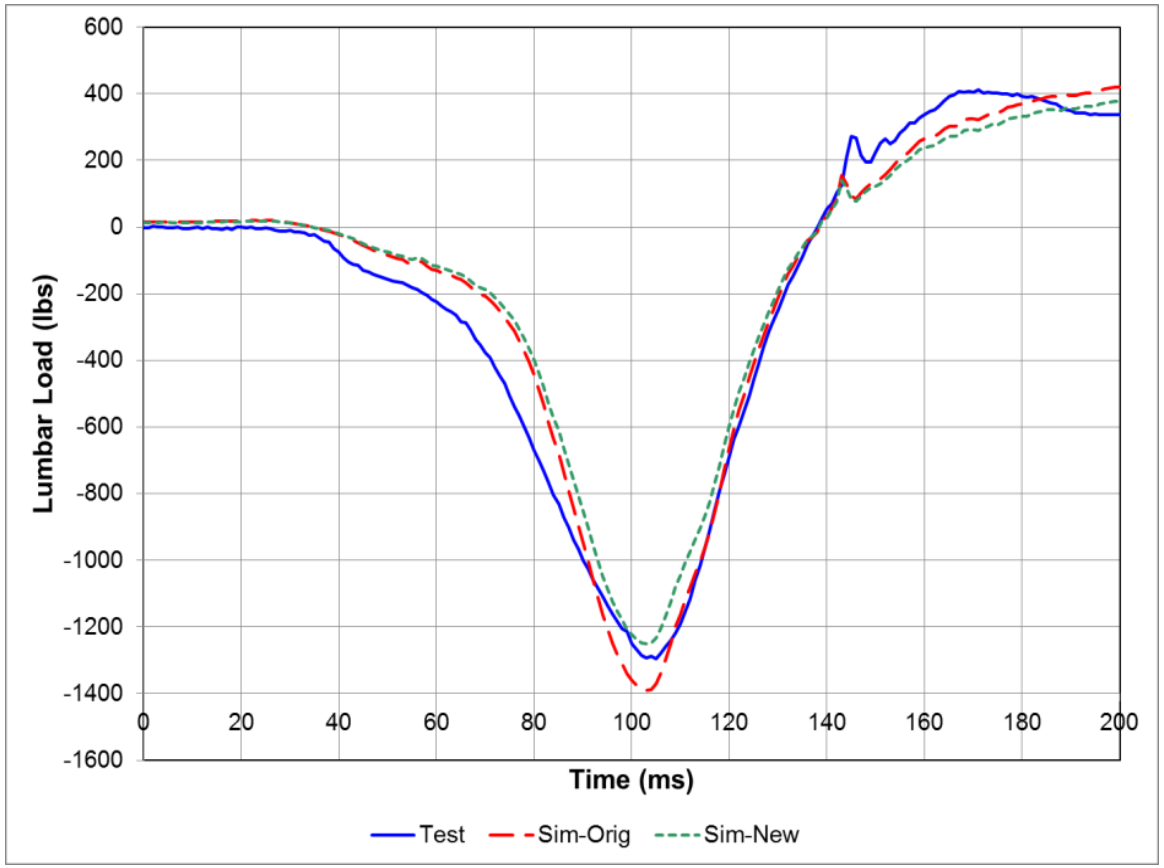
HIC	Validation	Model Use Hybrid II	Model Use FAA Hybrid III	Lumbar Load	Validation	Model Use Hybrid II	Model Use FAA Hybrid III
Model under predicts	Test = 850, Model = 800	Model = 840 or less	Model = 890 or less	Model under predicts	Test = 1400, Model 1350	Model ≤ 1380 lb	Model ≤ 1430 lb
Model over predicts	Test = 850, Model = 900	Model = 890 or less	Model = 890 or less	Model over predicts	Test = 1400, Model 1450	Model ≤ 1430 lb	Model ≤ 1430 lb

Model Use

- Application of the model to a new space
  - Ex: Application of Computer Modeling in Lieu of Dynamic Testing
  - Download test – Cushion replacement
    - Comparison of “validation” simulation with “model use” simulation
  - SRP, initial positions, changes between the two simulations
  - Results (plots and peaks)

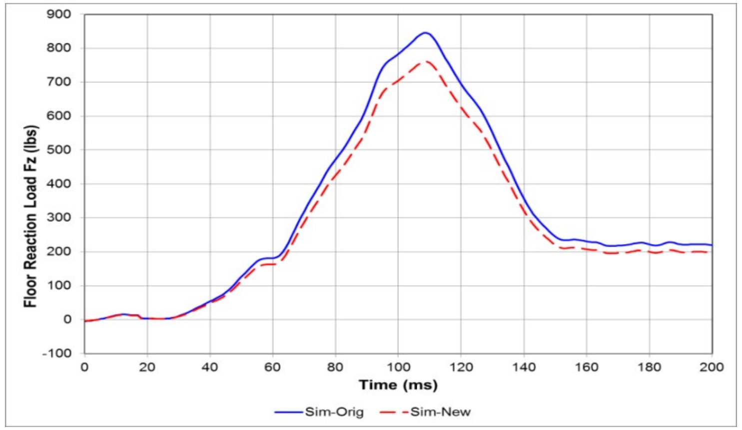
Model Use

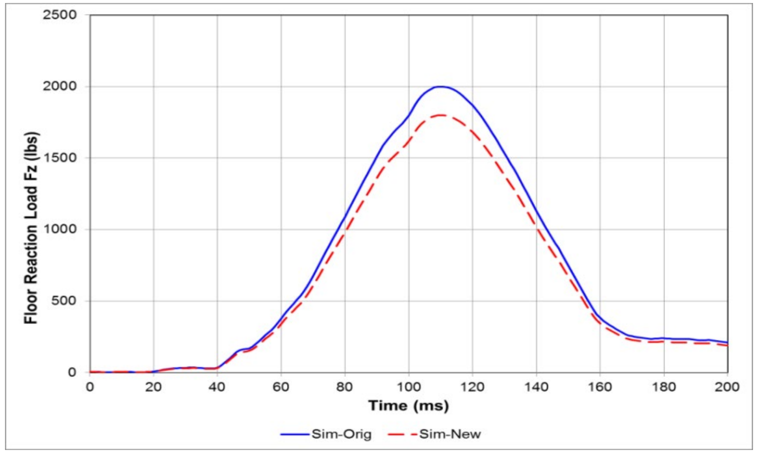
- Ex: Application of Computer Modeling in Lieu of Dynamic Testing

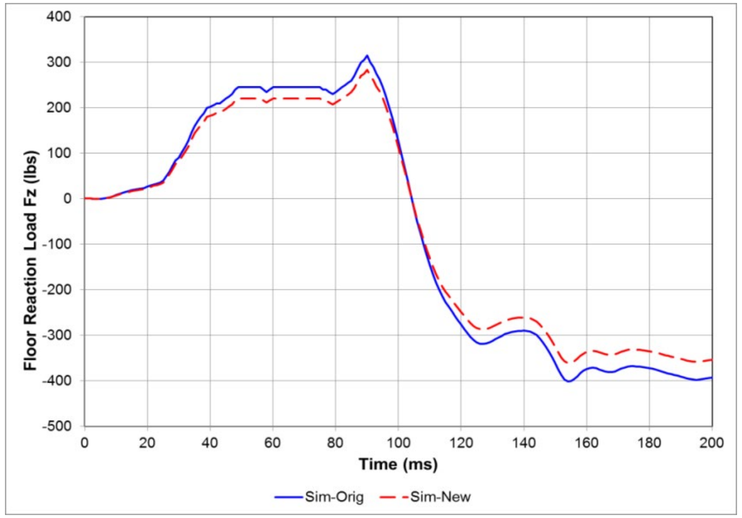


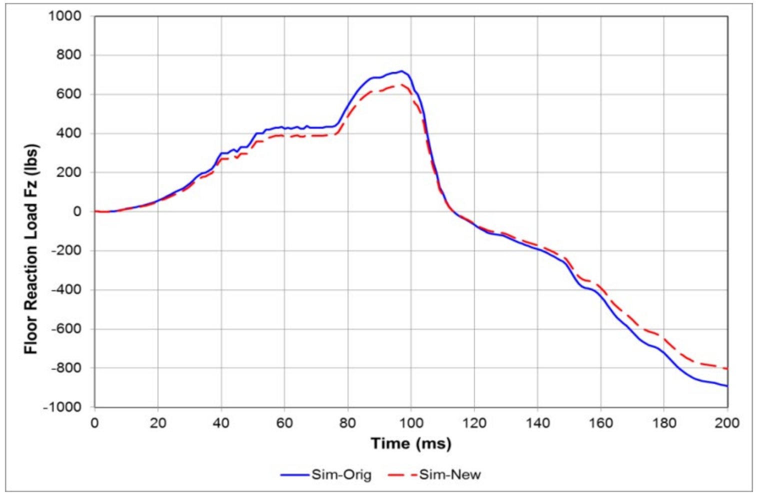
Model Use

- Floor reaction loads









Technical Meeting - Certification Plan Document

a. Description of seat to be modeled
b. Description of software
c. Description of compliance
d. Description of material data sources
e. Validation methods
f. Interpretation of Results
g. Substantiation documentation

Documentation Requirements

Validation and Analysis Report (VAR)

- Provide documentation of validation criteria and the analytical results

- Purpose of Model
  - Modeling in support of or in lieu of testing
  - List 14 CFR requirements
- Overview of Seating System
  - Seat Structure
  - Restraint System
  - Unique Energy Absorbing Features

Documentation Requirements

- Software and Hardware Overview
  - Define hardware (type & platform)
  - Define software (type & version)
- Description of Model
  - Assumptions with support
  - Finite element models & limitations
  - Material models and source of data
  - Constraints
  - Load application
  - Occupant model (include release number)
  - General analysis control parameters

Overview of VAR

- Model Documentation
  - Configuration control
- Model Validation
- Model Use – “Test Report” for simulation
  - Conformed Article
  - Acceptable Pulse
  - Acceptable ATD
  - No physical seat to inspect
  - No test to witness

Other Considerations

- Total cost includes model development (including physical tests), V&V, and documentation
- Verification of model inputs and outputs
  - User entered values
- Capabilities of the modeler(s)
- Capabilities of the reviewer(s) of the models

SAE ARP 5765 Rev B
Analytical Methods for Aircraft Seat Design and Evaluation

Published 30 March 2021

1. SCOPE
2. REFERENCES
3. V-ATD CALIBRATION
    a. **Calibration of ES2 (SFS dummy) (REV B)**
    b. Weight distribution (Rev B) - Completed
4. SYSTEM VERIFICATION AND VALIDATION
5. MODEL USE
6. DOCUMENTATION
    1. Certification approach (Rev B) – Completed
7. BEST PRACTICES
    1. Guidelines for Airbag modeling (Rev B) – Completed (move to AIR)
    2. Composite modeling (Rev B) – Completed (move to AIR)
    3. Check list (Rev B) – Completed -> Appendix F

APPENDIX

A: METHODOLOGY FOR THE COMPARISON OF TEST AND SIMULATION WAVEFORMS

B: FAA DATA SET FOR THE HYBRID II ATD

C: FAA DATA SET FOR THE FAA HYBRID III ATD

D: SAMPLE HYBRID II V-ATD CALIBRATION REPORT

E: SYSTEM VERIFICATION AND VALIDATION EXAMPLES

ATD Weight

- 14 CFR 25.562 calls out a 170 lb ATD that conforms to 49 CFR 572 Subpart B or equivalent
- 572 subpart B refers to a drawing package that specifies a weight of 164 +/- 3 lb [no clothing]
- Addition of shoes and cloths may or may not result in a total weight of > 170 lb
- FAA has accepted ATDs that meet 572 and are under 170 lb
- EASA will not accepted ATDs that are < 170 lb
- Bronze clavicles (allowed by the FAA/EASA) will add more weight

Guidelines for Airbag Modeling

PURPOSE:

- This section serves as a guideline for the VTEs (Virtual testing engineers) to model/design an airbag accurately by taking all the essential details into consideration in order to predict the performance as a system to substantiate a physical test.

- Airbags have become one of the most critical injury mitigating component, therefore, this section will also include all the details involved during design process where simulation can be used as a tool to make a predictable and robust design

Guidelines for Composite Modeling

PURPOSE:

- This section serves as a guideline for modeler to model/design/ assign a composite part accurately by taking all the essential details into consideration in order to predict the performance as a system to substantiate a physical test.

- Proposed section includes testing protocol, component level simulation, system level simulation and modeling guidelines.

SAE ARP Testing Best Practices

- Provide guidance for things to consider during test setup so that the necessary information is collected to support modeling
- Modifications to typical test protocols to collect quality data for modeling
  - Consistent ATD positioning
    - Joint locations, pelvic angle
  - Belt information (material props, lengths, pre-tension)
  - Tips for photometric analysis
    - H-pt
    - Knee

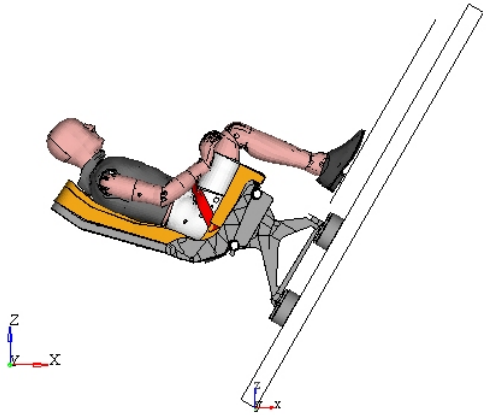
Setup Affects Results (Examples)

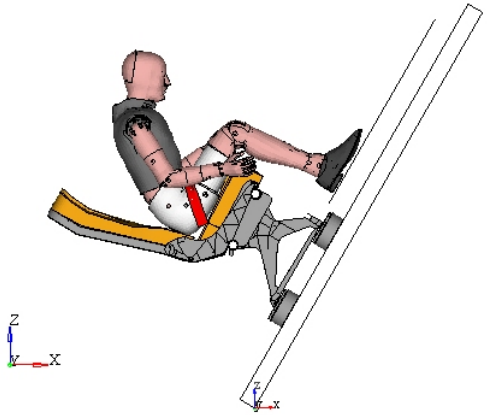
- 1 inch difference in initial cushion compression can change lumbar load 400 lbs*
- Arm interaction with legs or armrests can change lumbar load several hundred pounds
- Arm interaction with a wall can effect head path
- Leg flail can be effected by the placement of the ankles relative to the knees
- Setup control leads to repeatability and predictability

* Cushion specific

Validation Example

- **Part 25 Test 1**





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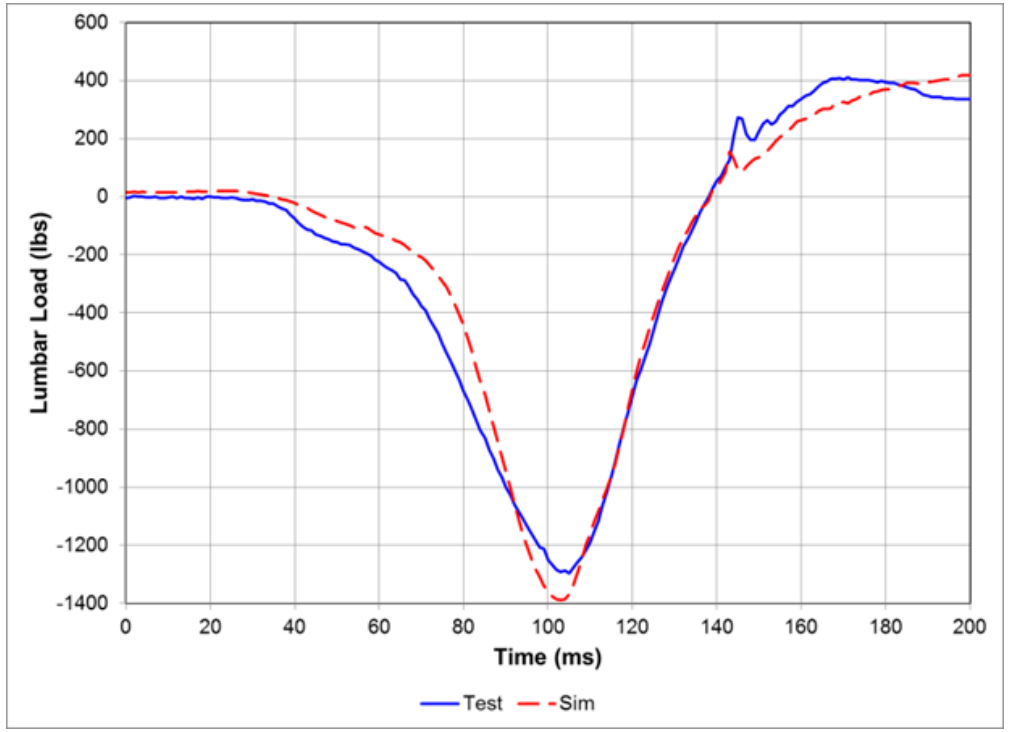
Validation Example - Lumbar Load

- Limit of 10% on magnitude and shape
- Magnitude error = 7.2%
- Shape error = 5.8%



Validation Example

- **Comparison of test and simulation**
  - Error metric calculations
  - Plots of test and simulation results
  - Discussion of any deviations from limits

Channel	Classification	Magnitude Error	Shape Error
Lumbar Fz	Primary	7.21%	5.79%
Front Left Fz	Primary	5.53%	6.31%
Front Right Fz	Primary	4.45%	9.37%
Rear Left Fz	Primary	1.31%	13.97%
Rear Right Fz	Primary	9.28%	20.24%
H-pt Z-motion	Support	0.06”	12.39%
Lumbar My	Support	48.94%	15.02%

Take Home Messages

- Model fidelity is different from model accuracy and different than model credibility
- Valid for one use doesn't necessarily mean valid for a different use
- Instead of saying I have a validated model, say "My model is valid to predict X in the context of Y"
  - My model is valid to predict the lumbar load of this seat, under the Part 25 test conditions, within the error limits defined in SAE ARP 5765a
- V&V (documentation) is about demonstrating, not simply claiming, credibility

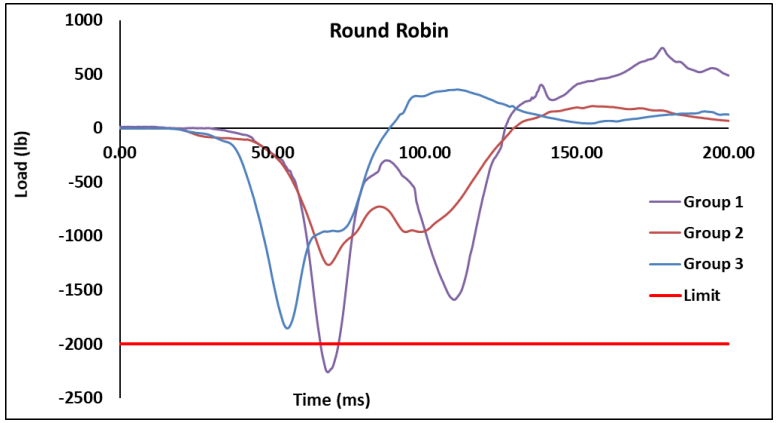
Potential Demonstration of M&S Abilities

- FAA decision makers are working with applicants to define the acceptability of analysis
  - Site inspections
    - The FAA does this for testing laboratories
  - Challenge problems
    - Demonstrate ability to solve a generic problem within the specific application realm
  - Pilot projects / Parallel efforts
    - Certify by testing while showing the M&S results along the way
- Allows us to work through potential issues before authorizing widespread use
- Multiple seat manufacturers/installers have submitted Issue Papers to the FAA for approval to use M&S to reduce the number of certification tests
  - The Issue Papers reference the companies quality manuals and standard operating procedure for the creation and evaluation of models and simulations
  - The FAA reviews these documents and participates in pilot/parallel projects

* Case studies extracted from: Experiences from Five Years of Certification by Analysis: Anonymized Case Studies from the Aviation Industry – ASME V&V Symposium 2020

Case Study 1: Round Robin

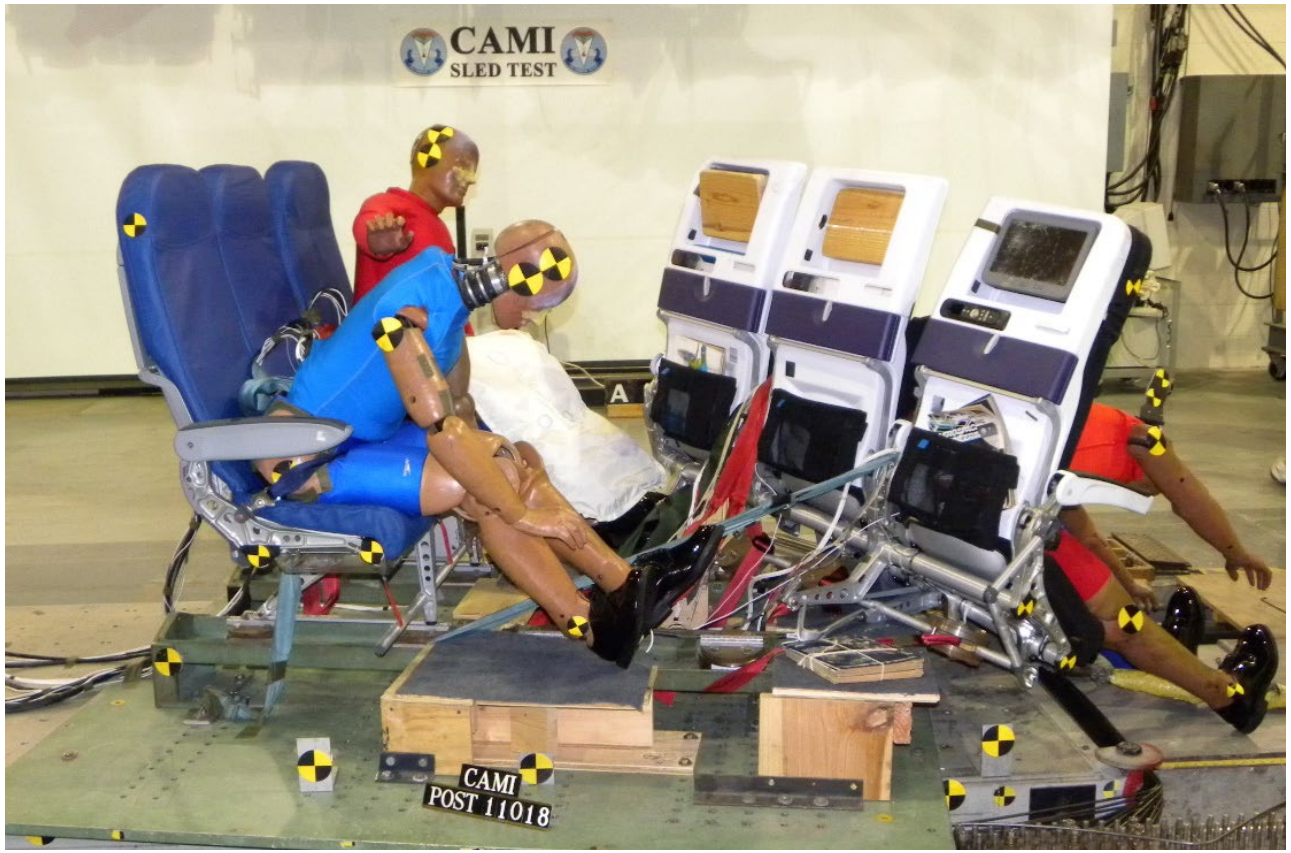
- Company requests FAA approval of their quality manual
- 3 groups provided the manual and tasked with building a model of a specific seat
  - 1 internal to the company, 1 supplier, 1 consultant
  - Model expected to predict X within 10%
- Review of simulation predictions for critical pass/fail criteria
  - Group 1: X = 1.15 Criteria
  - Group 2: X = 0.60 Criteria
  - Group 3: X = 0.85 Criteria



- FAA concern: manual is insufficient

Case Study 2: Parallel Project

- Applicant models their design and predicts results as if the decision will be based predominately on the simulation results
- In parallel, physical testing is conducted as official certification path and as a check on the model
- Simulation says the seat will stay attached to aircraft floor
- During testing, the seat broke loose
- Applicant determined that the mesh size of the floor track fitting was insufficient to predict failure
- Applicant: “The process worked”
  - “The test was a fail safe and the final design is safe”
- FAA: “Your process didn’t work”
  - The process the FAA was asked to approve doesn’t include a fail safe physical test, only this parallel project did

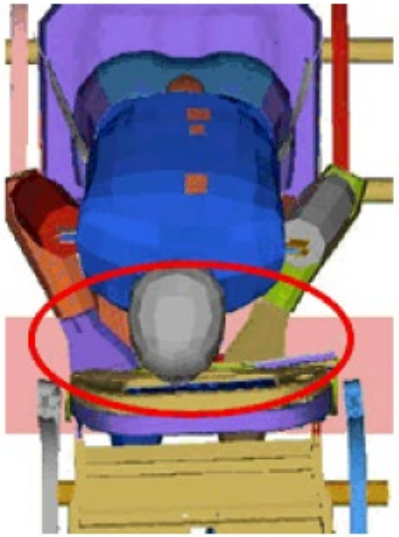


Case Study 3: Communication Issues?

- Company manual defines intermediate pass/fail criteria
  - Company defined process requires model updates when failing a criteria, no deviation specified
- Company analyst shows example model which does not meet criteria; modeling continues uninterrupted
- FAA asks company certification engineer if that is acceptable
- Company certification engineer unequivocally says “No”
- FAA: “Why weren’t you consulted as the certification engineer? Why did the process proceed? ”
- Cert Engineer: “Good questions. We’ll address and get back to you.”

Case Study 4: Pilot Project

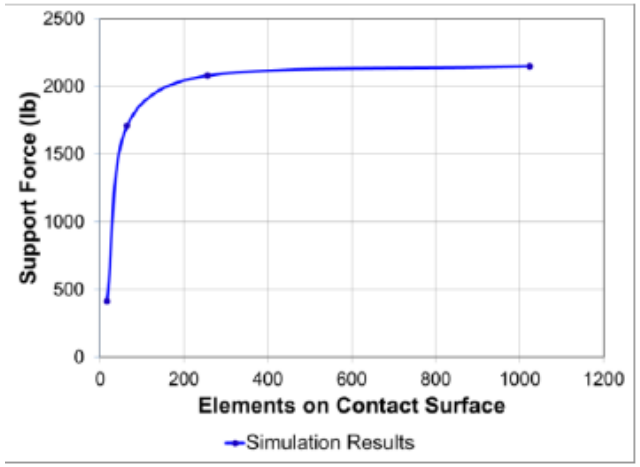
- Applicant requests FAA to approve process manual
  - Applicant and FAA working together on pilot project where applicant submits simulation results prior to conducting the test [good]
  - Validation requirement is simulation value within ± 10% of test result [per industry standard]
- Model predicts X = 0.95 Limit [Acceptable]
- Test X = 0.5 Limit
- Company standard operating procedure (SOP) for mesh size was used when constructing the model
- Subsequent efforts concluded that the mesh size was insufficient

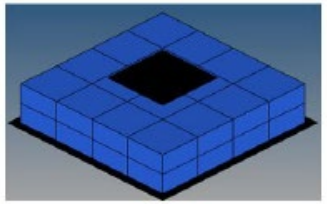


Picture from SAE ARP 5765

Case Study 4: Pilot Project (cont'd)

- New SOP for mesh size proposed
- FAA concerns:
  - No convergence study was completed for either the old SOP or new SOP
  - Selected mesh size (new) was the one that produced Sim X near Test X

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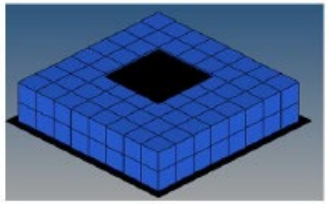
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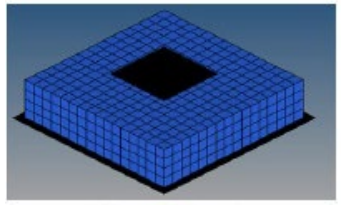
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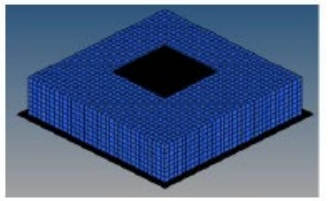
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Case Study 5: Proprietary Data

- Parts supplier will not release material properties to seat designer
- Model uses assumed properties while awaiting results of component testing
- Model results sent to FAA prior to incorporating the component data without noting the potential issue
- FAA: the open communication during pilot projects is excellent, but questions remain about the process

Case Study 6: Conformity

- Applicant built model based on initial drawings
- Test article based on final design drawings
- Test and sim results don’t match
- Issues:
  - Non-conformed article used in modeling
  - Company process broke down (M&S group not notified of changes to design, timeline insufficient)
  - Process manual did not define the submission of deviations to FAA
    - Some excluded parts didn’t affect results, but still need to be documented

General Concern: Calibration

- Applicant 1: Test result = 1405 lbs, Simulation result = 1405 lbs, “Model is perfect”
  - FAA concern: what is the chance that the simulation is a true prediction knowing that test scatter is at least 100 lbs
- Applicant 2: “My simulation is within 50 lbs of the test data” [Sim = 1450 lbs, test = 1405 lbs]
  - FAA provided the data: test 1 = 1405 lbs, test 2 = 1350 lbs, test 3 = 1305 lbs
  - FAA concern: cherry picked comparator
- Applicant 3 [part of challenge problem]: “I need the test data before I start the model”

Success

- Applicant has detailed manual with supporting evidence
  - SOPs based on good engineering practice
  - Have applied the SOP to multiple seat programs (outside of certification)
  - Demonstrated ability to predict failure
  - Linked material database and drawing library [automated]
  - M&S chain of command includes engineers with experience in certification
  - Initial projects are incremental

- FAA and Industry knew this would be a work in progress and consistent progress is being made
- Communication between applicants and FAA has been extensive and productive
- Applicants have had success with small projects that were approved on a case-by-case basis
- Multiple applicants are close to having broad quality manuals approved by the FAA

Summary

- The industry is moving forward and, while there are issues, this is laying the groundwork for future (broad) acceptance
- We (FAA and applicants) are asking the tough questions early to aid the decision makers job later on
- FAA and Industry are working to revise guidance material as we work through various projects and learn

Conclusions

- With proper planning and coordination, analytical methods can be inserted in the certification process
- The FAA has provided some basic guidance on Validation, but are open to discussions
- Validation is only part of the question, the process and how the data are used is as important
  - Delegation in the certification process requires the applicant to have a quality procedure that has been demonstrated to work and it needs to be followed
- Overall, the FAA wants to know that a company has a quality procedure that has been demonstrated to work and that they follow it leading to the design of safe systems
- Approvals based on M&S should provide data that is as reliable as data generated from physical testing

Questions?