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

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Change:

1. PURPOSE.

This advisory circular (AC) sets forth an acceptable means, but not the only means, for demonstrating compliance to the following by computer modeling analysis techniques validated by dynamic tests:

- Title 14 Code of Federal Regulations (14 CFR) parts 23, 25, 27, and 29, §§ 23.562, 25.562, 27.562, and 29.562.
- The Technical Standard Order (TSO) associated with the above regulations, TSO-C127/C127a.

This AC provides guidance on how to validate the computer model and under what conditions the model may be used in support of certification or TSO approval/authorization.

Material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation. In addition, this material is not to be construed as having any legal status and should be treated accordingly.

2. CANCELLATION.

This advisory circular does not cancel any previously issued AC.

3. BACKGROUND.

A series of proposals that focused on cabin safety and occupant protection design requirements were developed at the Small Airplane Airworthiness Review Conference, held in October 1984. The proposals culminated with Notice of Proposed Rulemaking (NPRM) 86-19, which included proposed rule § 23.562 "Emergency landing dynamic conditions."

The preamble to this rule states that at the time this rule was written, there was no sufficient database to permit the use of analysis in lieu 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 in lieu of dynamic tests. This document provides guidance for demonstrating compliance to § 23.562 by means of computer modeling techniques. Recognizing that this guidance is equally applicable to aircraft other than small airplanes, this document also applies to §§ 25.562, 27.562, and 29.562.

This document 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. It is a culmination of the efforts of the Advanced General Aviation Transportation Experiments Program (AGATE) Advanced Crashworthiness Workpackage Team. This team consisted 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 Advisory Circular is a direct result of that methodology.

In addition, TSO C127/C127a established a standard for the dynamic testing of seats as specified by §§ 23.562, 25.562, 27.562, and 29.562. Although installation approval under the airworthiness standards is required for any TSO item, applicants or holders of TSO C127/C127a may use the methodology presented in this AC.

s/

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4. APPLICABILITY.

This AC applies to several groups:

The first group that this AC applies to is those applicants who include the seat as part of the airplane/rotorcraft type design. In this case, the applicant is not using a TSO-C127/127a seat approved for installation in the aircraft. The applicant would satisfy the requirements of § xx.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 presented in this AC.

The second group this AC applies to is seat manufacturers who build seats to the requirements of TSO-C127/TSO-C127a and who hold either a letter of design approval or Technical Standard Order Authorization (TSOA) for those seats. In this instance, the TSO manufacturer would demonstrate compliance to the TSO standard by test for the baseline seat design. Subsequent changes to this seat may show compliance to the TSO by the use of the analytical techniques and limitations described in this AC.

The third group this AC applies to is an airplane/rotorcraft manufacturer or a modifier that wishes to install a TSO seat. The baseline seat approval and installation limitations are used to certificate the baseline installation approval. Modifications to any of these elements are eligible for certification via the analytical techniques and limitations described in this AC.

Computer modeling analytical techniques may be used to do the following, provided **all** pass/fail criteria identified in §§ 23.562, 25.562, 27.562, or 29.562 are satisfied:

- Establish the critical seat installation/configuration in preparation for dynamic testing (discussed further in Section 8). This does not suggest that previously approved methods can no longer be used to determine the critical test configuration.

- Demonstrate compliance to §§ 23.562, 25.562, 27.562, or 29.562 for changes to a baseline seat design, where **the baseline seat design has demonstrated compliance to these rules by dynamic tests.** Changes may include geometric or material changes to primary and non-primary structure. Section 9 discusses this item further.

Joints and fittings are typically highly loaded seat structural elements. In general, they possess indeterminate load paths, contact (free-play) nonlinearities, and may 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 must be modeled with care, paying particular attention to all possible failure mechanisms. While some changes to fittings and joints are acceptable to substantiate with modeling, significant changes to the material or mechanism of load transfer will require test.

5. RELATED PUBLICATIONS.

a. Orders, Federal Regulations, and AC's.

FAA Order 8110.4B, Type Certification.

Code of Federal Regulations (CFR), Title 14, part 21 – Certification Procedures for Products and Parts.

Code of Federal Regulations, Title 14, part 23 – Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes, Subpart C – Structure.

Code of Federal Regulations, Title 14, part 25 – Airworthiness Standards: Transport Category Airplanes, Subpart C – Structure.

Code of Federal Regulations, Title 14, part 27 – Airworthiness Standards: Normal Category Rotorcraft, Subpart C – Strength Requirements.

Code of Federal Regulations, Title 14, part 29 – Airworthiness Standards: Transport Category Rotorcraft, Subpart C – Strength Requirements.

Code of Federal Regulations, Title 49, part 572, Chapter 5 – Anthropomorphic Test Devices (ATD).

Technical Standard Order TSO-C127, Rotorcraft and Transport Airplane Seating Systems, dated March 30, 1992.

Technical Standard Order TSO-C127a, Rotorcraft, Transport Airplane, and Normal and Utility Airplane Seating Systems, dated August 21, 1998.

Copies of the current publication of the ACs listed below can be obtained from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785. The ACs are also available on the Internet at http://www.faa.gov/avr/air/airhome.htm.

AC 23.562-1, Dynamic Testing of Part 23 Airplane Seat/Restraint Systems and Occupant Protection, dated June 22, 1989.

AC 25.562-1A, Dynamic Evaluation of Seat Restraint Systems & Occupant Protection on Transport Category Airplanes, dated January 19, 1996.

AC 27-1B, Certification of Normal Category Rotorcraft, dated September 30, 1999.

AC 29-2C, Certification of Transport Category Rotorcraft, dated September 30, 1999.

b. 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 Aerospace Standard, SAE AS8049 Revision A, Society of Automotive Engineers International, September 1997.

Instrumentation for Impact Test - Part 1 – Electronic Instrumentation, SAE Surface Vehicle Recommended Practice, SAE J211-1, Society of Automotive Engineers International, March 1995.

Instrumentation for Impact Test - Part 2 – Photographic Instrumentation, SAE Surface Vehicle Recommended Practice, SAE J211-2, Society of Automotive Engineers International, May 2001.

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.

c. Other References.

Belytschko, T., Liu, W.K., and Moran, B., *Nonlinear Finite Elements for Continua and Structures*, John Wiley and Sons, Chichester, West Sussex, England, 2000.

Bathe, K.J., *Finite Element Procedures*, Prentice-Hall, Englewood Cliffs, NJ, 1996.

6. DEFINITIONS.

Seating Configuration. The airplane/rotorcraft interior floor plan, which defines the seating positions available to crew and passengers during taxi, takeoff, landing, and in-flight conditions.

<u>Seating/Restraint System</u>. A system that includes the seat structure, cushions, upholstery, the safety belt, the shoulder harness, and the attachment devices.

<u>Family of Seats</u>. A group of seat assemblies, regardless of the number of seat places, built from equivalent components in the primary load path.

<u>Seat Primary Load Path</u>. 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 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 – from point of ATD head contact to the attachment of seat primary structure

- Head Path (e.g., front row or large pitch seats) – same as structural.

<u>Baseline seat</u>. The first seat designed and manufactured within a new family of seats.

<u>Baseline testing</u>. The initial series of tests performed on the baseline seat as part of the original certification to substantiate the seat family.

<u>Computer Modeling</u>. 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.

The following combination of computer codes and occupant models have been used in support of the design and certification of dynamic seats. This is not an exhaustive list. Codes not identified here, but shown to be equivalent to those referenced below, may be utilized as well:

a. MADYMO transient finite element/multi-body software and the MADYMO 50 percent part 572 Subpart B Hybrid II occupant model. [MADYMO is a registered trademark of TNO Road-Vehicles Research Institute.]

b. MSC/DYTRAN transient finite element software and the ATB Hybrid II occupant model. [MSC/DYTRAN is a registered trademark of the MacNeal – Schwendler Corporation. ATB is a public domain code developed and maintained by Wright Patterson Air Force Base.]

c. LS-DYNA3D transient finite element software and the MADYMO 50 percent part 572 Subpart B Hybrid II occupant model. [LS-DYNA3D is a registered trademark of the Livermore Software Technology Corporation.] LS-DYNA3D may also be similarly interfaced with the Air Force developed ATB software. A finite element representation of the ATD is a third modeling alternative.

Software that utilizes Hybrid-III occupant models may be utilized if:

- All baseline testing was performed using a Hybrid-III ATD, where the ATD has been modified per SAE Technical Report 1999-01-1609;
- The requirements in SAE AS8049 Revision A, paragraph 5.3.2.4 are satisfied;
- The simulation software uses an ATD model validated to the modified (per SAE 1999-01-1609) Hybrid-III occupant model used during testing.

Mass Scaling. The integration time step for transient finite element codes is dependent upon the shortest natural period in the mesh. The integration time step must be less than the time required for a stress wave to cross the smallest element in the wave. Mass scaling is used to reduce the analysis time by artificially adding mass to the governing small elements.

The addition of mass reduces the natural period of the element, which increases the time required for a stress wave to cross that element. 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.

6.1 Stability of Explicit Codes

Most transient explicit finite element codes employ direct integration methods, and they take advantage of the numerical effectiveness of integration schemes such as the central difference method, Wilson-θ, or Newark-β methods. These integration schemes attempt to satisfy equilibrium only at discrete time intervals (Δt) rather than for the duration of the analysis.

The accuracy of the solution is path dependent. It relies heavily on the interpolated values of displacements, velocities, and accelerations within each time step interval. Bathe and Belytschko discuss the inherent numerical instabilities encountered with explicit dynamic analysis codes in detail, most notably in their respective publications. The solutions of these codes are, therefore, *conditionally* stable, a trade-off for the simplicity and cost effectiveness of the methods. The stability of the explicit methods is a function of the critical time step Δt_{cr} defined as

$$\Delta t_{cr} = \min(L_e/c),$$

where L_e is the effective length of the smallest element, and c is the stress wave speed (a function of material stiffness). In other words, the time step selected for the analysis must be smaller than the time for the stress wave to cross the smallest element in the finite element mesh. Otherwise, numerical instability may develop and cause the solution to diverge.

In theory, the most numerically efficient solution is obtained when an integrating time step equivalent to the stability limit is chosen. Commercial codes, such as MADYMO or LS-DYNA3D, attempt to offset the problems of numerical instability by regulating and constantly updating the time interval used throughout the analysis. Although the user may choose an initial time step to begin the analysis, the program will calculate the critical integration time step. The program will either terminate or default to the critical time step if the user input time step is larger than this minimum. A general guideline is to select a Δt smaller than the critical time step presented in the above equation. A margin of 20-30 percent will avoid the instability introduced by the inherent numerical disturbance associated with the integration process. The bit number accuracy of the computer configuration may affect this margin.

7. COMPUTER MODEL VALIDATION

Computer modeling and analysis techniques may be used to certificate incremental changes to a seat system designed to the requirements of 14 CFR parts 23, 25, 27, and 29, §§ 23.562, 25.562, 27.562, and 29.562. Computer analysis results may be used for certification purposes under the conditions specified in Sections 8 and 9 of this document.

As with any form of analytical modeling, validation of the seat/restraint model is a key step in determining whether the model is acceptable for use in certification. The sections that follow will provide a guide to those items that should be considered when comparing analytical modeling to dynamic test results.

However, in performing the validation of a finite element model, <u>there is no substitute for good engineering judgement</u>. As such, it is not the intent of this AC to circumvent the level of communication and coordination required between an applicant and the FAA Aircraft Certification Office (ACO) engineer when validating a finite element model.

Rather, this AC will provide guidance on the numerous parameters that deserve consideration when comparing the results of transient finite element analysis to actual test data. Clearly, the applicant should validate parameters that are important to the particular application of the analysis. However, depending on the purpose of the analysis, it may not be necessary to meet ALL validation criteria provided in this AC. The applicant is cautioned 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 this concept:

- Lumbar loads for the horizontal test (§ xx.562(b)(2)) are usually not critical. It is unlikely the applicant will have to meet the criteria established for validating the ATD lumbar loads.

- 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.

- For the horizontal test required by § xx.562(b)(2), 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 the three loads (vertical, lateral, horizontal) reported by each load cell. It is more reasonable to require validation for those loads critical to the application of the model.

The above 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 ACO to the proper validation criteria. As the above examples show, it is not always necessary to validate a model to each criteria identified in this AC.

7.1 General Validation Acceptance Criteria

Results of the computer model may be used to demonstrate compliance to §§ 23.562, 25.562, 27.562, or 29.562 if the criteria specified in this section have been satisfied. These criteria allow for subjective interpretation as long as this interpretation is consistent with good engineering judgement. The level of correlation required of the applicant should not be more stringent than the level of accuracy of the test data (i.e., the test instrumentation). The general validation acceptance criteria includes, but is not limited to, the following:

a. The model must be validated against dynamic tests.

b. The model should be utilized for conditions that are similar to the model validation conditions. Similarity should exist between the current seat analysis and the test and analysis used to validate the analysis model, including loading conditions, seat type, and worst-case conditions.

For example, test results from a four-legged seat should not be used to validate a three-legged seat computer model. As another example, test results from a forward facing seat should not be used to validate an aft-facing seat computer model.

c. The general occupant trajectory, verified by time history plots, should correlate against test data.

In addition to the general validation criteria above, the applicant may need to validate the model to some or all of the application specific criteria defined in Section 7.1.1.

7.1.1 Application Specific Validation Criteria

The applicant should validate parameters that are relevant to the application of the model. The ACO and the applicant should identify and agree upon the validation criteria that are specific to the application, and the certification plan should list those criteria.

The computer model is considered validated if reasonable agreement (as discussed in Sections 7.1.1.1 to 7.1.1.6) between analysis and test data can be shown for those parameters critical to the application of the model. Test data used to validate the model should be included as an appendix in the Validation and Analysis Report (VAR, see Section 11).

Sections 7.1.1.1 to 7.1.1.6 identify criteria used to evaluate the applicant's computer model. The ACO and the applicant should negotiate any additional validation criteria not listed in this AC. The following sections also define the acceptable correlation methods related to each specific validation criteria.

7.1.1.1 Occupant Trajectory

Occupant trajectory describes the overall translational and rotational motion of the occupant. *As used in this AC, the term "occupant" is actually a representation of the ATD. The occupant model is used to correlate the behavior of the ATD, as opposed to human biodynamic behavior.*

Occupant trajectory or position is determined using the Seat Reference Point (SRP), as defined in SAE AS8049 Revision A, as the datum. The trajectory of the occupant may include headpath, pelvic displacement, or torso displacement. If there is a concern regarding femur injury, then occupant trajectory may include leg motion as well.

The analytically 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 planar space time-history plots to calibrated photometric data obtained from the baseline dynamic test. When precise occupant trajectory information is not required, a visual comparison of the data may be sufficient.

For most applications, however, validating the occupant trajectory may be limited to the critical portion of the head strike envelope. The critical portion of the envelope is either that area just prior to contact or a time interval when the head is closest to a potential contact surface. For this application, the applicant should provide close agreement between test and analysis for head position and velocity. The applicant is cautioned that head angular velocity may also have a significant impact on head injury.

As it relates to occupant trajectory for side-facing seats, an applicant may use computer modeling to demonstrate that only incidental body-to-body contact will occur when the occupants are exposed to the accelerations and velocities of § xx.562. This assumes that the seat structure and occupant motion has been validated to a baseline side-facing seat test.

Appendix 1 illustrates some of the items to consider when evaluating occupant trajectory (and HIC). While Appendix 1 serves as an example on those items to consider in this type of validation, it is not a universal example. Other situations may require more or less stringent validation efforts.

7.1.1.2 Structural Response

Quantifying the structural response of the computer model includes evaluating the internal loads and structural deflections of the seat. Validation of the computer model should include a comparison of the structural performance criteria presented in Sections 7.1.1.2.1 and 7.1.1.2.2 to the predictions of the model.

7.1.1.2.1 Internal Loads

Critical floor reaction loads may be used to establish model validation. There should be reasonable agreement between time history plots of the critical floor reaction loads obtained in the analysis and the measured test data. As stated under Section 7, it is unlikely that the applicant will be able to correlate all three axial loads at each floor attachment. The applicant and the ACO must 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. In addition, the applicant should provide data showing that the time history plots of the critical floor load reactions correlate to the test results.

There may be times when an applicant has introduced 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 finite element model. In this instance, the applicant and the ACO should coordinate to determine how or if these loads will be used to validate the model.

Appendix 2 illustrates some of the items to consider when evaluating load time histories. The example in Appendix 2 is a generic hypothetical load. While Appendix 2 serves as an example on those items to consider in this type of validation, it is not a universal example. Other situations may require more or less stringent validation efforts.

7.1.1.2.2 Structural Deformation

Reasonable agreement should be obtained between the mode and magnitude of structural deformation obtained by analysis and test data 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 that the ACO and applicant believe will be critical. A comparison between the planar space plots obtained from the analysis to photometric data obtained from dynamic test can help validate the model. Non-critical structural members may utilize visual comparisons between the test and analytical data.

7.1.1.3 Restraint System

With few exceptions (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 acts as the primary load path from the occupant to the seat.

In this case, there should be correlation between the restraint loading time history and the maximum value. Maximum values that correlate to within 10 percent will ensure that the computer model will predict the inertial force transfer from the occupant to the seat.

Additional parameters, such as belt payout or permanent elongation, may be correlated if similar measurements were recorded during dynamic test. Monitoring and recording these additional parameters is not required for seat certification, but it may be an aid to the applicant during model validation.

Explanatory Note: Belt payout is a term used to describe how much of the shoulder harness restraint is released prior to locking of the inertial 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 that releases from the reel is the belt payout.

In general, occupant trajectory and restraint system loads are closely related functions. If it is necessary to validate restraint system loads, the ACO and applicant should compare the overall trajectory of the ATD and occupant models for correlation. It is not acceptable to show compliance to occupant trajectory in lieu of restraint system performance or to validate restraint system performance at the expense of occupant trajectory.

7.1.1.4 Head Injury Criteria (HIC)

14 CFR parts 23, 25, 27, and 29, §§ 23.562(c)(5), 25.562(c)(5), 27.562(c)(5) and 29.562(c)(5), define the certification requirements for Head Injury Criteria. An applicant may use the results of computer modeling to show compliance with these rules, within the limitations summarized below. However, an installation change that results in a significantly higher head strike velocity will likely require testing. The following is not

an exhaustive list, but the applicant may choose to use computer modeling under the following circumstances:

a. The predicted occupant head strike envelope will satisfy the above stated rules by showing that no contact with adjacent seats, structure, or other items in the cabin will occur, or;

b. 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 700 will typically not support analytical substantiation if the head impact velocity significantly increases.

c. The applicant has performed dynamic testing in the presence of a rigid structure. The applicant wishes to then reposition the seat in the aircraft where the head strike will be on a less rigid structure but with equivalent head strike velocities.

d. If the tested HIC value is below 700, and the analytical model correlates to within 50 HIC units, modeling may be used if the predicted HIC does not exceed 700. This includes situations where the head impact surface has changed.

The regulation specifies calculating HIC during the duration of the major head impact, with a maximum allowable HIC limit of 1,000 units. The selected time interval should correspond to the duration of the major head impact on aircraft interior features.

The profile (i.e., 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 applicant is cautioned that the average "G" loading 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.

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 50 HIC units of the maximum test derived HIC value. The applicant is encouraged to generate conservative HIC prediction models.

It is also unlikely that the analytical head deceleration time history function will match the test generated head deceleration time history function. Therefore, the initial and final integration times, t1 and t2, as defined and used in § xx.562, will likely vary between test and analysis.

7.1.1.5 Spine Load

14 CFR parts 23, 25, 27 and 29, §§ 23.562(c)(7), 25.562(c)(2), 27.562(c)(7), and 29.562(c)(7), define the certification requirements for lumbar spinal loading. The maximum allowable limit is 1,500 pounds of compression. The spine load time-history

and maximum spine load obtained in the analysis should correlate within 10 percent of the dynamic test data.

Correlating an analytically produced spine load to a test derived spine load is only necessary when the applicant and the ACO agree that design changes from a baseline seat will affect this parameter. One such design change may include a change to the seat foam.

7.1.1.6 Femur Compressive Load (part 25 airplanes only)

14 CFR part 25, § 25.562(c)(6), defines the certification requirements for axial compressive loading of the femur. The maximum allowable limit is 2,250 pounds. The femur compressive load is usually not an issue in the testing of part 25 seats. However, if the ACO or 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 compare to within 10 percent of the dynamic test results.

7.1.2 Discrepancies

Failure to satisfy all validation criteria does not automatically preclude the model from being validated. The applicant and the ACO 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.

In addition, the applicant may present evidence to show that 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.

7.1.3 Computer Hardware and Software

Certification work performed by the applicant's computer model should be performed on the same hardware and software platform on which the validation was conducted. If "Beta" or another non-production software is used, the applicant should provide documentation identifying the changes between the production and non-production software.

If a change to the software version and/or hardware platform used to validate the model results in significant changes to the performance of the model, the applicant should revalidate the model.

7.2 Documentation of Validation

The applicant is entitled to validation documentation, supplied by the FAA, indicating that the computer model is capable of generating certification data. This will allow the applicant to avoid revalidating the same model each time it produces certification data. It also avoids having to revalidate if business must be conducted at an ACO different from the ACO that approved the original validation.

The applicant and the ACO should negotiate the form this validation documentation will take (letter, formal memorandum, or other suitable form). In addition, once an applicant has provided sufficient evidence that a computer model is capable of generating certification data, the ACO and applicant should agree upon the content of the validation documentation. Possible items to include in the validation documentation are as follows:

- The FAA's acceptance of the computer model to produce certification data.
- Identification of the software version and hardware platform used to build and run the computer model.
- A description of any limitations on the application of the computer model.
- The FAA's expectations for how the applicant will maintain configuration control of the model.
- Other items as agreed to between the ACO and the applicant.

8. APPLICATION OF COMPUTER MODELING IN SUPPORT OF DYNAMIC TESTING

There will be occasions when the applicant wishes to determine the critical loading scenario for a particular seating system. This section provides guidance on those items to consider when performing trade studies with the purpose of identifying the most critical configuration/installation. A final certification test to the requirements of 14 CFR parts 23, 25, 27, or 29, §§ 23.562, 25.562, 27.562, or 29.562, will be required to certify this critical configuration/installation.

Sections 8.1 to 8.3 specify the conditions when a computer model may 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.

8.1 Determination of Worst-Case for a Seat Design

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

a. Identifying components of seat structure that are critically loaded.

b. The selection of the critical seat tracking positions (such as seat adjustment positions).

c. An evaluation of the restraint system (such as critical attachment location).

Explanatory Note: The restraint system is not limited to the actual belts; it also includes the required anchoring attachments. Computer modeling may be used to evaluate (i.e., analyze) the effect of anchoring the restraints at different locations in the aircraft.

d. An evaluation of the yaw condition to address loading on the seat frame and movement of the occupant out of the restraint system.

e. The number of seat places occupied.

f. The selection of the worst-case seat cushion build-up.

8.2 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 shall be analyzed in its production installation configuration. For example, an analysis to determine a worst-case seating system may include the following:

a. Comparing seating systems installed in an over-spar versus non over-spar configuration.

Explanatory Note: Some seats are partially or totally attached directly to the wing spar carry-through structure. Consequently, due to the rigid structure directly underneath the seat, care must be taken in the design of the seat to satisfy 14 CFR, § 23.562(b)(1). Part 23 airplanes occasionally use this seating arrangement.

b. Seating systems installed at different positions in the fuselage, which will result in various restraint anchor positions relative to the occupant and seat structure.

8.3 Determination of Occupant Strike Envelope

The results of the computer analysis may 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.

9. APPLICATION OF COMPUTER MODELING IN LIEU OF DYNAMIC TESTING

There will be occasions when the applicant wishes to certify a seat that is based on a certificated design concept (a family seat design) but differs from the certificated design. When the applicant intends to use the results of computer modeling to provide engineering/certification data in lieu of dynamic testing for a modified design, the results from this validated model may be applied to the modifications specified in Sections 9.1 and 9.2.

9.1 Seat System Modification

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.

There will be instances when a modified seat design results in a structural member (in the primary load path) that must react a dynamic load or stress greater than that reacted during the baseline design test. Note that the modified part is not necessarily the part that has increased criticality. For a non-critical structural member, i.e., the ultimate margin of safety of the baseline design (see Section 11.6) is greater than or equal to 1.0, the modified design ultimate margin of safety must be greater than or equal to 0.5.

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. In those cases where a design change reduces the ultimate margin of safety, the ultimate margin of safety for the structural element in question must be greater than or equal to 0.1. In all cases, the ultimate margins of safety must be positive.

9.2 Seat Installation Modification

Analysis based on a validated computer simulation may be used to substantiate configuration changes to seat installations. The primary application is to show HIC compliance (reference Section 7.1.1.4).

9.3 Applicability

The material in Sections 9.1 and 9.2 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-C127/127a), 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.

10. SEAT CERTIFICATION AND COORDINATION PROCESS

This section contains certification guidelines an applicant may follow when they wish to use computer modeling to generate engineering data to demonstrate compliance to 14 CFR parts 23, 25, 27, or 29, §§ 23.562, 25.562, 27.562, or 29.562. It defines the procedures that are involved concerning FAA coordination, guidelines for the preparation and validation of the computer model, and the minimum documentation requirements for FAA data submittal.

10.1 FAA Coordination

The FAA coordination process presented in this document is extracted from FAA Order 8110.4B. 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.

10.2 Certification Plan

The use of computer modeling to generate technical data in support of the establishment of dynamic test conditions or in lieu of dynamic test shall be negotiated with the FAA ACO. If the FAA establishes a Type Certification Board (TCB), negotiations should occur during the preliminary and interim TCB meeting. Regardless of the presence of a TCB, since a TCB is not always required for STC projects, the applicant's role is as follows:

a. Acquaint the FAA personnel with the project.

b. Discuss and familiarize the FAA with the details of the design.

c. Identify, with the FAA, applicable certification compliance paragraphs.

d. Negotiate with the FAA where the applicant will utilize computer modeling, and specify the intent and purpose of the analysis.

e. Establish means of compliance either by test, by rational analysis (i.e., computer modeling), or both, with respect to the certification requirements.

f. Establish the validation criteria for the computer model relative to its application for certification.

g. Prepare and obtain FAA ACO approval of the certification plan.

10.3 Technical Meeting

The details of the computer model are defined during scheduled technical meetings between the applicant and the FAA ACO. 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. A description of the seat system to be modeled.

b. A description of the software to be utilized in the analysis. This should include the operating assumptions and limitations of the software.

c. A description of how compliance will be shown.

d. A description of material data sources.

e. Validation methods, including a description and justification of the failure modes/theories.

f. Interpretation of results.

g. Substantiation documentation and data submittal package.

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

11. DOCUMENTATION REQUIREMENTS FOR COMPLIANCE

The applicant must create a document that provides the analytical results and comparisons to test data when computer modeling is submitted as engineering data. This document will be known as the Validation and Analysis Report (VAR).

The VAR defines the methodology used to demonstrate compliance to 14 CFR parts 23, 25, 27, or 29, §§ 23.562, 25.562, 27.562, or 29.562. The VAR addresses these methodologies when computer modeling results are submitted as engineering data. In addition, the VAR **must** document the appropriate validation criteria identified in Sections 7.1.1.1 to 7.1.1.6.

Sections 11.1 to 11.6 identify *additional* documentation requirements of the VAR. The ACO and the applicant should negotiate any further requirements.

11.1 Purpose of Computer Model

The applicant must define the purpose of the computer model as either:

a. Application of computer modeling in support of dynamic testing (Sec. 8), or,

b. Application of computer modeling in lieu of dynamic testing (Sec. 9).

The VAR must list the 14 CFR requirements relevant to the certification of the seating system. The VAR will emphasize how the computer model would be used to demonstrate compliance for each stated requirement.

11.2 Overview of Seating System

The VAR must 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.

11.2.1 Seat Structure

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

11.2.2 Restraint System

The VAR must 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 may include the shoulder and lap belts, load limiting devices, belt locking devices, pretensioners, and inflatable restraints. The VAR must also describe how the restraint system and its devices are anchored and list the material properties of the restraint system.

11.2.3 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 may include energy absorbing subfloor structure or inflatable devices mounted on the airframe but not considered a part of the seat/restraint system.

11.3 Software and Hardware Overview

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

a. Type and platform of computer hardware;

b. Software type and versions; and

c. Basic software formulation.

11.4 Description of Computer Model

The VAR must contain a detailed description of the computer model, including the input data. The VAR must also include a discussion on the topics presented in sections 11.4.1 through 11.4.7.

11.4.1 Engineering Assumptions

The applicant must document assumptions used for the analysis. Assumptions may 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 must provide a rational support for the use of the assumption. The applicant may be required to demonstrate that the assumptions do not negatively affect the analytical results.

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

11.4.2 Finite Element Modeling of the Physical Structure

The VAR must provide a description of the finite element mesh of the structure. It will 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 must describe the limitations of the mesh element used. If the mesh element is either unconventional or is a new element, the VAR must provide the mathematical formulation of that element, engineering assumptions made during the element's formulation, and any limitations that apply to its usage.

11.4.3 Material Models

The applicant must 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 must identify the source of the material data.

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

11.4.4 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 must document the boundary conditions applied in the model and discuss how the model boundary conditions correspond to the test conditions. The VAR must also provide a description of contact definitions and nodal constraints. Finally, the VAR must document the values used to represent frictional constants and the validity of such values.

11.4.5 Load Application

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

11.4.6 Occupant Simulation

The use of appropriate occupant models depends on the objective of the analysis and should be negotiated with the FAA. If the analysis is used to certify a seat/restraint system to the requirements of 14 CFR parts 23, 25, 27, or 29, §§ 23.562(b), 25.562(b), 27.562(b), or 29.562(b), then a validated occupant model (see paragraph 6) representing a 50th percentile male per 49 CFR part 572, Subpart B, or an equivalent approved model shall be used. The VAR must describe the development and validation of the occupant model.

11.4.7 General Analysis Control Parameters

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.

The VAR must 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. Section 6 of this AC provides a description of mass scaling.

11.5 Analytical Result Interpretation

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

11.5.1 Energy Balance

The applicant must 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 must assess the hourglass modes to quantify their influence on the accuracy of the analysis. The applicant will need to correct the model if it does not attain the appropriate energy balance. The VAR must contain a summary of the ratio of initial energy to final energy and provide a comparison of hourglass energy to total energy.

11.5.2 Data Output

The transient analysis should generate data at channel class 1000. This will maintain an equivalent practice with the instrumentation requirements specified in SAE J211, and it will allow for a meaningful comparison between analytical data and test data.

If the output of the data channels is dependent on the integration time step of the analysis, and its sample rate is higher than channel class 1000, the data should be reduced to be consistent with channel class 1000 prior to filtering. The VAR must document any deviations to this practice.

11.5.3 Data Filtering

The filtering practices of SAE J211 apply for all applications.

11.6 Ultimate Margin of Safety

The ultimate margin of safety represents the ultimate strength of the structure in relation to the strength required to carry the ultimate load. It is traditionally presented as a percentage value, defined as the following:

$$MS_{ultimate} = 100 \text{ x } ([\text{Ultimate Strength} / \text{Ultimate Load}] - 1)$$

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

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APPENDIX 1

OCCUPANT TRAJECTORY AND HIC

There has been an extensive amount of research focusing on the analytical prediction of HIC, head impact velocity, head impact angle, and other analytical data related to full-scale dynamic testing. The information provided in this Appendix will illustrate some of the items to consider when conducting a HIC and head path trajectory validation (reference Section 7.1.1.1 and 7.1.1.4). Figures 1 through 4 in this Appendix were generated and provided by the National Institute for Aviation Research (NIAR) at Wichita State University.

Figure 1 shows an XZ-Plane view of a Hybrid II ATD MADYMO model in a pretest state at 1G. In addition to the Hybrid II ATD, the following items are modeled:

- Seat back
- 2-point restraint
- Seat pan
- Bulkhead
- Foot rest
- Floor

Consistent with Section 7.1.1.1, occupant trajectory or position is established using the Seat Reference Point (SRP) as the datum. The SRP is identified in Figure 1. In addition, the seat setback, or distance from the SRP to the bulkhead, is also shown. In general, the information provided in Figure 1 is considered a minimum for this type of analysis.

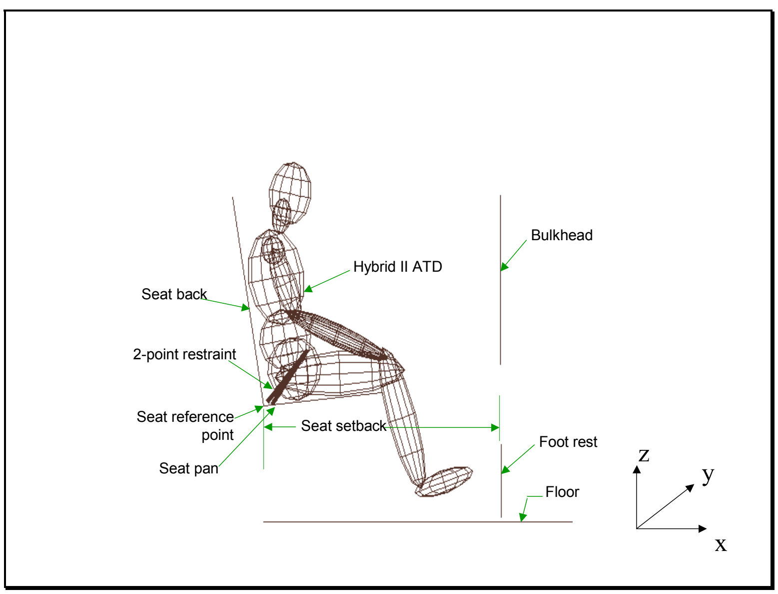

Figure 1 - Pretest Geometry at 1G

Figure 2 presents the ATD motion from a dynamic sled test and the corresponding MADYMO model simulation. The sled test and simulation were conducted using the deceleration forcing function provided in § 25.562(b)(2).

There are two occupant trajectory items to compare in this figure: head path and pelvic displacement. As discussed in Section 7.1.1.1, visual comparison may be used when precise occupant trajectory is not required. For a HIC analysis, the visual evaluation is probably not sufficient, but it will offer some confidence in the model. This evaluation will be followed by a quantitative comparison of the head paths (Figure 3).

Notice that there is a considerable amount of pelvic displacement, which is expected when using a simple 2-point restraint. Section 7.1.1.1 states that the trajectory of the occupant may include head path, pelvic displacement, or torso displacement. Pelvic displacement will clearly contribute to the final head path, but that does not necessarily mean pelvic displacement requires a separate validation. If the head path compares well, and the pelvic displacement compares well, that is usually sufficient for validating the occupant trajectory.

For this particular data, the MADYMO simulation compares well to the ATD motion. Notice that we are not concerned with arm or leg flail. With the possible exception of femur loads, there is no regulatory requirement to measure arm/leg flail.

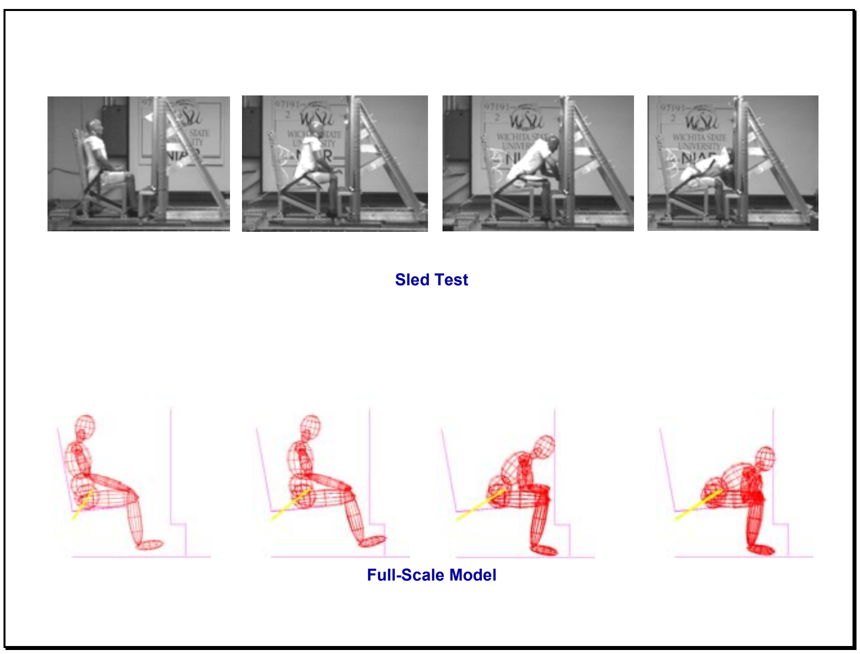

Figure 2 – Occupant Displacement, ATD versus MADYMO

Figure 3 is one more element of the HIC/occupant trajectory validation. Figure 3 compares head path in the XZ plane. This data supports the guidance provided in Section 7.1.1.1, which states that the ability of the computer model to predict occupant trajectory can be established by comparing planar space time history plots. If the applicant is required to evaluate XY plane trajectory, it too should be validated. It is not considered in this example.

Head path trajectory can be, in and of itself, a validation item. For example, if an applicant conducted a validation effort to support a claim that **no** head contact occurs, then head path is a unique validation item. However, in this example, it is used to support or verify another parameter (HIC).

The head path in the XZ plane indicates a greater travel in the Z direction for the ATD, compared to the MADYMO model. Likewise, the MADYMO model appears to travel further along the X direction than the ATD. This is explained by noting that the head paths do not diverge until contact with the glareshield. Correlating post-impact trajectory is difficult and can often be ignored during the validation process.

In general, it is appropriate 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 stand to this type of scrutiny.

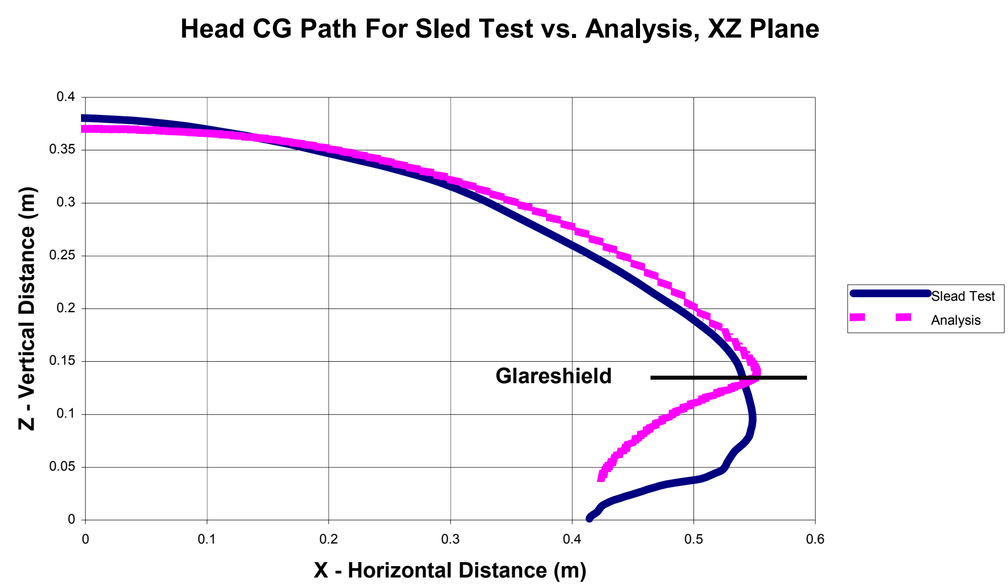

Figure 3 – Comparison of Head Path

The goal of this particular example is to validate HIC predictions. We are provided data to compare the test generated HIC to the analytical prediction. Figure 4 presents comparisons for the Head CG Resultant Acceleration time history, final HIC values, the delta t, and the average acceleration.

As explained in 7.1.1.4, it is unlikely that tight correlation will exist between the analytical head deceleration time history function and the test generated head deceleration time history function. However, there are other parameters that should indicate correlation between test and analysis.

For example, the HIC values between the test data and analysis data compare well (within the limit of 50 HIC units), with the analytical data being slightly conservative. The delta-t time and average G values are also comparable. These three items, when evaluated collectively, suggest the ability of the computer model to perform and predict HIC values.

It is worth noting that Figure 4 also illustrates the difficulty associated with validation. A cursory inspection shows that the peak test values are greater than the analytical peaks. It is not clear, however, if this is real data or a data spike (noise). Therefore, as indicated in the previous paragraph, it may be necessary to evaluate data in a collective manner. For this example, the maximum HIC value, the average G value, and delta-t were used to assess the analysis.

If an ACO engineer still doubted the accuracy of the model, then the applicant should offer further explanation on the items of concern. For this particular example, the ACO engineer may ask for a comparison between test data and analytical predictions for the head impact velocity and head impact angle, which also influence HIC values.

In addition, the ACO engineer may ask for modeling details to help explain the differences in the head acceleration time-history curves. This gives the applicant the opportunity to explain their modeling techniques, assumptions used during modeling, and any limitations associated with those assumptions. The ACO engineer and the applicant would make use of engineering judgment at this point to determine the capability of the model to predict HIC. As discussed numerous times in the AC, engineering judgment is an integral part of model validation.

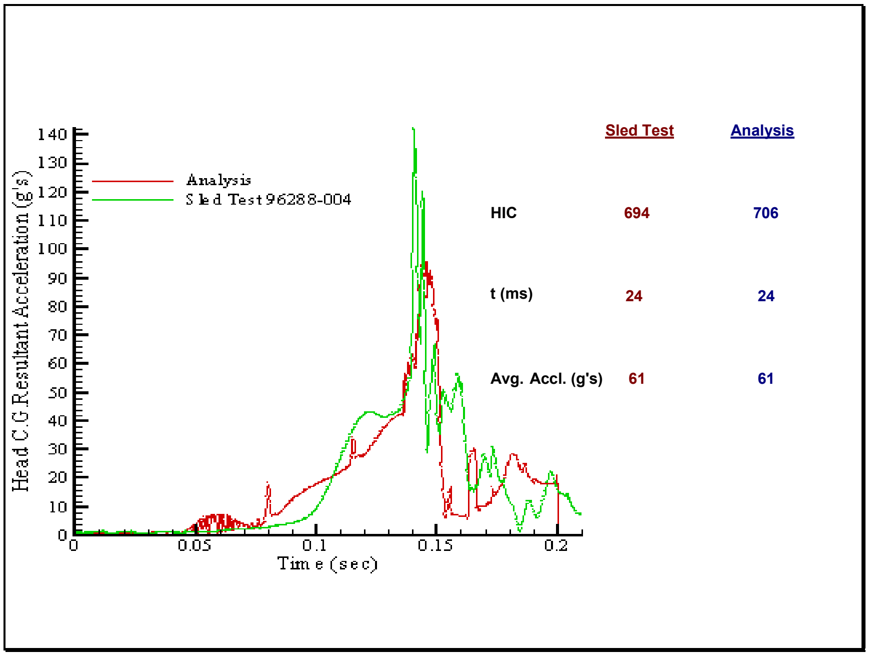

Figure 4 – Test and Analytical HIC Values

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APPENDIX 2

LOAD TIME HISTORIES

The signals from a dynamic test generally present a half-cycle time history. That is, they present a non-cyclic loading/unloading behavior, due the half-cycle deceleration forcing function imposed during the test.

Figure 5 presents a hypothetical comparison between experimental and analytical time history results. For this example, it is not important what actual measurand is being compared. It is identified simply as a hypothetical load.

The peak load between test and analysis correlates to within 10 percent. In addition, in relation to the entire time history, it is clear the character of the loading event is preserved. Although parts of this AC provide guidance on performing a comparison using quantifiable criteria, it may be difficult to rely only on these criteria. In other words, part of the validation should include asking the following question: "Does the comparison **look** reasonable?" This qualitative assessment is a part of the validation.

Figure 5 would support a validation claim by the applicant. This curve shows that the applicant has met the quantitative guidelines (i.e., peak load within 10 percent). The applicant has also established a good correlation of the time-history plot. In addition, note that the analysis tends to be conservative, at least during the loading portion of the time-history. That is, for a selected time, the analytical load is greater than the test load. Therefore, not only do the peaks loads correlate well, the analysis is also conservative.

Regarding the unloading portion of the curve, this part of the event is usually not important to model validity, thus little effort is expended to get precise correlation. In many instances, it would not be reasonable to require tight correlation for this particular portion of the time history curve.

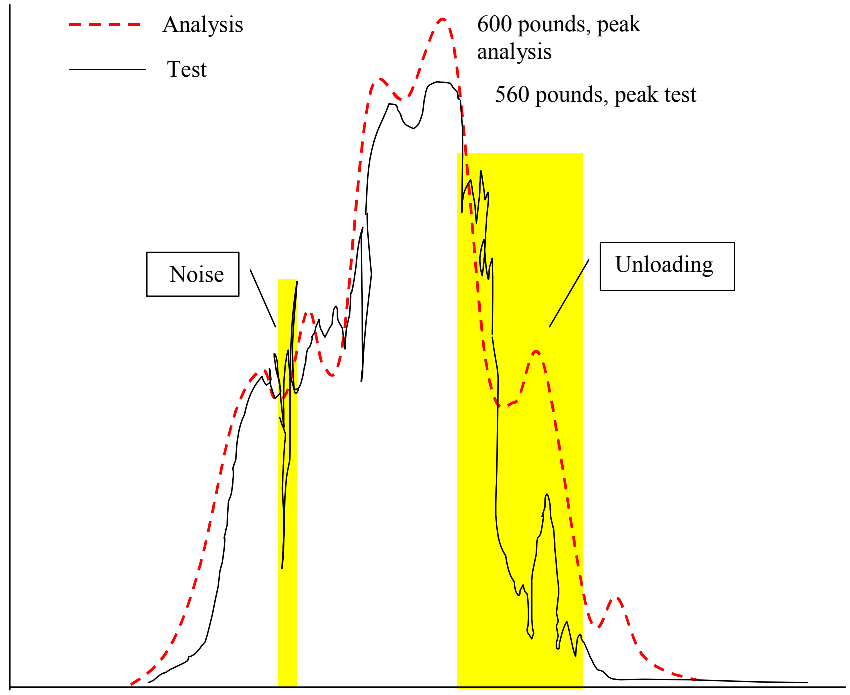

Figure 5 – Hypothetical Load vs. Time (Good correlation)

As a stark contrast, Figure 6 shows it is not always sufficient to rely on peak value to determine correlation. Model validation may require the peak load to correlate within 10 percent. The data in Figure 6 meets that criterion. However, there are other elements to consider that are not easily verbalized, described, or quantified. One such item focuses on how the analytical time history tracks with the test time history. The data in Figure 6 does not satisfy this element. From a qualitative view, the analysis fails to adequately reproduce the test measurement.

It is not the intent of this AC to suggest that the applicant is burdened to preserve the dynamic response of a parameter throughout the full time history and within a strict tolerance. While Figures 5 and 6 are simple examples, they serve to demonstrate this important point.

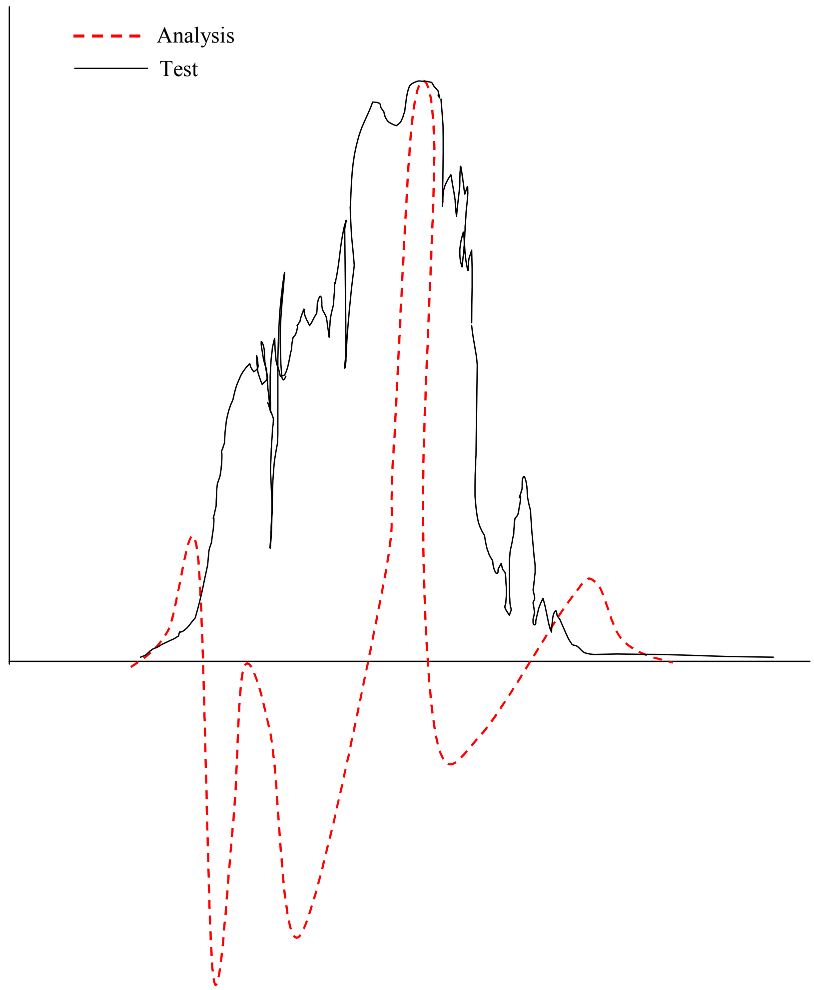

Figure 6 – Hypothetical Load vs. Time (Obvious poor correlation)

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