U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

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

Date:

Initiated By: AIR-600

AC No: 20-146A

Change: 1

1 **PURPOSE.**

This 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, 23.2270, 25.562, 27.562, and 29.562, as well as technical standard order (TSO) TSO-C127, TSO-C127a, TSO-C127b, and TSO-C127c. This AC includes guidance for certifying seats by computer modeling analysis techniques that are validated by dynamic tests. This AC defines the acceptable applications, limitations, validation processes, and minimum documentation requirements involved when substantiation by computer modeling is used to support a seat certification program.

2 **PRINCIPAL CHANGES.**

This change clarifies provisions, removes redundant language, and modifies the use of the Federal Aviation Administration (FAA) Hybrid III Test Dummy. This change also updates AIR organizational designations and references to related ACs, and industry documents, as well as other minor editorial changes.

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DANIEL J. ELGAS

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of Transportation
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This advisory circular (AC) sets forth an acceptable means, but not the only means, for demonstrating compliance with title 14 of the 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. This AC includes guidance for certifying seats by computer modeling analysis techniques that are validated by dynamic tests. This AC defines the acceptable applications, limitations, validation processes, and minimum documentation requirements involved when substantiation by computer modeling is used to support a seat certification program.

If you have any suggestions for improvements or changes, you may use the Advisory Circular Feedback form at the end of this AC.

Dr. Michael C. Romanowski
Director, Policy and Innovation Division
Aircraft Certification Service

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1 PURPOSE

This AC sets forth an acceptable means, but not the only means, for using computer modeling analysis techniques validated by dynamic tests to demonstrate compliance with §§ 23.562, 23.2270, 25.562, 27.562, and 29.562, *Emergency landing dynamic conditions*. Hereafter, these regulations are referred to as "§ 2X.562," as well as the applicable dynamic strength and occupant protection minimum performance standard (MPS) specified in TSO-C127, TSO-C127a, TSO-C127b, and TSO-C127c, hereafter. referred to as "TSO-C127x." This AC provides guidance on how to validate the computer model and under what conditions the model may be used in support of certification, TSO approval, or authorization.

2 APPLICABILITY.

2.1 The guidance in this AC is applicable to transport category aircraft for which an applicant is seeking approval pursuant to § 2X.562 or TSO-C127x.

2.2 The material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for showing compliance with the applicable regulations. The FAA will consider other means of showing compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. If, however, the FAA becomes aware of circumstances that convince the agency that following this AC would not result in compliance with the applicable regulations, the FAA will not be bound by the terms of this AC, and the FAA may require additional substantiation or design changes as a basis for finding compliance.

2.3 The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

2.4 This AC applies to the following aircraft and seat manufacturers, modifiers, foreign regulatory authorities, and FAA certification branch aerospace engineers and designees:

2.4.1 <u>Applicants Who Include the Seat as Part of the Aircraft Design.</u>

In this case, the applicant is not using a TSO-C127x seat eligible for installation in the aircraft. The applicant would satisfy the requirements of § 2X.562 for the baseline seat using the specific interior configuration of the target aircraft (including attachment hardware and fittings). The applicant can substantiate modifications to this seat design and installation using the guidance in this AC.

2.4.2 <u>Seat Manufacturers Building Seats to the Requirements of TSO-C127x.</u>

In this case, the applicant may hold either a letter of TSO design approval or TSO authorization for those seats. In this instance, the TSO manufacturer would demonstrate compliance to the TSO standard by test for the baseline seat design. The TSO manufacturer can show compliance to the TSO for subsequent changes to this seat by using the analytical techniques and limitations described in this AC.

2.4.3 Aircraft Manufacturers or Modifiers Who Wish to Install a TSO-C127x Seat as Part of the Aircraft Type Design.

In accordance with AC 21-50, *Installation of TSOA Articles and LODA Appliances*, dated February 11, 2011, the data approved under the TSO-C127x seat approval and installation limitations may be used to support certification of the seat installation. Modifications by the installation approval holder to the TSO seat system are eligible for certification via the analytical techniques and limitations described in this AC.

2.5 If all pass/fail criteria identified in § 2X.562 or TSO-C127x are satisfied, applicants can use computer modeling analytical techniques to complete the following:

2.5.1 Establish the critical seat installation or configuration in preparation for dynamic testing (refer to paragraph 9 of this AC). However, applicants can still use any other FAA-approved methods to determine the critical test configuration.

2.5.2 Demonstrate compliance with § 2X.562 or TSO-C127x for changes to a baseline seat design, where the applicant has shown with dynamic tests that the baseline seat design meets these requirements. Changes can include geometric or material changes to primary and non-primary structure (refer to section 10 of this AC). Some changes to fittings and joints are acceptable to substantiate with modeling; however, significant changes to the material or mechanism of load transfer are considered major changes. Major changes to the TSO-C127x seat design require demonstration by dynamic testing unless a deviation is granted to substantiate via analysis. Additional guidance on the classification of seat design change is contained in FAA Policy Memorandum PS-AIR100-9/8/2003, *Classification of Design Changes to TSO-C39b, TSO-C127, and TSO-C127a Articles*, dated September 8, 2003.

3 CANCELLATION.

This AC cancels AC 20-146, *Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, and 29 Airplanes and Rotorcraft*, dated May 19, 2003.

4 BACKGROUND.

4.1 Attendees at the Small Airplane Airworthiness Review Conference, held in October 1984, developed a series of proposals that focused on cabin safety and design requirements for occupant protection. The proposals culminated with a notice of proposed rulemaking (NPRM) 86-19 (51 FR 44878) on December 12, 1986, which included proposed rule § 23.562. The preamble to that proposed rule stated that no sufficient database existed to permit the use of numerical analysis instead of dynamic testing to show compliance with this requirement. However, the preamble also states that the language of § 23.562 is intended to provide flexibility when the state of analytical techniques evolve sufficiently to permit these techniques instead of dynamic tests.

4.2 This AC provides guidance for demonstrating compliance pursuant to §§ 23.562 and 23.2270 by means of computer modeling techniques. Recognizing that this guidance is equally applicable to aircraft other than small airplanes, this AC also applies to §§ 25.562, 27.562, and 29.562.

4.3 This AC defines the acceptable applications, limitations, validation processes, and minimum documentation requirements involved when an applicant uses substantiation by computer modeling to support a seat certification program. The original release of this AC was the culmination of the efforts of the Advanced General Aviation Transportation Experiments (AGATE) Program's Advanced Crashworthiness Work Package Team. The AGATE project was a consortium consisting of representatives from private industry, research institutions, academia, and the Federal Government. As part of the AGATE effort, the team developed a methodology for seat certification and design by analysis. This AC is a direct result of that methodology.

4.4 In addition, TSO-C127x established a standard for the dynamic testing of seats as specified by § 2X.562. Although installation approval under the airworthiness standards is required for every TSO item, applicants or holders of TSO-C127x may use the methodology presented in this AC in accordance with the applicability defined in paragraph 2 of this AC.

5 RELATED DOCUMENTS.

5.1 Title 14, Code of Federal Regulations (14 CFR).

The following regulations are related to this AC. You can download the full text of these regulations at the U.S. Government Printing Office e-CFR website.

- Part 21, *Certification Procedures for Products and Parts.*
- Part 23, subpart C—*Structure*.
- Part 25, subpart C—*Structure*.
- Part 27, subpart C—*Strength Requirements*.
- Part 29, subpart C—*Strength Requirements*.

5.2 Title 49, Code of Federal Regulations (49 CFR).

Part 572, *Anthropomorphic Test Devices.*

5.3 **FAA Orders**.

If any FAA order is revised after publication of this AC, you should refer to the latest version on the Dynamic Regulatory System (DRS) at https://drs.faa.gov.

- FAA Order 8110.4C CHG 7, *Type Certification.*
- FAA Order 8150.1D CHG 1, *Technical Standard Order Program.*

5.4 **FAA Advisory Circulars.**

The following ACs are related to the guidance in this AC. You should refer to the latest AC version for guidance, which is available on the DRS at https://drs.faa.gov.

- AC 20-107B CHG 1, *Composite Aircraft Structure*.
- AC 21-25B, *Approval of Modified Seating Systems Initially Approved Under a Technical Standard Order.*
- AC 21-46A, *Technical Standard Order Program.*
- AC 21-50, *Installation of TSOA Articles and LODA Appliances.*
- AC 23.562-1B, *Dynamic Testing of Part 23 Airplane Seat/Restraint Systems and Occupant Protection.*
- AC 25.562-1B CHG 1, *Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes.*
- AC 27-1B CHG 9, *Certification of Normal Category Rotorcraft.*
- AC 29-2C CHG 8, *Certification of Transport Category Rotorcraft.*

5.5 **Technical Sources.**

The following TSO is related to the guidance in this AC. You should refer to the latest TSO version for guidance, which is available on the DRS at https://drs.faa.gov.

TSO-C127c, *Rotorcraft, Transport Airplane, and Small Airplane Seating Systems.*

5.6 **Industry Documents.**

- *Methodology for Seat Design & Certification by Analysis*, NASA Advanced General Aviation Transportation Experiments (AGATE) Report WP3.4-034012-077, NASA, Washington, DC, August 31, 2001.
- *Performance Standards for Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft*, SAE International Aerospace Standard, SAE AS8049 Revision C, SAE International, August 14, 2015.
- *Analytical Methods for Aircraft Seat Design and Evaluation*, SAE Aerospace Recommended Practice (ARP), SAE ARP 5765, Revision A, SAE International, December 2015.
- *Instrumentation for Impact Test - Part 1 - Electronic Instrumentation*, SAE Surface Vehicle Recommended Practice, SAE J211-1, SAE International, July 2007.

- *Instrumentation for Impact Test - Part 2 - Photographic Instrumentation*, SAE Surface Vehicle Recommended Practice, SAE J211-2, SAE International, November 2008.
- Gowdy, V., DeWeese, R., Beebe, M., Wade, B., Duncan, J., Kelly, R., and Blaker, J., *A Lumbar Spine Modification to the Hybrid III ATD For Aircraft Seat Tests*, SAE Technical Paper 1999-01-1609, General, Corporate, and Regional Aviation Meeting and Exposition, Wichita, KS, April 20-22, 1999.
- *Metallic Materials Properties Development and Standardization (MMPDS) Handbook*, MMPDS-07, Battelle Memorial Institute, April 2012.
- *Composite Materials Handbook (CMH-17)*, SAE International, July 11, 2012.

5.7 **Other References.**

- *American Society of Mechanical Engineers (ASME) V&V 10-2019, Guide for Verification and Validation in Computational Solid Mechanics, 2019.*
- *Belytschko, T., Liu, W.K., and Moran, B., Nonlinear Finite Elements for Continua and Structures, John Wiley and Sons, Chichester, West Sussex, England, 2000.*

6 DEFINITIONS.

6.1 **Baseline Seat.**

The seat that encompasses the common design methodology from which other seats within a family of seats can be derived. This includes items such as geometry, material, manufacturing method, and attachment methods. The baseline seat is typically the seat selected for testing based on its criticality. Other seats in the family will be similar to the baseline seat but might vary based on select details. Some of these details include, but are not limited to, leg spacing, placement of reinforcements (to support attachments), and rivet locations.

6.2 **Baseline Testing.**

The initial series of tests performed on the baseline seat as part of the original certification to substantiate the seat family.

6.3 **Computer Modeling.**

The use of computer-based finite element or multi-body transient analysis to simulate the emergency landing dynamic condition of the applicable airworthiness standard. These codes typically follow an explicit formulation for calculation of the structural response but can follow a centered mass formulation for calculation of the occupant response.

6.4 Family of Seats.

A group of seat assemblies, regardless of the number of seat places, built from equivalent components in the primary load path.

6.5 Mass Scaling.

In finite element modeling, the process of adding nonphysical mass to the structure to increase the time step, thereby reducing the run time.

6.6 Occupant.

In this AC, occupant is not synonymous with the word passenger; occupant refers to the anthropomorphic test device (ATD). The occupant model is used to correlate the behavior of the ATD, as opposed to human biodynamic behavior.

6.7 Seating Configuration.

The interior floor plan of the aircraft, which defines the seating positions available to crew and passengers during taxi, takeoff, landing, and in-flight conditions.

6.8 Seat Primary Load Path.

The components within the seat that carry the load from the point of load application to the structure that reacts the load from the seat system or sub-system. The seat primary load path varies depending on the parameter being evaluated, as follows:

- Structural—from seat belt/harness to fittings attaching seat system to aircraft structure.
- Lumbar—from bottom cushion to fittings attaching seat system to aircraft structure.
- Row-to-row head injury criterion (HIC)—from point of ATD head contact to the attachment of seat primary structure.
- Head path (for example, front row or large pitch seats)—from seat belt/harness to fittings attaching seat system to aircraft structure.

6.9 Seating/Restraint System.

A system includes the seat structure, cushions, upholstery, safety belt, shoulder harness, and attachment devices.

7 VERIFICATION OF EXPLICIT CODES.

The verification process determines the computational model accurately represents the underlying mathematical model and its solution (reference paragraph 5.6 of this AC). Verification of explicit codes precedes validation, as it is important to minimize errors before progressing. Verification consists of two components, code verification, and calculation verification. Calculation verification is further divided into temporal and spatial convergence. The following sections discuss how this process could be applied for explicit codes. In certain situations, implicit codes may be used, and verification methods should be applied.

7.1 Code Verification.

7.1.1 Code verification is the process of determining that the numerical algorithms are correctly implemented in the computer code and identifying errors in the software. (Refer to ASME V&V 10-2019 listed in paragraph 5.6 of this AC). Verification helps ensure the implementation of the mathematical model and solution algorithms are working correctly in the code, and that the code solution predicts the analytical solution to a certain extent.

7.1.2 Computer analyses used for certification purposes are typically conducted on a commercially available computer code. It is the applicant's responsibility to select and assess that computer code produces valid results. The applicant or their software provider performs code verification on the hardware and software environment of their design. In addition to performing code verification, the applicant or their software provider should also include copies of their quality assurance policies and procedures in the verification data submitted for certification.

7.2 Calculation Verification.

Calculation verification, also called solution verification, is the process of determining the solution accuracy of a particular calculation (refer to ASME V&V 10-2019). The goal of calculation verification is to show that discretization errors due to insufficient spatial or temporal discretization is small, and that the model converges to a unique solution with spatial and temporal refinement, respectively. The convergence errors in the numerical model outputs for the system response quantities of interest should be minor compared to the differences allowed in validation comparisons.

7.2.1 <u>Temporal Convergence.</u>

7.2.1.1 The dividing of the total time of a simulation into smaller segments is called temporal discretization. Each segment is typically referred to as a time step, denoted as Δt below. The stability of explicit time integration methods depends on the time step. If the time step is too large for a given element size and material, the method fails, either because of stability issues or poor accuracy. If the time step size is getting too small, the solution time becomes impractical, thus diminishing the effectiveness of the method. The critical time step for a given finite element according to the Courant stability condition is $\Delta tcr = 2/\omega = \min(L/c)$. In this equation, ω is the natural frequency of the finite element, L is the characteristic length of the finite element, and c is the sound wave speed (a function of material stiffness and density) as described by Belytschko, et al. (reference paragraph 5.6 of this AC). The time step used for the calculation is the smallest Δtcr of all finite elements in the model. The time step selected for the analysis should be smaller than the time for the sound wave speed to cross the smallest element in the finite element mesh. Otherwise, numerical instability might develop and cause the solution to diverge. Belytschko addresses the inherent numerical instabilities encountered with explicit dynamic analysis codes.

7.2.1.2 In theory, the most numerically efficient solution is obtained when an integrating time step equivalent to the stability limit is chosen. Commercial codes attempt to offset the problems of numerical instability by regulating and constantly updating the time interval used throughout the analysis. The simulation uses a time step based on the element size, material, and element type. The time step is recomputed at each cycle based on the mesh size and stiffness of the materials.

7.2.1.3 Occasionally, the simulation time step is controlled by only a few small or stiff elements in the model. When this happens, it is typically useful to remesh the controlling elements. In the case of extreme compression, such as with foams consolidating, some codes can automatically remove elements when the length becomes a small fraction of the initial length to avoid extreme time steps or instabilities.

7.2.1.4 When updating the mesh is not practical, mass scaling can be employed. Mass scaling is the process of adding nonphysical mass to the structure to increase the time step, thereby reducing the run time. Choose a minimum time step (Δt) that is greater than the time step required to satisfy the Courant criteria. The software adds mass in all the elements with a critical integration time step smaller than this given value. A scale factor is applied on the critical time step to take into account that the time step for the current configuration is computed based on the previous configuration ($t-\Delta t$). A scale factor applied to the time step can be used to prevent the instability by enforcing the time integration algorithm to use a smaller time step. Depending on the quality of the mesh, and strain rate properties a different scale factor may be used. Typically, the scale factor varies from 0.6 to 0.9.

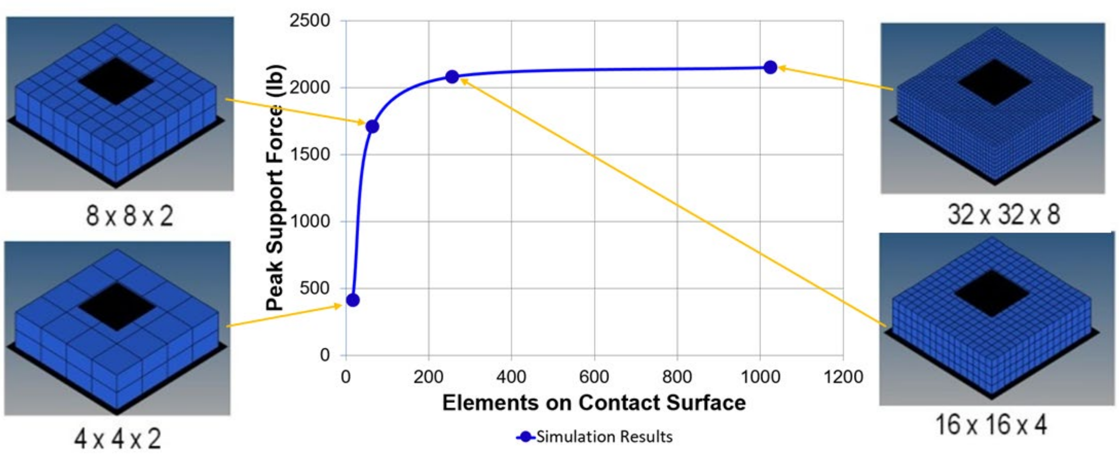
7.2.1.5 Mass scaling should only be used on the smallest elements contained in the model, so as not to affect the overall mass of the system. The FAA recommends that the overall mass scaling should not exceed 5 percent for critical seat components. For non-critical seat components, an increase in mass of up to 10 percent is acceptable. For quasi-static simulations, it is acceptable to increase the mass scaling up to 10 percent since the kinetic energy is small. Rigid body techniques do not use mass scaling.

7.2.2 Spatial Convergence.

7.2.2.1 The finite element analysis technique divides a continuum into finite elements, volumes, surfaces, and line segments that are, interconnected at a discrete number of points, called nodes, and solve the boundary-value problem. The number of elements and the types of elements used greatly affect the accuracy of the result. For example, a coarse mesh can produce erroneous results. Construction of a model includes a trade-off between the accuracy of the solution resulting from the mesh, and the amount of time it takes to run the simulation. Typically, one uses the coarsest mesh that produces a sufficient level of accuracy. As such, evaluation of spatial convergence is necessary in components that are in the critical load path.

7.2.2.2 An estimate of the spatial convergence can be generated based on two or more mesh refinements. If the results of the numerical solution do not change significantly from the refinement, one can expect to be close to the asymptotic region. For example, the compression of a square cushion via a weight can be computed for differing mesh sizes. (See figure 1 below.) The results have converged at the fourth mesh, but the third mesh may be acceptable. Exact calculation of the spatial convergence error of an explicit structural analysis is a non-trivial pursuit that is an ongoing research activity. Adaptive meshing techniques and extreme compression of elements or removal of elements will have unknown effects on the spatial convergence.

Figure 1. Mesh Refinement Example



8 COMPUTER MODEL VALIDATION.

8.1 Overview.

8.1.1 The validation process determines the degree to which a model is an accurate representation of corresponding physical experiments from the perspective of the intended uses of the model (refer to ASME V&V 10-2019). The ability of the model to represent a physical phenomenon is evaluated by comparing the model predictions with physical test data. This process relies on high-quality test data and a quantitative comparison of test and simulation results. Validation is not an iterative process of refining the model to reduce discrepancies between the experimental systems and model outcomes. Refining the model is called calibration; it does not provide confidence that the model can accurately predict the system's response to untested conditions.

8.1.2 This AC provides guidance on the numerous parameters that deserve consideration when comparing the results of numerical analysis to actual test data. However, in performing the validation of a numerical model, there is no substitute for good engineering judgment. An applicant should not use the guidance in this AC as a substitute for communicating and coordinating with the applicable certification branch when validating a numerical model. Sections 9 and 10 of this AC define the conditions where an applicant may use the results from computer analysis for certification purposes.

8.1.3 Any virtual anthropomorphic test device (v-ATD) used in the analysis should simulate the same type ATD that was used in the physical testing, which is defined in § 2X.562, TSO-C127x, or FAA policy. The applicant should demonstrate that the v-ATD is calibrated to behave similarly to the physical ATD or that it meets the guidance in SAE ARP 5765, revision A or later. Before any of the validation criteria are calculated, check the occupant simulation software for the reference location of all sensors of the v- ATD compared to the corresponding locations of the sensors on the ATD.

8.2 General Validation Acceptance Criteria.

8.2.1 The model should be validated against the original dynamic tests in accordance with § 2X.562(b) or TSO-C127x. The FAA will not accept a model validated against another validated model.

8.2.2 Model extrapolation should be limited to conditions that are similar to the model validation conditions. Occupant trajectory and head injury criteria detailed in appendix A of this AC. The current seat analysis should be similar to the test and analysis used to validate the numerical model, including loading conditions, seat type, and worst-case conditions. For example, the applicant should not use test results from a four-legged seat to validate a three-legged seat model. As another example, a model validated against longitudinal test data should not be used to evaluate vertical test conditions.

8.2.3 Conservative simulation results are encouraged, but not required. In the context of simulation, conservatism relates to the model over-predicting a particular response or under-predicting a particular strength. For example, if in the test, the calculated HIC was 700, but the model denoted 725, then the simulation is conservative.

8.2.4 The level of correlation required should not be more stringent than the level of accuracy of the test data, which is dependent on the test instrumentation.

8.2.5 The FAA considers the computer model validated if an acceptable agreement can be shown between the analysis and test data for those parameters critical to the application of the model. The calculation methods are detailed in appendix B of this AC. Test data used to validate the model should be included as an appendix in the validation and analysis report (VAR), refer to section 12 of this AC.

8.2.6 When precise occupant trajectory information is not required, a visual comparison of the event can be sufficient.

8.2.7 In addition to the general validation criteria above, the applicant might need to validate the model to some or all of the application specific criteria defined in paragraph 8.3 of this AC to ensure that the design requirements of the computer model are correct.

8.3 **Application-Specific Validation Criteria.**

The applicant should validate relevant parameters to the application of the model. The applicant and the certification branch should identify and agree on the validation criteria specific to the application, and the certification plan should list those criteria. The applicant and the certification branch should negotiate any additional validation criteria not listed in this AC. The following paragraphs provide guidance on the validation parameters to consider and suggested correlation levels. However, the final levels should be coordinated with the certification branch prior to the initiation of any program. If no acceptable rationale is available to make this determination, then the details listed in the following paragraphs may be followed:

8.3.1 Occupant Trajectory.

8.3.1.1 The general occupant trajectory should correlate to the test data. The trajectory should be specified by time history plots under SAE J211-2. Occupant trajectory describes the overall translational and rotational motion of the occupant. SAE AS8049 defines use of the seat reference point (SRP) as the datum to determine occupant trajectory or position. The trajectory of the occupant can include head path, pelvic displacement, or torso displacement. When the pelvis is not visible, the knee can be used as a surrogate. If there is a concern regarding femur injury, occupant trajectory can include leg motion as well.

8.3.1.2 Head path trajectory can be, in and of itself, a validation item. For example, if the applicant conducted a validation effort to support a claim that no head contact occurs, head path is a unique validation item. It can also be used to support another parameter, such as HIC.

8.3.1.3 The numerically derived occupant trajectory should be compared to high-speed video obtained from dynamic tests. The ability of the computer model to predict an occupant trajectory can be established by comparing time-history plots, for example, x-position versus time, and z-position versus time to calibrated photometric data obtained from the baseline dynamic test. Acceptable limits for model validation may be based on criteria established between the applicant and the FAA.

8.3.1.4 Quantitative evaluation of extremity flail is typically not required, specifically for forward- and aft-facing seats. However, arm and leg interaction with other seats or monuments can have a significant effect on the motion of the head and pelvis and, therefore, should not be completely ignored.

8.3.1.5 For side-facing seats, the applicant can use computer modeling to demonstrate that only incidental body-to-body contact will occur when the occupants are exposed to the accelerations and velocities pursuant to § 2X.562. This assumes that the seat structure and occupant motion have been validated to a baseline side-facing seat test.

8.3.1.6 Appendix A of this AC illustrates some of the items to consider when evaluating occupant trajectory and HIC. Although appendix A is an example of those items to consider in this type of validation, it is not a universal example. Other situations might require more or less stringent validation efforts.

8.3.2 Structural Response.

Quantifying the structural response of the computer model includes evaluating the internal loads and structural deformations of the seat. Validation of the computer model should include a comparison of the structural performance criteria.

8.3.2.1 **Internal Loads.**

8.3.2.1.1 The applicant and the certification branch should work together to establish what floor reaction loads, if any, are critical to the application of the analysis. Correlation of the floor reaction loads demonstrates a properly modeled load path from the occupant to the restraint system to the floor. 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. In addition, the applicant should provide data showing that the critical floor load reactions correlate to the test results as described in appendix B of this AC.

8.3.2.1.2 There may be times when the applicant introduces a unique design for a primary load path member. The applicant may choose to install test instrumentation to monitor the internal loads or strains on this member. This instrumentation is not required for certification but may be useful in validating the numerical model. In this instance, the applicant and the certification branch should work together to determine how or if these loads will be used to validate the model.

8.3.2.2 **Structural Deformation.**

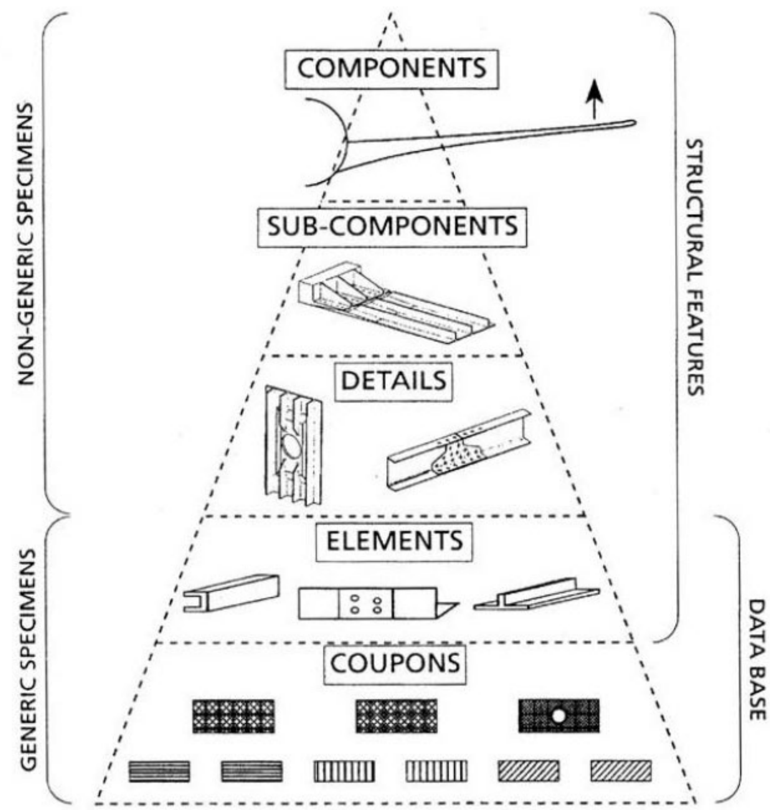
8.3.2.2.1 A comparison of the planar space plots of structural deformation obtained from the analysis and photometric data obtained from dynamic test can help validate the model. Acceptable agreement should be obtained between the shape and magnitude, within 10 percent as described in appendix B of this AC unless a different level of correlation was accepted prior to the initiation of any program, for members that are critical to the overall performance or structural integrity of the seat or seating system. Not all safety margins or all modes of failure need to be examined, only those the certification branch and applicant believe will be critical. The applicant can use visual comparisons between the test and analytical data for non-critical structural members.

8.3.2.2.2 If analysis of dynamic tests requires the determination of post-test permanent deformation such as that required for a structural test, then the analysis should differ by no more than 10 percent, unless a different level of correlation was determined prior to the initiation of any program, from the test and should not exceed any allowable deformations.

8.3.2.3 **Failure Modes.**

Failure modes of components may be validated through full-scale dynamic tests or component tests following a building block approach. See figure 2 of this AC. Modeling of tests that show structural failure can provide confidence in the model's ability to capture relevant failure modes. If the model is only validated against tests with no failure or permanent deformation, there is little confidence that the model is capable of predicting failure. The conceptual framework of component and subcomponent level tests typically included in the building block approach can be adapted to the seat structure. The large quantity of tests needed to provide a statistical basis comes from the lowest levels, coupons, and elements (which are used to calibrate the numerical model), and the performance of structural details are validated in a lesser number of subcomponent and component tests. Detail and subcomponent tests may be used to validate the ability of analysis methods to predict local strains and failure modes. Added statistical considerations—for example, repetitive point design testing and/or component overload factors to cover material and process variability—will be needed when analysis validation is not achieved. The static strength substantiation program should also consider all critical loading conditions for all critical structure. Refer to AC 20-107B, CHG 1 for further information.

Figure 2. Schematic Diagram of Building Block Approach



8.3.2.4 **Joints and Fittings.**

Joints and fittings are typically highly loaded seat structural elements. In general, they possess indeterminate load paths and contact (free-play) nonlinearities and might be difficult to model mathematically. Changes in the load path or material properties of these elements can affect the structural integrity and performance of the seat. Therefore, these parts of a seat structure should be modeled with care, paying particular attention to all possible failure mechanisms. Some changes to fittings and joints are acceptable to substantiate with modeling. However, significant changes to the material or mechanism of load transfer require tests.

8.3.3 Restraint System.

8.3.3.1 With few exceptions, such as aft-facing seats and side-facing seats bounded by a wall or divider, the restraint system contributes significantly to the retention of the occupants and is part of the primary load path from the occupant to the seat. In this case, the test-simulation correlation should be evaluated for the restraint loading time history and the maximum value. Maximum values that correlate to within 10 percent, unless a different level of correlation was determined prior to the initiation of any program, will ensure the computer model will predict the inertial force transfer from the occupant to the seat. For a seating configuration with a shoulder belt, conservatism is not always straightforward. Over-estimation of the shoulder belt load can lead to under-estimation of the ATD head x-motion and vice versa.

8.3.3.2 Additional parameters, such as belt payout or permanent elongation, when present, are not required for seat certification, but should be taken into account in order to provide additional confidence that the model is capturing the pertinent physics. Another factor to consider is any belt tightening that can occur after an inertial reel lock.

8.3.3.3 Belt payout is a term used to describe how much of the shoulder harness restraint is released before locking of the inertia reel. In a sudden deceleration, it is unlikely the shoulder harness instantly locks in place. There is a finite length of time where the harness is free to release from the reel. The amount of restraint released from the reel is the belt payout.

8.3.3.4 Occupant trajectory and restraint system loads are closely related functions. The necessity of validating the restraint system loads does not negate the necessity of validating the occupant trajectory in situations where the restraint system loads are required. It is not acceptable to show compliance to occupant trajectory instead of restraint system performance or to validate restraint system performance at the expense of occupant trajectory.

8.3.4 Spine Load.

8.3.4.1 Section 2X.562 and TSO-C127x defines the certification requirements for lumbar spinal loading. The maximum allowable load is 1,500 pounds (lbs) of compression. The computed spine load should be correlated with the test data when appropriate. This includes, but is not limited to, the initial validation of a test scenario or situations where a design change could affect this parameter such as a seat cushion change. The spine load time-history and maximum spine load obtained in the analysis should correlate to within 10 percent of the dynamic test data unless a different level of correlation was determined prior to the initiation of any program and the numerical spine load should not exceed 1,500 lbs.

8.3.4.2 To account for the testing uncertainty, conservatism can be incorporated into validation and model use via a factor of safety. Repeated testing of seat cushions shows a typical test variability in lumbar load of about ±125 lbs, which gives a data spread of 250 lbs in lumbar load when testing parameters are tightly controlled. Assuming uncertainty is normally distributed, this data spread gives a standard deviation of approximately 42 lbs Based on this standard deviation, there is a 95 percent confidence that the true load is below the regulatory limit of 1,500 lbs, if the measured or simulated load is no greater than 1,430 lbs.

Note: TSO-C127x references SAE AS8049 and SAE ARP 5526C as the source of minimum performance standards (MPS) for seating systems. SAE ARP5765A defines a means of assessing the credibility of computer models of aircraft systems.

8.3.4.3 Setting the cumulative probability of 95 percent equal to 1,500 lbs for normally distributed data using a standard deviation of 42 lbs results in a mean value of 1,430 lbs for the distribution. Therefore, only seat configurations with dynamic test data that yield spine loads below 1,430 lbs should be used for validation. Likewise, for model use, it is recommended that only models that produce a lumbar load below 1,430 lbs be used.

8.3.4.4 In the validation phase, models can exceed 1,430 lbs. In situations where the numerical spine load under-predicts the dynamic test data, the numerical spine load should not exceed 1,430 lbs minus the magnitude of the under-prediction for the Hybrid II; there is no adjustment made for under-prediction for the FAA Hybrid III.

8.3.4.5 Table 1 below provides an example of validation under-prediction and validation over-prediction and the corresponding model use recommended limits. In the first case, the model under predicts by 50 lbs, so the model use is limited to 1,380 lbs (1,430 lbs minus 50 lbs) for the Hybrid II, and there is no adjustment made for the FAA Hybrid III. In the second case, the model over predicts and the model use is simply limited to 1,430 lbs.

Table 1. Example Peak Lumbar Loads

Example Peak Lumbar Loads	Validation	Hybrid II Model Use	FAA Hybrid III Model Use
Model under-predicts	Test = 1,400 lbs, Model = 1,350 lbs	Model = 1,380 lbs or less	Model = 1,430 lbs or less
Model over-predicts	Test = 1,400 lbs, Model = 1,450 lbs	Model = 1,430 lbs or less	Model = 1,430 lbs or less

8.3.5 Head Injury Criteria (HIC).

8.3.5.1 Section 2X.562 or TSO-C127x defines the certification requirements for HIC. The applicant can use the results of computer modeling to show compliance with these requirements, within the limitations summarized below. However, an installation change that results in a significantly higher head strike velocity will likely require testing.

8.3.5.2 The regulation specifies calculating HIC during the duration of the head impact, with a maximum allowable HIC limit of 1000 units. The selected time interval should correspond to the duration of the major head impact on aircraft interior features.

8.3.5.3 The profile, that is, the shape and peak "g" of the acceleration time-history plot, as well as the average "g" loading for resultant head accelerations obtained in the analysis, should correlate to the results of the dynamic test. The acceleration is measured at the head center of gravity for an ATD. Occupant simulation software should be checked for the reference location of the head acceleration output. Sensor locations should be documented in the v-ATD calibration report.

8.3.5.4 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 unless a different level of correlation was determined prior to the initiation of any program. The FAA encourages generation of 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 in paragraph 8.3.4.2 of this AC, and assuming a typical data spread of ±200 HIC units, the 95 percent confidence HIC value is 890 HIC units. Therefore, the FAA recommends that only seat configurations with dynamic test data that produce a HIC value below 890 HIC units should be used for validation. Likewise, for model use, the FAA recommends that only models that produce a HIC value below 890 HIC units be used.

Note: Models can exceed 890 HIC units in the validation phase.

8.3.5.5 It is also unlikely that the analytical head deceleration time history function will perfectly match the test-generated head deceleration time history function. Therefore, the initial and final integration times, t1 and t2, as defined and used in § 2X.562 or TSO-C127x, will likely vary between test and analysis. These time values should differ by no more than 5 ms (milliseconds). In addition, the contact velocity should match within 10 percent and location of the contact should match.

Note: Regardless of the validation of the model and the specific configuration, the predicted HIC must always remain below 1,000 HIC units for the data to comply with the § 2X.562.

8.3.5.6 The following is not an exhaustive list, but the applicant may choose to use computer modeling under the following circumstances:

1. The predicted occupant head strike envelope will satisfy the above stated requirements by showing that no contact with adjacent seats, structure, or other items in the cabin will occur.
2. To evaluate a modified seat installation where the potential head impact surfaces are identical, only the geometric strike envelope has changed. Original HIC values exceeding 890 HIC units will typically not support numerical substantiation.
3. The applicant has performed dynamic testing in the presence of a rigid structure. The applicant would then reposition the seat in the aircraft where the head strike will be on a less rigid structure but with equivalent head strike velocities.
4. For scenarios that meet the guidelines in table 2 below. This includes situations where the head impact surface has changed.

Table 2. Example HIC Values

Example HIC Values	Validation	Hybrid II Model Use	FAA Hybrid III Model Use
Model under-predicts (in HIC units)	Test = 850, Model = 800	Model = 840 or less	Model = 890 or less
Model over-predicts (in HIC units)	Test = 850, Model = 900	Model = 890 or less	Model = 890 or less

8.3.6 Femur Compressive Load (Part 25 Airplanes Only).

Section 25.562(c)(6) or TSO-C127x defines the certification requirements for axial compressive loading of the femur. The maximum allowable limit is 2,250 lbs. The femur compressive load is usually not an issue in the testing of part 25 seats. However, if the certification branch or the applicant determines it should be evaluated, the load time-history profile for the compressive femur load obtained in the analysis should correlate to the dynamic test data. The peak load value, as determined by the analysis, should correlate to within 10 percent of the dynamic test results unless a different level of correlation was determined prior to the initiation of any program.

8.3.7 Non-Critical Criteria.

8.3.7.1 The applicant should validate parameters that are important to the particular application of the analysis. Depending on the purpose of the analysis, it may not be necessary to meet all validation criteria in this AC. However, the FAA cautions that gross discrepancies in the model (such as unrealistic load paths or failure modes) may impact the ability of the model to predict parameters of interest. The following examples are offered to illustrate non-critical criteria for the specified model use condition:

8.3.7.1.1 Lumbar loads for the horizontal test, refer to § 2X.562(b)(2) or TSO-C127x, with a two-point restraint are usually not critical. It is unlikely the applicant will have to evaluate the ATD lumbar load in this test condition.

8.3.7.1.2 The upper torso restraint for a side-facing seat, where the occupant is adjacent to a structural barrier, typically carries small loads. It may be of little value for the applicant to correlate the analytical upper torso restraint loads to the test data.

8.3.7.1.3 For the horizontal test required by § 2X.562(b)(2) or TSO-C127x, lateral (y-axis) floor reaction loads are small compared to the vertical or horizontal reaction loads. It is not reasonable to expect the applicant to correlate the model to all three loads (that is, vertical, lateral, and horizontal) reported by each load cell. It is more reasonable to require validation for those loads critical to the application of the model.

8.3.7.1.4 Restraint loads in a § 25.562(b)(1) or TSO-C127x test are essentially zero throughout the critical portion of the test. It is unlikely the applicant will have to evaluate these loads.

8.3.7.2 These examples do not constitute an exhaustive list. They are simply meant to illustrate that engineering judgment and the particular application of the model should guide the applicant and the certification branch to the proper validation criteria.

8.4 **Discrepancies.**

8.4.1 Failure to satisfy all validation criteria does not automatically preclude the model from being validated. The applicant and the certification branch engineer should evaluate whether the deviations impact the ability of the model to predict credible results and determine if deviations from the validation criteria are acceptable.

8.4.2 In addition, the applicant may present evidence to show the deviation is within the inherent reliability and statistical accuracy of the test measurements. The applicant should quantify any discrepancies between the results obtained from analysis and the dynamic test data for those parameters that are critical to the application of the analysis.

8.5 **Computer Hardware and Software.**

Any analysis should be conducted on a platform, which has been shown to be reliable and acceptable. Certification data produced by a computer model should be performed on the same hardware, compute environment (operating system, auxiliary software, components, etc.), and software version on which the validation was conducted. If a different software version, hardware platform, and/or compute environment is used, the applicant should revalidate the model using the new configuration.

9 **APPLICATION OF COMPUTER MODELING IN SUPPORT OF DYNAMIC TESTING.**

9.1 **General.**

9.1.1 There will be occasions when the applicant wants to determine the critical loading scenario for a particular seating system. This paragraph provides guidance on those items to consider when the applicant performs trade studies to identify the most critical configuration/installation. A final certification test is required to certify the critical configuration/installation to the requirements of § 2X.562 or TSO-C127x.

9.1.2 Paragraphs 9.2 through 9.4 of this AC specify the conditions when a computer model can be used to provide engineering analysis and rationale in support of dynamic testing. These conditions do not form an exhaustive list of items to consider, but they are the most common.

9.2 **Determination of Worst-Case Scenario for a Seat Design.**

After the computer analysis is complete, the results from the simulation can be used to determine the worst-case or critical loading scenario for a particular seating system. This may include the following:

- Identifying components of seat structure that are critically loaded.
- The selection of the critical seat tracking positions, such as seat adjustment positions.
- An evaluation of the restraint system, such as critical attachment location.

Note: The restraint system is not limited to the actual belts; it also includes the required anchoring attachments. Computer modeling may be used to analyze the effect of anchoring the restraints at different locations on the seat frame or in the aircraft. The restraint system would also include any inflatable devices used for restraint or occupant protection. This AC does not address the issues that may be necessary to correctly model and validate their operation; however, the general principles discussed here apply.

- An evaluation of the yaw condition to address loading on the seat frame and movement of the occupant out of the restraint system.
- The number of seat places occupied.
- The selection of the worst-case seat cushion build-up.

9.3 Determination of Worst-Case Scenario for Seat Installation.

Results of a validated computer model may be used to select the worst-case seat system installation as a candidate for dynamic testing. In determining the most critical seat installation, each seating system should be analyzed in its production installation configuration. For example, an analysis to determine a worst-case seating system may include seating systems installed at different positions in the fuselage, which will result in various restraint anchor positions relative to the occupant and seat structure.

9.4 Determination of Occupant Strike Envelope.

The results of the computer analysis can be used to determine the occupant strike envelope with aircraft interior components. Each seating system should be analyzed in its production installation configuration. The occupant strike envelope will determine if a potential for head strike exists and, if so, which items are required in the test setup during the HIC evaluation tests.

10 APPLICATION OF COMPUTER MODELING INSTEAD OF DYNAMIC TESTING.

There will be occasions when the applicant wants to certify a seat that is based on a certificated design concept, such as a family seat design, that differs from the certificated design. If the applicant intends to use the results of computer modeling to provide engineering/certification data instead of dynamic testing for a modified design, then the results from this validated model can be applied to the modifications specified in paragraphs 10.1 and 10.2 of this AC.

10.1 Seat System Modification.

10.1.1 Analysis based on a validated computer simulation may be used to substantiate seat designs or installations that have been modified from a certificated configuration. These modifications may include changes to primary and non-primary load path structural members.

10.1.2 There will be instances when a modified seat design results in a structural member, in the primary load path, that reacts to a dynamic load or stress/strain greater than that reacted to during the baseline design test. Note the modified part is not necessarily the part that has increased criticality. For a non-critical structural member, that is, where the ultimate margin of safety of the baseline design is greater than or equal to 1.0, the modified design ultimate margin of safety should be greater than or equal to 0.5. Refer to paragraph 12.8, *Ultimate Margin of Safety*, of this AC.

10.1.3 For critical structural members where the ultimate margin of safety for the baseline design structural member is less than or equal to 0.5, design changes to the seat cannot result in an ultimate margin of safety that is reduced greater than 25 percent from the original margin. For critical structural members where the ultimate margin of safety is between 0.5 and 1.0, design changes to the seat cannot result in an ultimate margin of safety that is reduced greater than 50 percent from the original margin. In those cases, where a design change reduces the ultimate margin of safety, the ultimate margin of safety for the structural element in question should be greater than or equal to 0.1.

10.1.4 For all structural members, the ultimate margins of safety must be positive, in accordance with § 2X.305, *Strength and Deformation*.

10.2 Seat Installation Modification.

Analysis based on a validated computer simulation can be used to substantiate configuration changes to seat installations. The primary application is to show HIC compliance. Refer to paragraph 8.3.5, *Head Injury Criteria*, of this AC.

10.3 Applicability.

The material in paragraphs 10.1 and 10.2 of this AC is not applicable to changes to the seat-floor attachment structure. Significant changes to the material or mechanism of load transfer of the seat-to-floor attachments from the certificated baseline seat design, which includes the seat-to-track fitting and track substantiated under TSO-C127x, will require a new series of dynamic tests. Simple changes to the location of the seat-to-floor attachments are not included in this limitation, and they can usually be analyzed using static methods.

11 SEAT CERTIFICATION AND COORDINATION PROCESS.

This section focuses on the process to coordinate the use of computer modeling to generate engineering data to demonstrate compliance to § 2X.562 and follows Order 8110.4. A TSO manufacturer should coordinate the acceptable use of computer modeling with the certification branch using the applicable technical standard order program guidance in AC 21-46.

11.1 FAA Coordination.

FAA coordination is essential to ensure the proper and timely execution of any certification program. The guidelines presented will assist in the implementation of computer modeling as a means of compliance.

11.2 **Certification Plan.**

The applicant and the certification branch will negotiate the use of computer modeling to generate technical data in support of establishing dynamic test conditions or instead of dynamic test conditions. If the FAA establishes a type certification board (TCB), negotiations should occur during the preliminary and interim TCB meeting. A TCB is not always required for supplemental type certificate projects. Whether there is a TCB or not, the applicant's role is as follows:

- Acquaint the FAA personnel with the project.
- Discuss and familiarize the FAA with the details of the design.
- Identify, with the FAA, applicable certification compliance paragraphs.
- Negotiate with the FAA where computer modeling will be used and specify the intent and purpose of the analysis.
- Establish means of compliance either by test, by rational analysis (that is, computer modeling), or both, with respect to the certification requirements.
- Establish the validation criteria for the computer model relative to its application for certification.
- Prepare and obtain certification branch approval of the certification plan.

11.3 **Technical Meeting.**

11.3.1 The details of the computer model are defined during scheduled technical meetings between the applicant and the certification branch. The applicant should prepare a document for the FAA describing the purpose of the analysis, the validation methods, and the data submittal format. As a minimum, the following items should be contained in the document:

- A description of the seat system to be modeled.
- A description of the software to be used in the analysis. This should include the operating assumptions and limitations of the software.
- A description of how compliance will be shown.
- A description of material data sources.
- A list of validation methods, including a description and justification of the failure modes/theories.
- An interpretation of results.
- Substantiation documentation and data submittal package.

11.3.2 The document, referred to as the certification plan, should be developed in conjunction with the seat design evaluation phase and approved by the FAA as early in the certification process as possible.

12 DOCUMENTATION REQUIREMENTS FOR COMPLIANCE.

12.1 Overview of a Validation and Analysis Report (VAR).

Section 21.21(b) requires an applicant to submit type design, test reports, and computation necessary to show compliance to the applicable airworthiness requirements. Section 21.603(a)(2) requires an applicant for a TSO authorization to submit a copy of the technical data required in the applicable TSO. This section describes the minimum data and information necessary for substantiation of compliance with § 2X.562 or TSO-C127x when computer modeling is submitted as engineering data. The applicant and the certification branch should negotiate any additional data necessary. The document containing this information will be referred to as the VAR in this AC.

12.2 Purpose of Computer Model.

The VAR lists the certification regulations or TSO requirements relevant to the certification of the seating system. The VAR should state how the computer model would be used to demonstrate compliance for each stated requirement. The applicant should define the purpose of the computer model as either:

- Application of computer modeling in support of dynamic testing (refer to section 9 of this AC), or
- Application of computer modeling instead of dynamic testing (refer to section 10 of this AC).

12.3 Validation Criteria.

The VAR should document the appropriate validation criteria identified in sections 7 and 8 of this AC.

12.4 Overview of Seating System.

The VAR should contain an overview of the design of the seating system. This overview will describe the seat layout in the aircraft, the occupant restraint type, and the attachment method of the restraint. If applicable, the VAR will describe the adjustment positions required during takeoff and landing. In addition, the VAR will contain a description of any special occupant protection features included in the seat/restraint system design.

12.4.1 <u>Seat Structure.</u>

The VAR should provide a description of the seat's critical components, primary load paths, energy absorbing features, the seat attachment hardware, and the floor attachments or seat tracks. The VAR will describe the material properties of the primary structural and energy absorbing components, along with the method of fabrication. Give special attention to describing which primary structural members are designed to displace, deform, elongate, or crush to dissipate kinetic energy.

12.4.2 Restraint System.

The VAR should provide a description of the restraint system, including part number, and any other devices designed to restrain the occupant in the seat or reduce the occupant's movement under emergency landing conditions. This might include the shoulder and lap belts, load limiting devices, belt locking devices, pre-tensioners, and inflatable restraints. The VAR should also describe how the restraint system and its devices are anchored and list the material properties of the restraint system.

12.4.3 Unique Energy-Absorbing Features in the Installation.

Unique energy-absorbing features are components, other than the seat and restraint system, that are designed to limit the load imposed on the seating system or occupant. Examples include energy-absorbing subfloor structure or inflatable devices mounted on the airframe but not considered a part of the seat/restraint system.

12.5 Software and Hardware Overview.

The VAR should contain a brief description of the software and hardware used to perform the analysis, including the following information:

- CPU type and instruction set of computer hardware.
- Operating system.
- Auxiliary software components (message passing interface (MPI) product, etc.).
- Finite element binary specifics (version, revision, precision, parallel application, etc.) if applicable.

12.6 Description of Computer Model.

The VAR should contain a detailed description of the computer model, including the input data.

12.6.1 Engineering Assumptions.

12.6.1.1 The applicant should document assumptions used for the analysis. Assumptions can include, but not be limited to, simplification of the physical structure, the use of a particular material model, methods used for applying boundary conditions, failure theories, and the method of load application. The VAR should document a rational support for the use of each assumption. The FAA may require the applicant to demonstrate that the assumptions do not negatively affect the analytical results.

12.6.1.2 Those components that are not critical to the performance of the seating system and do not influence the outcome of the analysis can be omitted from the model. However, the mass of the system must be preserved. The VAR should list all components excluded from the analysis and provide justification for the exclusion of those components from the model.

12.6.2 Modeling of the Physical Structure.

12.6.2.1 The VAR should provide a description of the structure. If the model is constructed with finite element techniques, this documentation should include a description of the finite element mesh. It should describe how the critical components of the structure were modeled and provide the rationale for the selection of the element types that were used to represent the structure. In addition, the applicant should describe the limitations of the mesh element used in the analytical modeling. If the mesh element is either unconventional or is a new element, the VAR should provide the mathematical formulation of that element, engineering assumptions made during the element's formulation, and any limitations that apply to its usage.

12.6.2.2 The choice of element, material models, and other model features can greatly affect the accuracy of a finite element solution. For example, a membrane element carries in-plane loads only, while a shell element also carries perpendicular loads (bending). Depending on the loading conditions present, a membrane element could produce significant errors that would not cause the solution to abort. Likewise, an elastic material model cannot predict plastic behavior. The applicant should justify the choice of elements, material models, and other model features for all components that are in the critical load path.

12.6.2.3 If the model is constructed with multi-body dynamics, this documentation should include a description of the properties of the multi-bodies and details on the connectivity, joint properties, and any contact functions.

12.6.3 Material Models.

12.6.3.1 The applicant should document the material models used in the analysis. This may include a list of the materials used by the analysis software and a general description of the material properties. In addition, the applicant should identify the source of the material data.

12.6.3.2 When standard material property data are used, the guidelines outlined in the MMPDS and CMH-17 should be followed. (Refer to the *Metallic Materials Properties Development and Standardization Handbook* and *Composite Materials Handbook*.) It is acceptable to use S-basis or typical properties in the model when conducting validation simulations. A-basis material values for components in the structural load path, and B-basis material values for all other structural parts, should be used when the model is used for certification purposes without supporting dynamic tests. The material values are explained in the referenced handbooks.

12.6.3.3 Any material data acquired through in-house tests should be supported by appropriate documentation that describes the basis of such test, test methods, and results. When applicable, material strength and material variability properties must comply with §§ 23.613, 25.613, 27.613, and 29.613. This includes proprietary data.

12.6.4 Constraints.

Constraints are boundary conditions applied in the model. This includes single and multi-point constraints, contact surfaces, rigid walls, and tied connections. The applicant should document the boundary conditions applied in the model and discuss how the model boundary conditions correspond to the test conditions. The VAR should also provide a description of contact definitions and nodal constraints. Finally, the VAR should document the values used to represent frictional constants and the validity of such values.

12.6.5 Load Application.

Loads that are applied in the computer model may include concentrated forces and moments, pressure, enforced motion, and initial conditions. The VAR should contain a description of how external loads are applied to the model and should list all nodal points affected by the load application. The VAR should also provide a copy of the acceleration/deceleration profile time history.

12.6.6 Occupant Simulation.

The VAR should document the v-ATD including the version number and the calibration data. The v-ATD calibration should state whether it meets SAE ARP 5765, Revision A, or other means, and it should document any usage limitations.

12.6.7 General Analysis Control Parameters.

12.6.7.1 General analysis control parameters are features of a program that control, accelerate, and terminate an analysis. This may include parameters that enhance the performance of the software for reducing the computational time or the use of subroutines that facilitate the post-processing of results.

12.6.7.2 The VAR should include a summary of the control parameters used for a particular analysis. There should be ample justification for parameters that may influence the outcome of the analysis. As an example, the analyst should show that the artificial scaling of mass for reducing computational time is acceptable and does not negatively influence the results of the model. Paragraph 6.5 of this AC provides a definition of mass scaling.

12.7 **Result Interpretation.**

This paragraph contains guidance and recommendations for the output, filtering, and the general methods of reporting numerical data. The purpose is to achieve uniformity in the practice of reporting numerical results. The use of the following recommendations will provide a basis for a meaningful comparison to test results from different sources.

12.7.1 Energy Balance.

If the numerical analysis uses an explicit finite element formulation, the applicant should evaluate the presence of hourglass modes, also known as zero energy modes, to determine if they are located at critical structural components. If this evaluation determines that these modes are present, the applicant should assess the hourglass modes to quantify their influence on the accuracy of the analysis. The applicant should correct the model if it does not attain the appropriate energy balance. The VAR should contain a summary of the ratio of initial energy to final energy and provide a comparison of hourglass energy to total energy.

12.7.2 Data Output.

12.7.2.1 The transient analysis should generate data at a minimum frequency of 10,000 Hz for electronic data and 1,000 Hz for trajectories. This will maintain an equivalent practice with the instrumentation and data requirements specified in SAE J211, and it will allow for a meaningful comparison between numerical data and test data.

12.7.2.2 If the output of the data channels is dependent on the integration time step of the analysis, and its sample rate is higher than the rate of the test data, the reported simulation data should be subsampled for comparison. If any post-analysis filtering is to be applied, the generated data may need to be reported at a higher frequency than 10,000 Hz (or 1,000 Hz) to remain consistent with the requirements outlined in SAE J211. The VAR should document any deviations to this practice.

12.7.3 Data Filtering.

The filtering practices of SAE J211 apply for all applications.

12.8 Ultimate Margin of Safety.

12.8.1 The ultimate margin of safety represents the ultimate strength of the structure in relation to the strength required to carry the ultimate load. In this AC, it is presented as a decimal value defined as:

$$MS_{ultimate} = ([\text{Ultimate Strength} / \text{Ultimate Load}] - 1)$$

12.8.2 For the structural substantiation of the seat/restraint system and attachment structure, the ultimate margin of safety must show a positive value. The VAR should document the ultimate margins of safety for those structural elements the applicant or the FAA identifies as critical.

Appendix A. Occupant Trajectory and Head Injury Criteria (HIC)

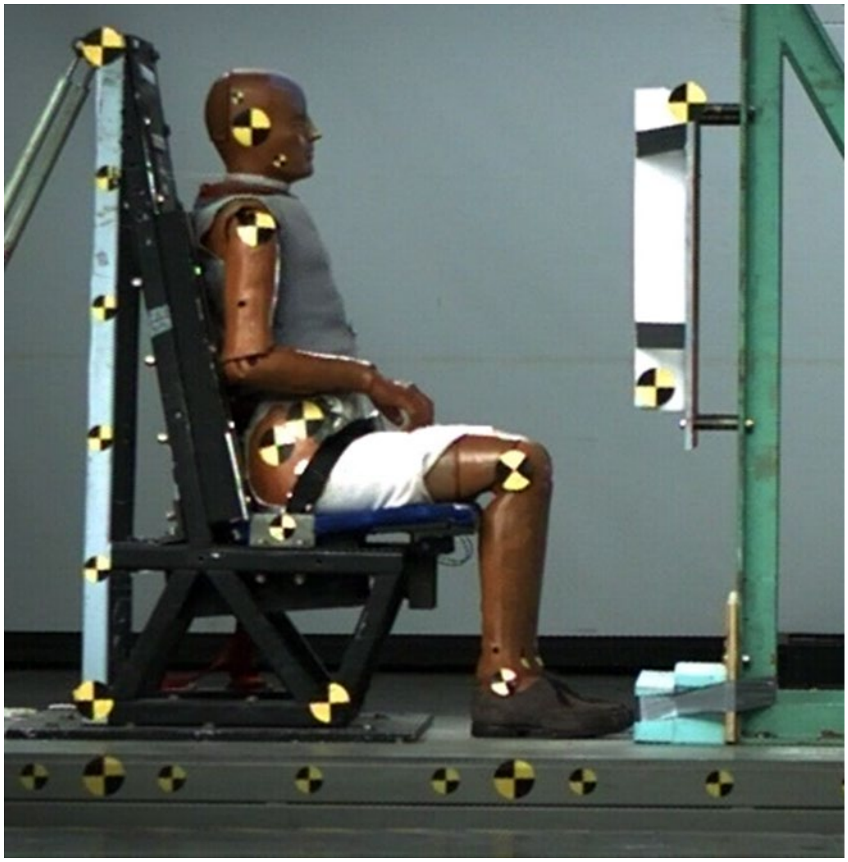
A.1 OVERVIEW.

This appendix serves as an example of items to consider and document when validating occupant trajectory and HIC. Refer to paragraphs 8.3.1 and 8.3.5 of this AC for validation criteria regarding occupant trajectory and HIC. This is not meant to be a universal example. Other situations may require more or less stringent validation efforts.

A.2 TEST SETUP.

A.2.1 The scenario is a front-row seat with a foam-covered bulkhead 25 inches forward of the occupant. Refer to Figure A-1 below. The launch seat has been represented by a rigid fixture for simplicity. The seat cushion is one-half inch thick stiff foam covered in fabric. The occupant is represented by a 50th Percentile Male (Hybrid II) ATD and is restrained by a standard nylon lap belt. The impact condition is from § 25.562(b)(2), with no yaw or floor misalignment. The anthropomorphic test device (ATD) has been instrumented with three linear accelerometers in the head (Endevco model 7264B). Based on the specific geometry of this aircraft configuration, it was determined that femur compression was not an issue. Therefore, no femur load cell was installed (refer to paragraph 8.3.6 of this AC). Webbing transducers were attached to both ends of the lap belt to record belt loads (Denton model 3255).

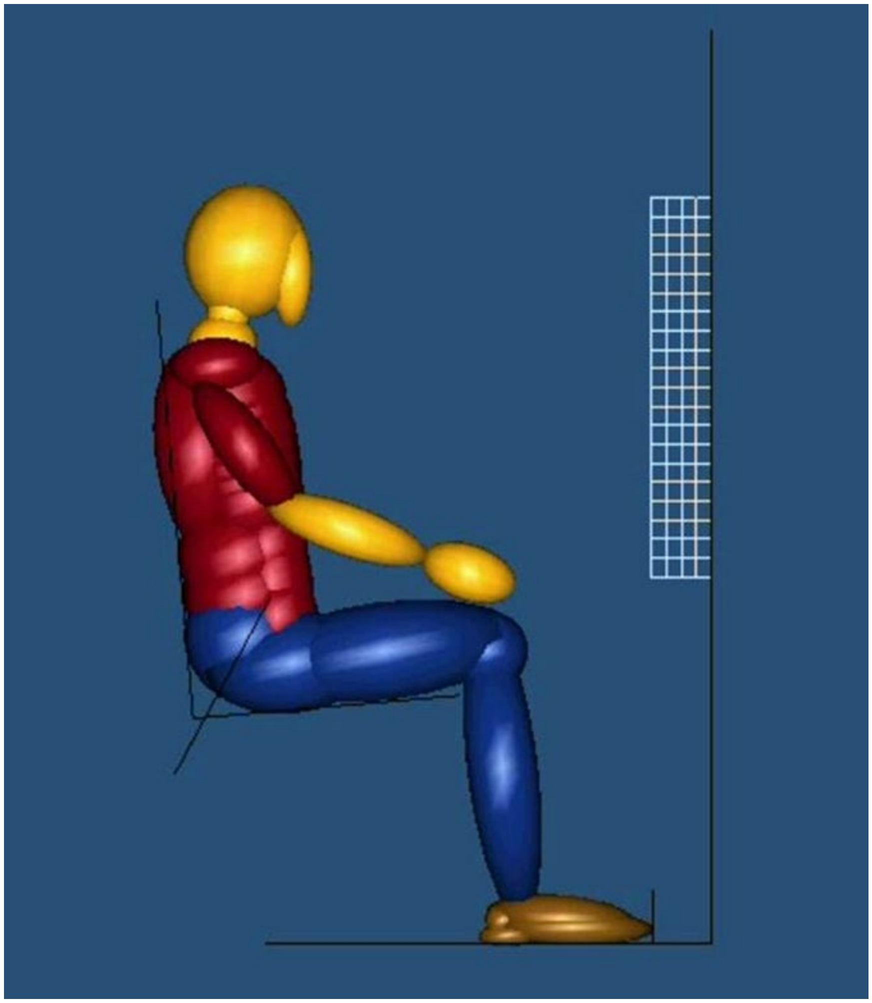
Figure A-1. Test Setup (xz-plane)



A.2.2 Pre-test measurements included the head center of gravity (CG), hip-point (H-point), knee, and ankle of the ATD, along with the SRP, belt anchor location, multiple points on the lap belt, points on the floor, foot stop, bulkhead (including the foam), and targets required for photometric scaling and validation.

A.2.3 The model was generated using MADYMO 6.1. The seat is represented by rigid planes and the seat cushion was excluded from the model. Refer to figure A-2 below. The friction coefficient between the ATD and seat was defined to represent the effect of the fabric-covered foam. The occupant model is the MADYMO Hybrid II 50th Percentile Male (p572 version 3.3). The lap belt is represented by simple springs with material properties derived from high rate tests of the webbing. The foam on the bulkhead is modeled by finite elements, and the material properties were determined by load frame tests. The sled pulse from the physical test was applied to the ATD in the x-direction and gravity was applied in the z-direction. No penetration contacts were defined between the ATD and all rigid surfaces, bulkhead, seat, floor, and foot stop, as well as between the individual parts of the ATD. A kinematic contact was defined between the ATD and the foam on the bulkhead.

Figure A-2. Numerical Model Setup (xz-plane)



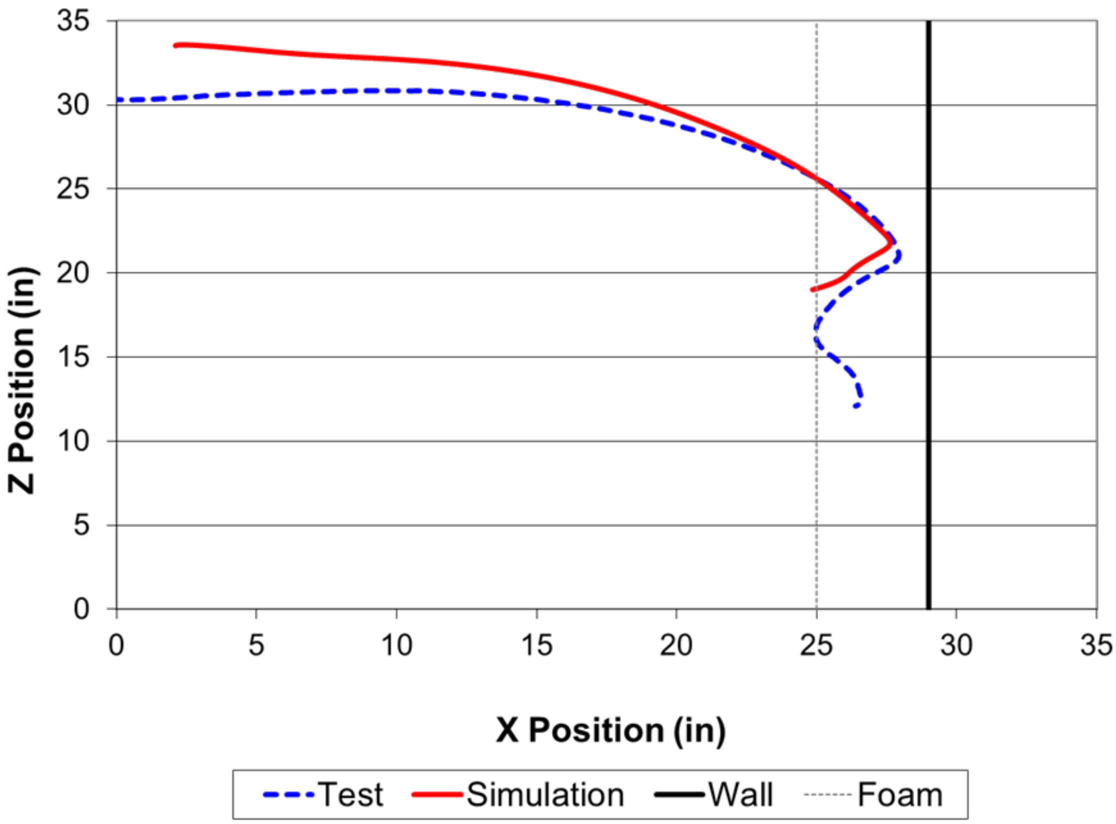
A.2.4 MADYMO 6.1 is a commercially available rigid body dynamics and finite element simulation code. As part of the development process and distribution to its customers, the developer provides a theory and reference manual to assist the user in applying the code and material models appropriately. No formal statement of code conformity or code verification was available from the developer (as discussed in paragraph 7.1 of this AC); however, the user attests that the code is acceptable for its intended use.

A.2.5 The bulkhead foam was modeled using eight-node solid elements that carry tensile, compressive, and shear loads. This type of element provides good accuracy for simple, rectangular shapes. The load frame test used to generate material properties was simulated to show that the mathematical implementation of this foam block is correct. The time step was controlled by the software, updating as necessary to maintain compliance with the Courant criteria (as discussed in paragraph 7.3.1.1 of this AC). No mass scaling was used in this model. The mesh resolution was evaluated as described in paragraph 7.2.2 of this AC.

A.2.6 The v-ATD selected is the MADYMO Hybrid II 50th Percentile Male (p572 version 3.3). This v-ATD predates the publication of SAE ARP 5765, Revision A, *Analytical Methods for Aircraft Seat Design and Evaluation*, and, therefore, has not been evaluated by the developer to show compliance with the dynamic calibration paragraph of the ARP (as discussed in paragraph 8.1.3 of this AC). The developer has shown compliance with the head drop test. During end-user evaluation of the head path from the SAE ARP dataset, this v-ATD had acceptable agreement up to 30 inches of head x-direction travel. For this current simulation, this v-ATD can be considered to be conditionally compliant with the limitations that the v-ATD be used for a § 25.562 Test 2 pulse with limited head excursion.

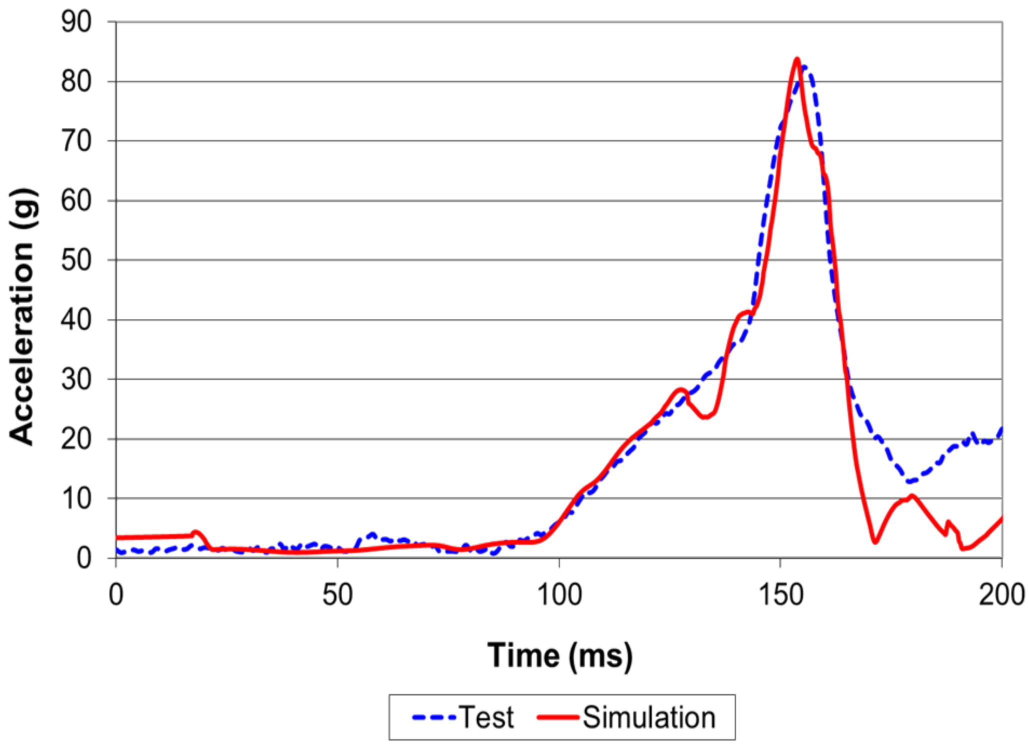
A.2.7 For this test setup, there are two primary occupant trajectory items to consider: head path and pelvic motion. For brevity, only xz-plane head motion is examined here. If there is significant lateral trajectory, the applicant will likely be required to validate the y-axis motion. Y-axis motion is not considered in this example. Figure A-3 of this AC shows the xz-plane motion of the head CG for the test and simulation. The figure also shows the location of the wall and front edge of the foam. The origin of the figure is the SRP. Qualitatively, the impact location was similar, with the measured height and estimated lateral location of initial head contact occurring at roughly the same location between test and simulation. Because the impact surface is completely homogenous, this estimation is sufficient to meet the impact location requirement in paragraph 8.3.5.6 of this AC. Differences exist between the initial position of the head and the depth the head travels into the foam. In general, it is appropriate for the FAA to ask the applicant to explain discrepancies and to present data to defend these explanations. This is not the same as allowing the applicant to rationalize the differences. An explanation can be supported with data. A rationalization cannot usually standup to this type of scrutiny. Calculation of the curve shape error requires that the x-position versus time and z-position versus time be evaluated separately; curve shape error on the x-position is 5.1 percent and 8.5 percent on the z-position. The magnitude error is 0.3 in on the peak x-position with the simulation under-predicting the motion. For this impact scenario, the maximum position in the z-axis does not have significance. As referenced in paragraph 8.3.3 of this AC, lap belt loads should be evaluated separately from occupant trajectory, omitted for brevity.

Figure A-3. Comparison of Head Path (xz-plane)



A.2.8 Before evaluating HIC, aspects of the head CG resultant acceleration should be considered, as illustrated in figure A-4. The test peak is 82.3 g, and the simulation peak is 83.8 g. The difference is 2 percent, well below the 10 percent limit, and the simulation result is conservative. The curve shape error is 9.8 percent. Depending on the impact scenario, the FAA may also ask the applicant to evaluate the components of the resultant acceleration separately. The head resultant velocity at impact was 38.5 feet per second (fps) in the test and 37.7 fps in the simulation (magnitude error of 2.0 percent).

Figure A-4. Comparison of Head Resultant Acceleration



A.2.9 The simulation produced a HIC value within the required 100 HIC units, test HIC of 700, simulation HIC of 650. The initial and final integration times selected by the HIC calculator was similar: t1 for the test is 144 ms; t1 for the simulation is 139 ms; and t2 for both test and simulation is 164 ms. The HIC duration differs by 5 ms, which meets the 5 ms limit listed in paragraph 8.3.5.5 of this AC. The average acceleration value during the HIC window is 65.3 g for the test and 57.2 g for the simulation.

A.2.10 The proposed simulation achieved the required error metrics, all below 10 percent. The simulation was not a conservative one, so any future use will require that it is limited to simulations where the expected HIC will be below 840 HIC units. Other limitations include that this model is pursuant to § 25.562 Test 2 (16 G) pulse with a 50th Percentile Male (Hybrid II) ATD for determining head accelerations and belt loads for this particular seat geometry near a padded bulkhead.

Appendix B. Test-Simulation Comparison Methodology

B.1 OVERVIEW.

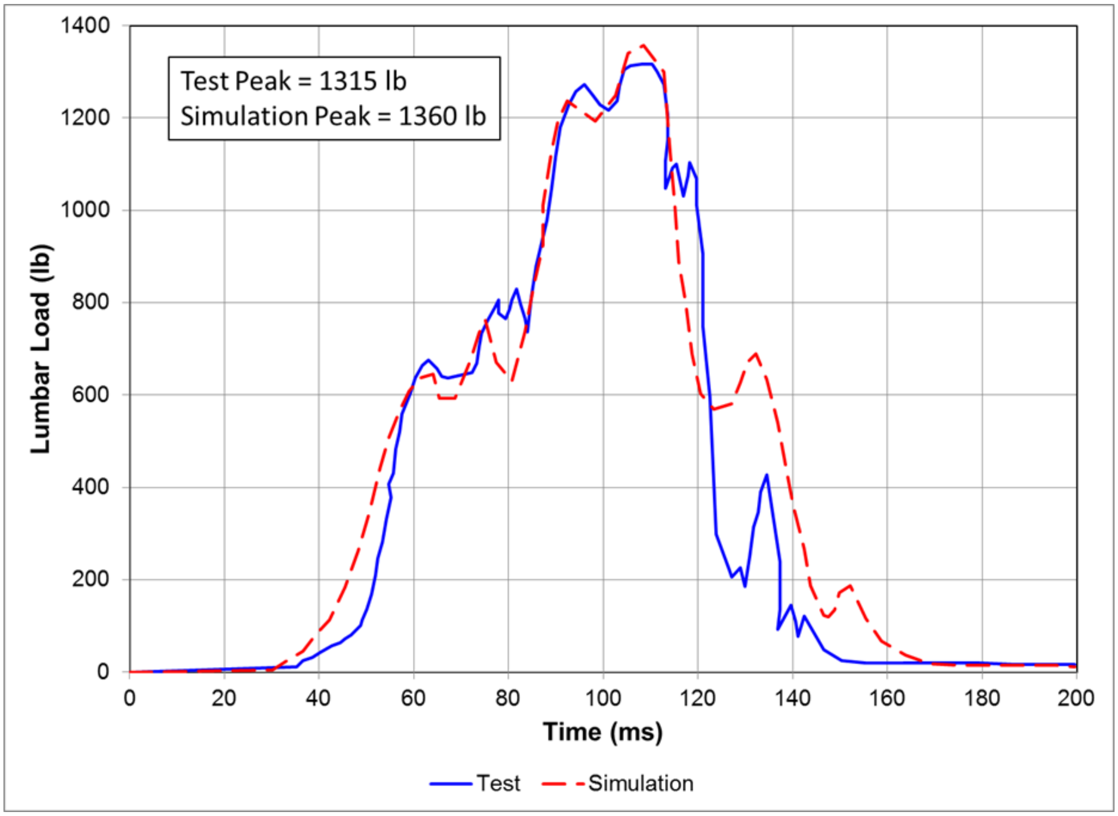
This appendix describes one method to calculate the error between the results of a numerical simulation and the results of a physical test. Unless otherwise specified, for each required channel, two features should be evaluated: magnitude error and curve shape error. Time histories should be evaluated beginning with the onset of the test pulse and through significant system response, often the motion of the anthropomorphic test device(s), as seen in the physical test. Channel inputs should have consistent units, appropriate sampling rates, minimum 10,000 Hz for electronic instrumentation data and 1000 Hz for photometric data, and equal time lengths. Test and simulation position data need to have the same global origin, typically the SRP. If necessary, units, data set length, and origin offsets can be corrected during post processing.

B.2 TEST CALCULATIONS AND SIMULATIONS.

B.2.1 The magnitude error for load, moment, acceleration, or velocity can be calculated using a relative error on the peak in equation 1. In figure B-1 below, the simulation peak is 1,360 lbs and the test peak is 1,315 lbs. The magnitude error, using equation 1, is 3.4 percent.

$$Error = \frac{\left|Peak_{test} - Peak_{sim}\right|}{\left|Peak_{test}\right|} * 100\% \quad [1]$$

Figure B-1. Test and Simulated Results from Dynamic Tests: Example 1



B.2.2 The curve shape error is calculated using the Sprague and Geers Comprehensive Error, equations 2-7. For Figure B-1 above, the Sprague and Geers Comprehensive Error is 7.2 percent. (Refer to Sprague, M.A. and Geers, T.L. *A Spectral-Element Method for Modeling Cavitation in Transient Fluid-Structure Interaction*, International Journal for Numerical Methods in Engineering, Volume 60, Issue 15, pages 2467-2499, dated August 21, 2004).

$$I_{mm} = (t_2 - t_1)^{-1} \int_{t_1}^{t_2} m^2(t)dt \qquad [2]$$

$$I_{cc} = (t_2 - t_1)^{-1} \int_{t_1}^{t_2} c^2(t)dt \qquad [3]$$

$$I_{\mathrm{mc}} = (t_2 - t_1)^{-1} \int_{t_1}^{t_2} m(t) \cdot c(t)dt \qquad [4]$$

The magnitude error, biased towards the test, is then defined as—

$$M_{SG} = \sqrt{I_{cc} / I_{mm}} - 1 \qquad [5]$$

The phase error is defined as—

$$P_{SG} = \frac{1}{\pi} \cos^{-1}(I_{mc} / \sqrt{I_{mm} I_{cc}}) \qquad [6]$$

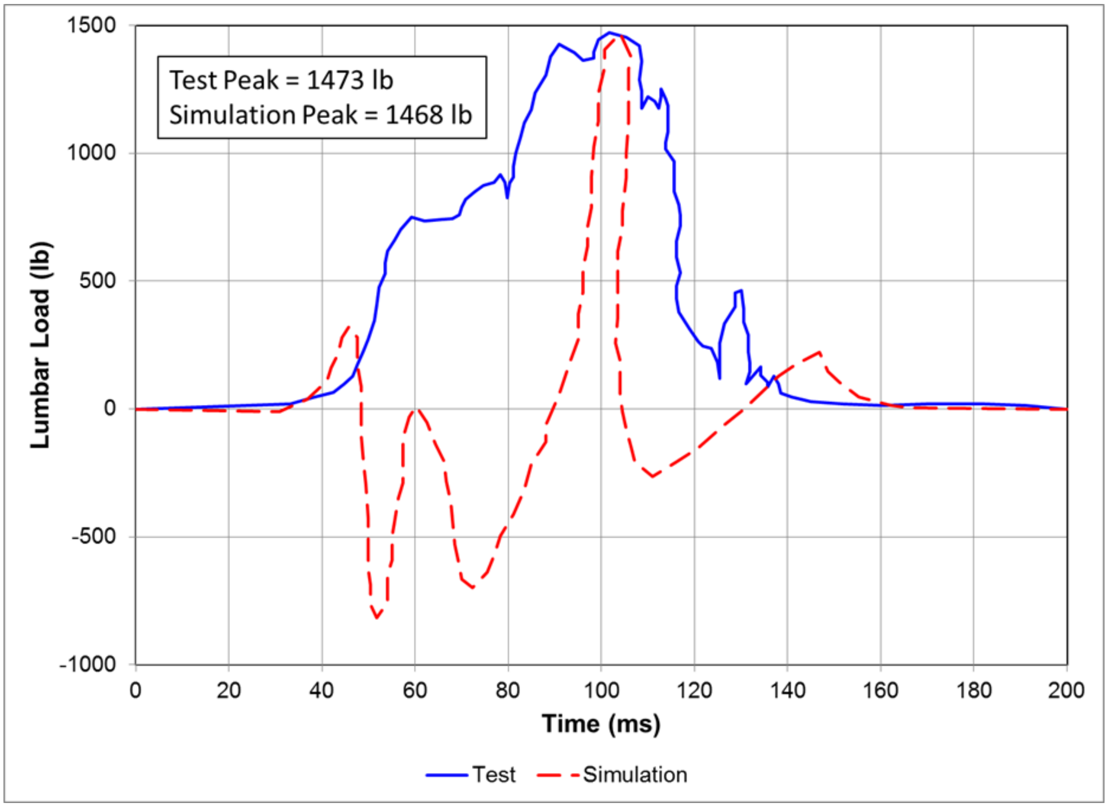
The comprehensive error is defined as—

$$C_{SG} = \sqrt{M_{SG}^2 + P_{SG}^2} \qquad [7]$$

B.2.3 Based on the quantitative results above, the simulation meets the requirements set forth in paragraph 8.3 of this AC. The simulation curve shows that the magnitude guidelines are met, that is, peak load within 10 percent. A good correlation of the time-history plot is also established, with the curve shape error within 10 percent. In addition, note that the analysis tends to be conservative (simulation load is greater than the test load).

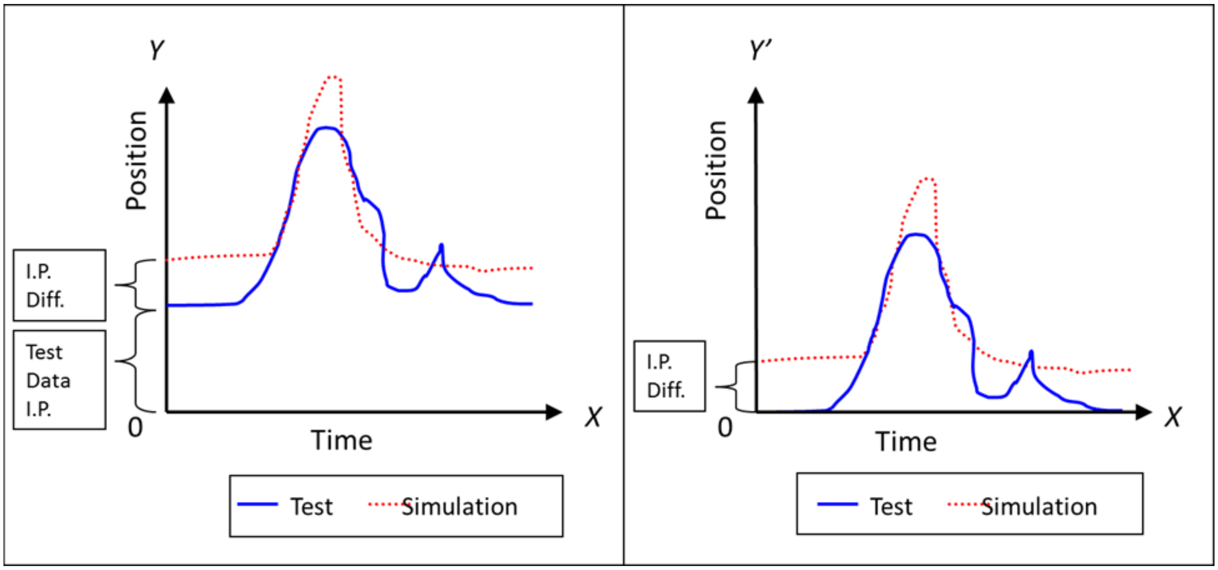
B.2.4 As a stark contrast to Figure B-1 of this AC, figure B-2 shows relying on peak value is not always sufficient to determine correlation. Although the relative error on the peak is 0.3 percent, from a qualitative view, the analysis is clearly not simulating the same physical phenomenon as the test. Calculation of the Sprague and Geers Comprehensive Error yields a 60.4 percent curve shape error providing a quantitative confirmation of the poor correlation.

Figure B-2. Test and Simulated Results from Dynamic Tests: Example 2



B.2.5 Photometric/motion data should be handled differently than force, acceleration, velocity, or moment data. Position data for the test and simulation should be offset by the test data initial position (IP) as seen in figure B-3 below. This approach preserves any initial differences between the test and simulation results. To accomplish this, subtract the test data IP from the entire time history of both the test data and simulation data. Once the data has been offset, *Y'* axis, the magnitude error, whether positive or negative, can be determined by a simple difference, equation 8 of the peak. The curve shape error should be determined using the Sprague and Geers comprehensive error on the offset data. The basis for any differences in the IP should be discussed in the VAR.

Figure B-3. Motion Data Offset Example



$$Error = \left| Peak_{Test} - Peak_{Sim} \right| \quad [8]$$

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Subject: AC 20-146A, CHG 1, *Methodology for Dynamic Seat Certification by Analysis for Use in Parts 23, 25, 27, and 29 Airplanes and Rotorcraft.* Date: ________________

Please mark all appropriate line items:

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☐ Other comments:

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Submitted by:__________________________________Date: ________________________