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Evaluation of Head Impact Kinematics for Passengers Seated Behind Interior Walls

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16. Abstract

Federal Aviation Regulations for crashworthy seats include the Head Injury Criteria (HIC) as part of the pass-fail performance specifications. For passenger seats located behind interior walls to meet this requirement, the dynamics of head impact with the wall must be evaluated from a system approach. Procedures for conducting system tests and analyzing the head motion of an anthropomorphic test dummy (ATD) are described. Analyses of head kinematics from dynamic impact tests with a lap belt restrained ATD are presented.

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EVALUATION OF HEAD IMPACT KINEMATICS FOR PASSENGERS SEATED BEHIND INTERIOR WALLS

INTRODUCTION

Federal Aviation Regulations (FARs) that specify crashworthiness performance criteria for airplane seats include the assessment of occupant injury (1,2,3). Included in these regulations are requirements to demonstrate the protection from head injury to the occupant of a seat. The method for evaluating protection for the head involves acquiring head impact acceleration responses from a Hybrid II 50th percentile male ATD (4). The ATD is restrained in the seat, which is mounted on an impact test sled and subjected to a specified dynamic test. Structures representing the surroundings of the aircraft interior are included on the test sled when feasible. If the results from the dynamic test indicate the head will contact any furnishing or structure in the airplane, the resulting head accelerations must be analyzed using the Head Injury Criteria (HIC) as defined in the FARs. The analytical result of the HIC computation must be less than 1000 for the seat to be certified as meeting the regulations. A HIC value of 1000 is considered to be the threshold above which serious head injury is likely.

There are cases in which the surrounding structures are not known at the time of the test. In addition, it may not be possible to include a complete installation on a test sled due to size and costs. In these situations special test procedures, which are beyond the scope of this paper, must be developed to demonstrate compliance with the HIC requirement.

This report describes the procedures and results from a series of impact sled tests conducted to assess the kinematic motion of an ATD's head. The test configurations represent the geometry of a typical transport passenger seat located aft of a cabin wall. The protocol included the 44 ft/sec 16 Gpk vehicle deceleration pulse per FAR 25.562. The tests presented were conducted in a forward impact orientation with no yaw component in the velocity vector. A primary goal of the project was to acquire ATD head trajectory and velocity information for tests of this orientation subjected to specific impact severities.

This information may be useful in evaluating head position and velocity parameters for similar test conditions. However, methods and procedures presented should not be interpreted as the only means of measuring head motions. Analytical results from these tests are not intended to represent any particular aircraft, seat, or cabin wall installation.

PASSENGER SEATS BEHIND WALLS

Transport passenger seats located behind the vertical wall of a galley, class divider, or lavatory are examples of installations that require evaluation in demonstrating compliance with the HIC requirement. Figure 1 shows a common installation. Seat manufacturers develop seats to meet dynamic load conditions without knowing the properties of structures which may be located near the seats. Usually, the aircraft operator selects the equipment installed near these seats. The installer has the responsibility to ensure the regulatory requirements are satisfied when all the components are in place. Since head impact dynamics are affected by seat performance, interior structures, and installation geometry, a systems integration approach should be applied for these installations.

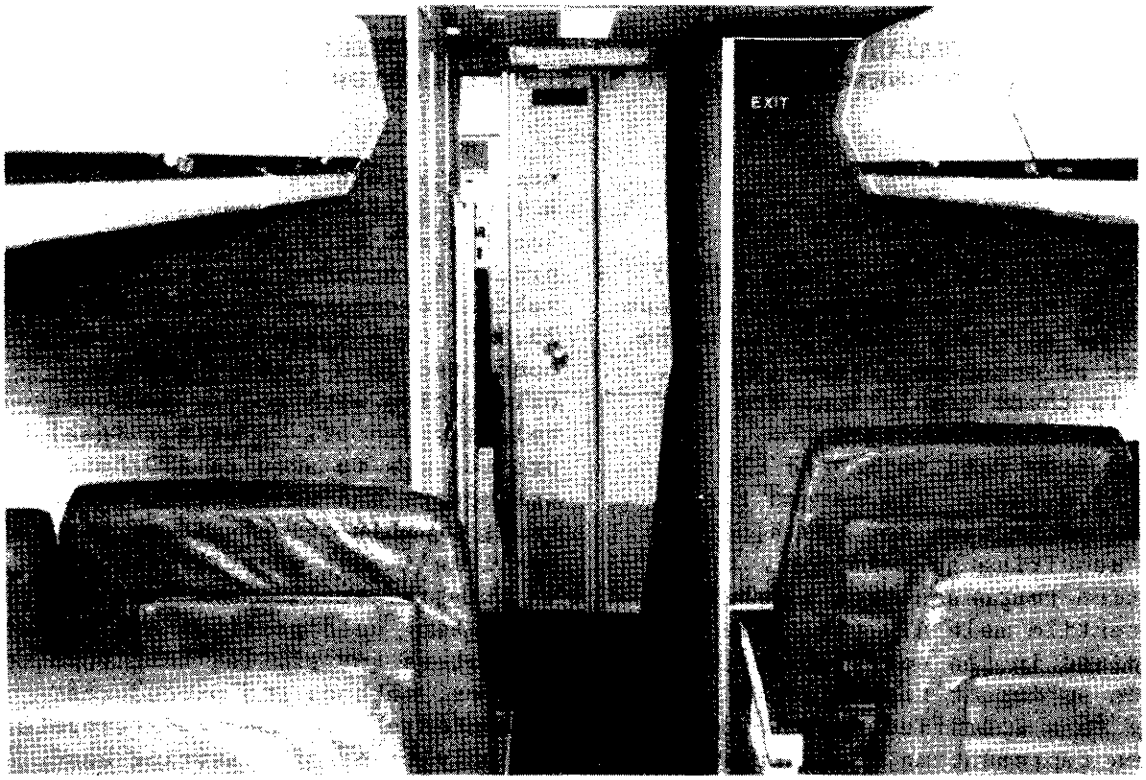

Figure 1.

Factors that affect the severity of head strike against a wall include: seat dynamic deflection; restraint performance; seat cushion properties; occupant size; installation geometry; and the dynamic stiffness characteristics of the impact surface. The dynamic performance characteristics of a seat are design-dependent. Differences in leg symmetry, energy attenuation mechanisms, and the number of occupied seating positions precipitate different dynamic reactions. These factors are determined by the seat manufacturer during the development and certification tests, and the information should be conveyed to the installer.

Installation geometry is a more consistent feature in transport interiors. A horizontal distance of 35 inches between the seat cushion reference point (CRP) and the wall has been traditionally accepted as the necessary spacing between wall and seat for compliance with FAR 25.785. (The CRP is customarily defined as the intersection of the center lines of the seat cushion and seat back.) The 35 inch spacing between the seat CRP and the class divider is sufficient for an average size passenger to lean forward without head contact at the wall. The photos in figures 2 and 3 depict this typical geometry.

PURPOSE AND SCOPE OF RESEARCH

As part of a cooperative project between the FAA Civil Aeromedical Institute (CAMI) and the Air Transport Association (ATA), a series of dynamic tests were conducted to investigate head

Figure 2.

Figure 3.

impact for passengers seated behind cabin walls. The initial phase of the project examined the kinematics of head motion during the impact. The protocol was developed to measure the head path and velocity of a 50th percentile Hybrid II ATD restrained in a passenger seat. A mockup of a vertical wall in front of the seat was included in the fixtures. All of the tests were conducted in a horizontal impact orientation. There was no yaw component in the deceleration vector.

METHODS

The test articles installed on the impact sled did not replicate a specific aircraft interior; however, the configuration for the tests was considered representative of typical installation geometry. Figure 4 shows the test setup. The seats used for these tests were similar to production models. To minimize the effects of dynamic deflection in the seat frame, the ATD was placed in the most rigidly supported seat position. No floor distortion was induced for these tests. The wall fixture was located 35 inches forward of the seat CRP. Figure 5 shows the dimensions of the test fixtures installed on the impact sled.

The simulated wall was comprised of a head-strike-panel 28 inches square and a plywood panel replicating the lower part of the wall. The head-strike-panel was a one-inch thick Nomex open cell honeycomb panel with a thin fiberglass laminate on both sides. The head-strike-panel was attached at the corners of the sled vertical fixture with 3 inch standoffs located on a 24 inch square pattern. There was open space beyond the forward face of the panel.

The scope of the initial phase of the project was limited to investigating the kinematics of head motion under this test configuration. To confine the motion of the ATD head to the longitudinal-vertical plane, the seat and fixtures were oriented parallel to the longitudinal axis of the test sled. This orientation provided a view perpendicular to the plane of motion for the camera used to acquire photometric data.

MATRIX OF TESTS

Table 1 lists the series of tests described in this report. The first two tests in table 1 were conducted with a trapezoidal shaped 7 Gs deceleration pulse. These relatively low severity tests were included in the test protocol

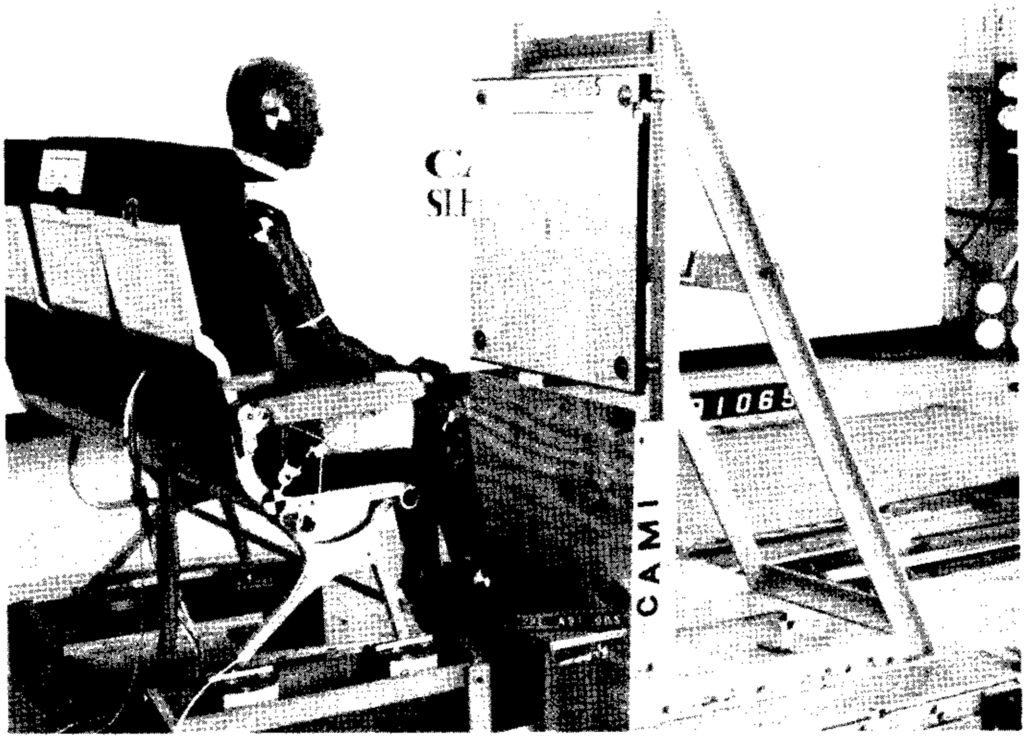

Figure 4.

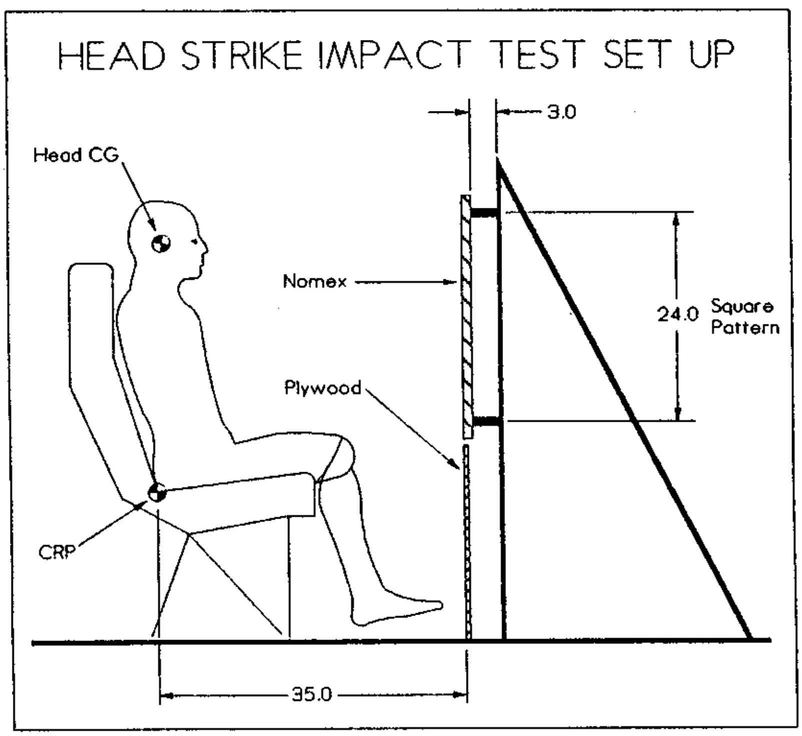

Figure 5.

Test Number	Pulse Shape	Sled Gpk (G)	Vel. (ft/s)	Head Vel (ft/s)	Contact** Time (sec.)	HIC	Note.
A91058	Trapezoid	~7	20.7	----	----		1
A91062	Trapezoid	~7	44.7	36.5	.132	749	
A91064	Triangle	18.5	44.9	41.4	.126	1120	2
A91065	Triangle	16.9	44.9	41.3	.125	862	3
A91082	Triangle	16.7	45.1	46.1	.123	---	4

Notes. (** Contact after onset of pulse)

1. The ATD's head barely glanced wall, no significant impact.
2. An unmodified panel of Nomex used as strike panel.
3. Modified Nomex panel by cutting slits in laminate on strike face of panel. This was done to reduce stiffness.
4. No strike panel, velocity and contact time at plane of wall.

Table 1.

to measure the effect of sled impact velocity on the HIC value, using a "quasi-static" deceleration pulse. The remaining tests had a triangular-shaped 16 Gs peak deceleration pulse, as specified in FAR 25.562. The last test of table 1 was conducted without a head-strike-panel to acquire head path data through the plane of the panel.

Photometric Data: Methods and Procedures

The primary information obtained from these tests was the head motion during the impact. Procedures were implemented as a part of the test protocol to obtain accurate photometric data from the high speed 16 mm camera. The focal plane of the camera was perpendicular to the plane of motion of the ATD's head. This confined the analysis to a two dimensional process. The camera was located approximately 45 feet from the plane of motion to reduce distortion error. A nominal frame rate of 1000 per second was acquired for these tests, and timing pulses were recorded on the film to compensate for frame rate deviation.

Prior to each test, photometric targets were located on the test specimens to ensure accurate dimensional data. Key target locations were identified as: the lateral axis through the center of gravity (CG) of the ATD's head; the plane of the strike face on the wall mockup; the lap belt attachment point on the seat; and two frame dimension targets located on the sled in the prime plane of motion. The ATD was adjusted in the seat to replicate the same initial upright position for each test.

The target motions were digitized from the film and analyzed by the procedures shown in figure 6. The film frame data points were first converted to the dimensions of the sled installation. Film speed compensation

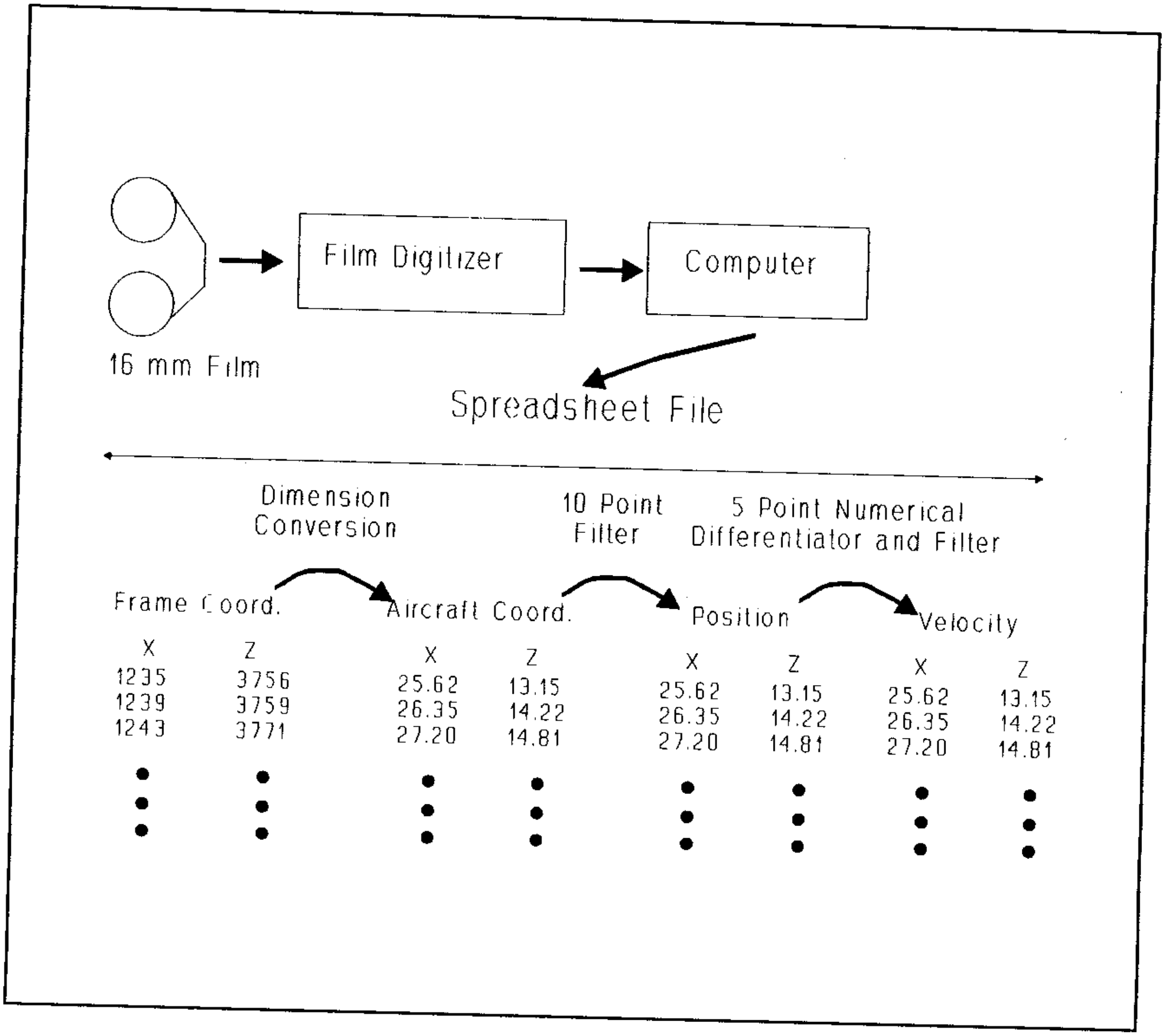

Figure 6.

was determined from the IRIG pulses recorded on the film during the impact. Time history data sets were generated for X and Z direction (horizontal and vertical) motion of the head. Next, a ten point non-recursive low pass filter algorithm was used to reduce the "jitter" resulting from the manual digitization process. A low pass cutoff frequency of 25 Hz was selected for the filter. Finally, a five point numerical differentiation process was applied to the smoothed position data to produce velocity data. Time history plots of the data are presented in figures 7 through 10. The digital filter and numerical differentiation algorithms are described in (5) and (6).

RESULTS

Films and data from the first low severity "quasi-static" test, A91058, show the fiftieth percentile ATD's head barely glanced the wall when the test velocity was 20.7 ft/sec. The second low severity test, A91062, resulted in a significant head strike event during the 7 Gs deceleration pulse with a test velocity of 44.7 ft/sec. The impact pulse and head accelerations for these two tests are shown in figures 7 and 8, respectively.

Although the impact severity for these two tests was below the required 16 Gpk pulse of FAR 25.562, the data acquired provides two important points for consideration. First, using the geometry of this installation mockup, a head strike will occur with a 50th percentile ATD sitting initially in an upright position and subjected to a low level "quasi-static" impact pulse with a velocity greater than 20 ft/sec. The HIC resulting from such a test condition is below 1000; however, this may be considered as a baseline data point, indicating the impact condition where head contact with the wall can occur.

Second, at a higher velocity the head contacts the wall during the 7 G trapezoid shape deceleration pulse. As shown in figure 8, the head acceleration data indicate the time of contact with the wall at approximately 140 milliseconds on the data plot. The sled continued to decelerate after head contact. The initial 44.7 ft/sec sled velocity was not completely dissipated when head impact occurred. The relative velocity between the head and wall at the time of head impact was analyzed to be 36.5 ft/sec as shown in table 1. Thus the kinematics of head motion, initial vehicle velocity, deceleration pulse shape, and duration of the impact pulse combine to produce the relative velocity between the head and wall. Obviously, the severity of the subsequent head impact is affected by this relative velocity vector.

The three other tests presented were conducted with triangular-shaped pulses, which complied with FAR 25.562. Note that head contacts occurred near the end of the deceleration pulses, as indicated by the head acceleration responses in figures 9 and 10. It can be deduced from this observation that the wall velocity is almost zero when the head strikes the wall. The ATD's head, unrestrained as it flailed forward with the upper torso during the impact, contacted the wall with a velocity close to the initial velocity of the sled (44 ft/sec).

The results from analyses performed on the photometric data from the series of tests were consistent and within the expected responses for these test conditions. Figures 11 and 12 display the ranges of results provided by this analysis. The head path, wall impact velocity, and time of contact after the onset of deceleration were comparable.

Position and velocity data from the tests with the wall were not processed past the time of contact with the wall. Rapid onset and high magnitude accelerations occur in the head of the ATD at contact with the wall in a very brief interval of time after contact. Due to the sampling rate from the film of nominally 1000-per-second, the violent, high velocity motion of the head through a small distance after head contact occurred could not be accurately determined. However, the objective of these tests was limited to analyzing of head motion prior to contact; therefore, procedures and special instrumentation for measuring head displacement post contact were not included in this phase of tests. Efforts to derive the radius of curvature for the head path at the time of contact did not produce consistent results. One possible reason for this inconsistency is that the radius changes rapidly as the head nears the plane of the wall panel and could not be precisely measured at the acquired data rate.

The dynamic deflection of the lap belt attachment point on the seat was also measured from the film data. Elastic deflection observed at the seat belt attachment was approximately 2 inches. Seat performance was not intended to be variable in these tests, and the effects of seat deflection during the impact were minimized by the selection of the seat model. Dynamic deflection of the seat will affect both the head motion and relative velocity between the head and wall. Likewise, the dynamic stiffness and energy absorbing characteristics of the wall material will have an effect on the severity of head impact. Although HIC computations were performed on the data from this series, the HIC values should not be considered representative of the results that might be acquired from tests with structures used in airplanes. The Nomex panels used as the head strike surface deflected elastically as much as three inches during this series. Walls supported more rigidly or walls with greater stiffness would result in significantly greater HIC values.

An additional test, A91082, was performed with no wall mockup in front of the seat. The head path result for this test in figure 11 indicates a distance of at least 42 inches between the seat CRP and the wall would be required to prevent a head strike. This spacing is based on the 37 inch forward excursion of the head CG, plus a nominal five inch radius of the head profile. Also, minimal seat dynamic deformation is assumed. The distance would increase for a seat that deflects further forward.

CONCLUSIONS

1. The analytical procedures used to process the photometric data produced consistent results for the head path and velocity. Further refinement and verification of these methods are recommended. A reliable and verifiable methodology for processing photometric data should be established as a standard means for interpreting this type of information.

2. Results from these tests may be used to analyze the basic kinematics of head motion for the test conditions conducted in this project. It should be noted that the effects of seat dynamic deflection and floor distortion were not included in this project. Also, these tests were conducted with a longitudinal deceleration without the 10 degree yaw orientation specified in FAR 25.562.

3. The customary installation geometry of placing forward facing seats with lap belt restraints 35 inches aft of interior walls may result in difficulties meeting the HIC criteria due to the high velocity head impact with the wall. When exposed to the 44 ft/sec 16 Gs peak pulse of FAR 25.562, the head velocity at the time of impact with the wall is virtually the same as the velocity of the impact test.

4. The high velocity head impacts acquired from these tests indicate the necessity for an energy absorbing wall surface if the current installation geometry of 35 inches between the seat CRP and interior wall is to remain the same.

5. The methods and procedures implemented during these tests may prove useful in the system integration for interior installations where the HIC requirement must be demonstrated. Conceivably, the seat manufacturer would supply head path and velocity data from the certification tests with a seat model. The installer of the seats would use this data to assess the interior furnishings of the airplane cabin that may be head strike surfaces. The manufacturer of the interior furnishings might then provide energy absorbing materials that have been proven to limit the HIC value when tested with the same head strike dynamics.

RECOMMENDATIONS

The limited scope of testing and data presented in this report dictate that further research be conducted in the matter of head protection for passengers seated aft of walls. Effects of variables such as seat deflection, occupant size, wall materials, and the dynamics of head impact need to be investigated. Test fixtures, which include actual or proposed seats and equipment installations, should be included in the tests. Finally, alternative measures such as upper torso restraints, added space between the seat and wall, aft facing seats, air bags, or impact-controlled seat motion are ideas that should be considered to eliminate severe head contact.

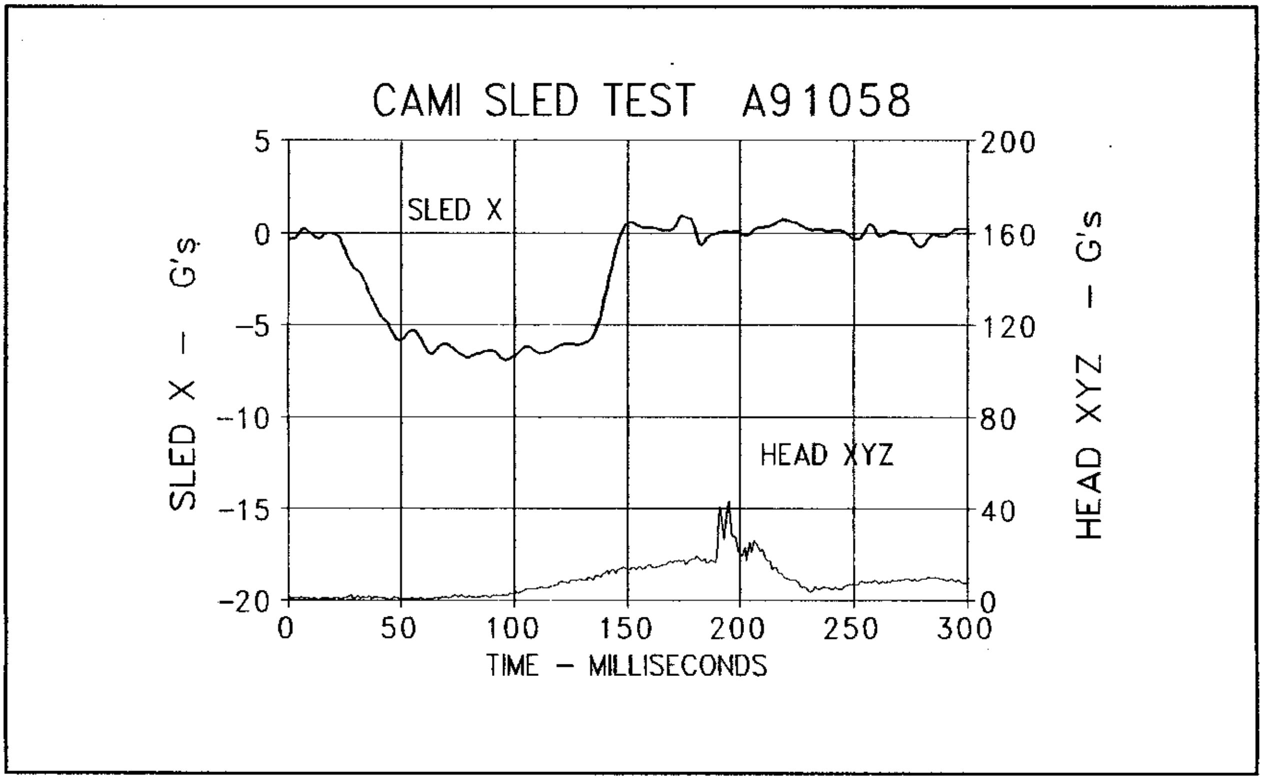

Figure 7.

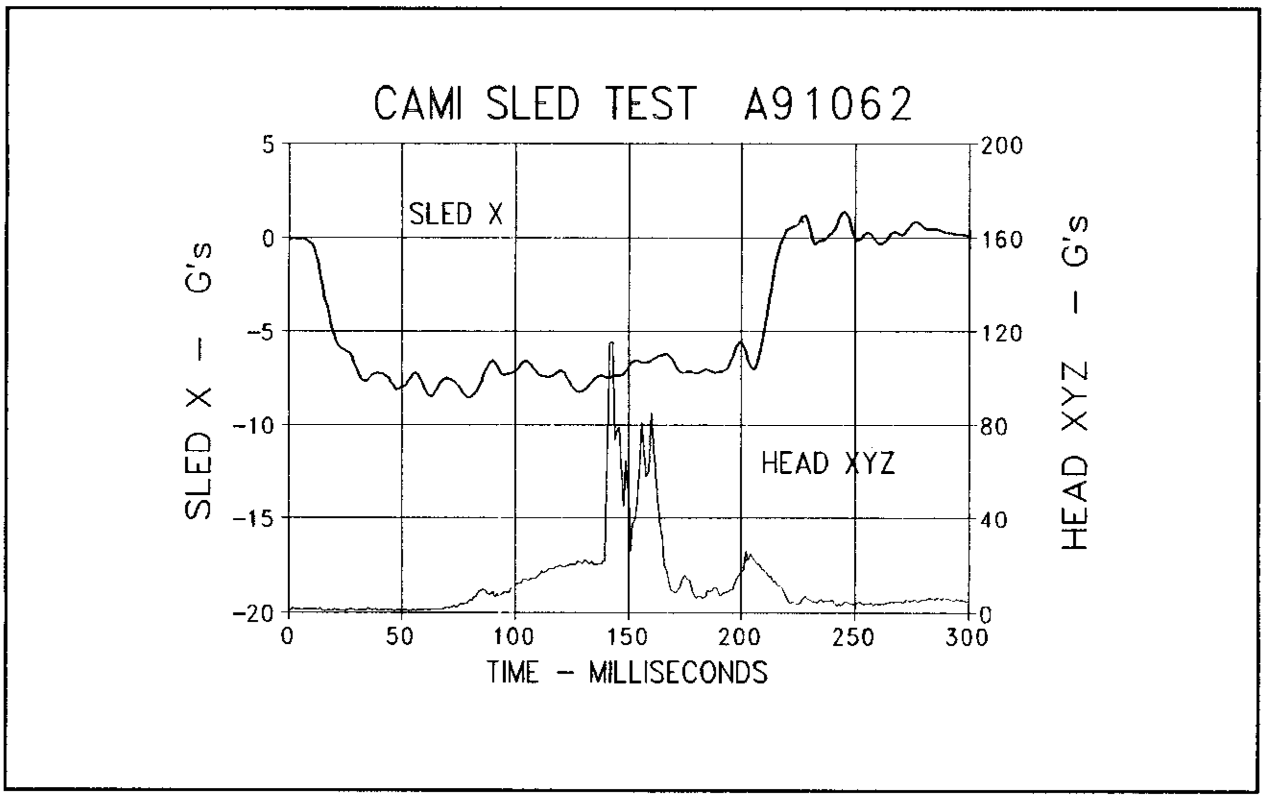

Figure 8.

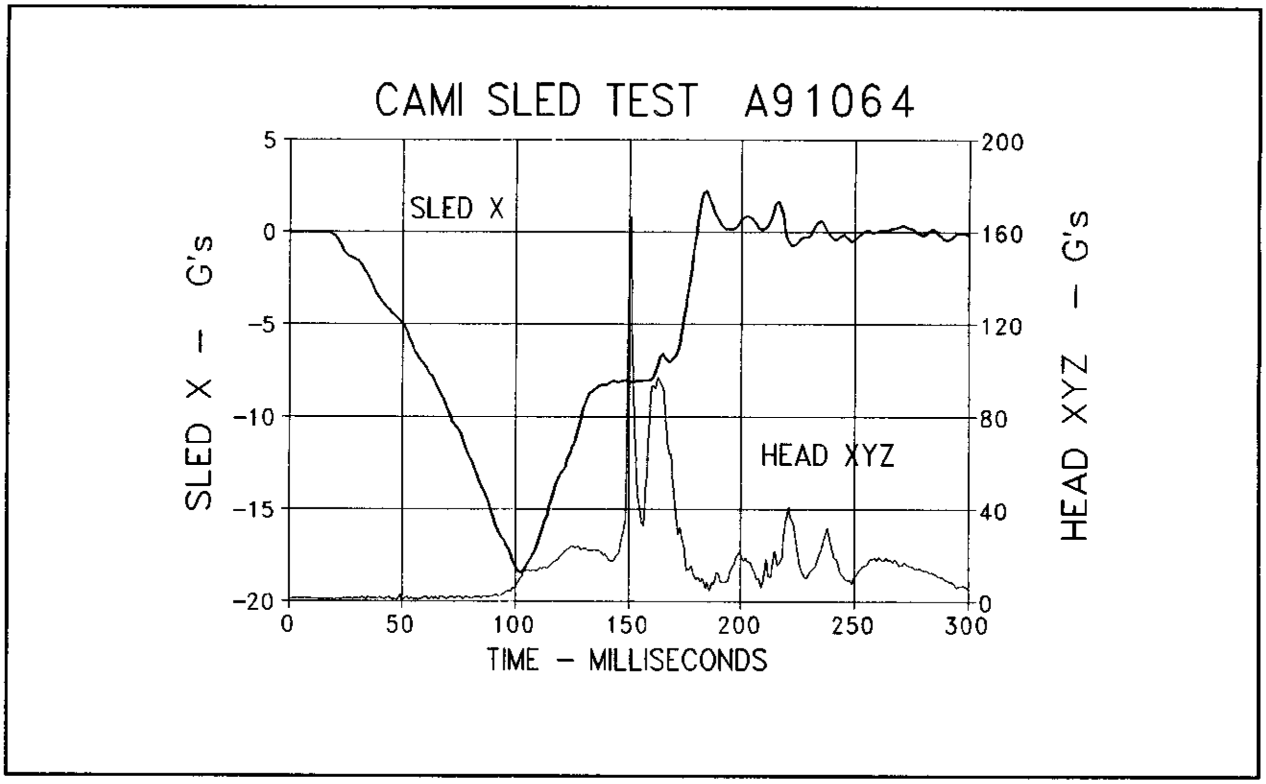

Figure 9.

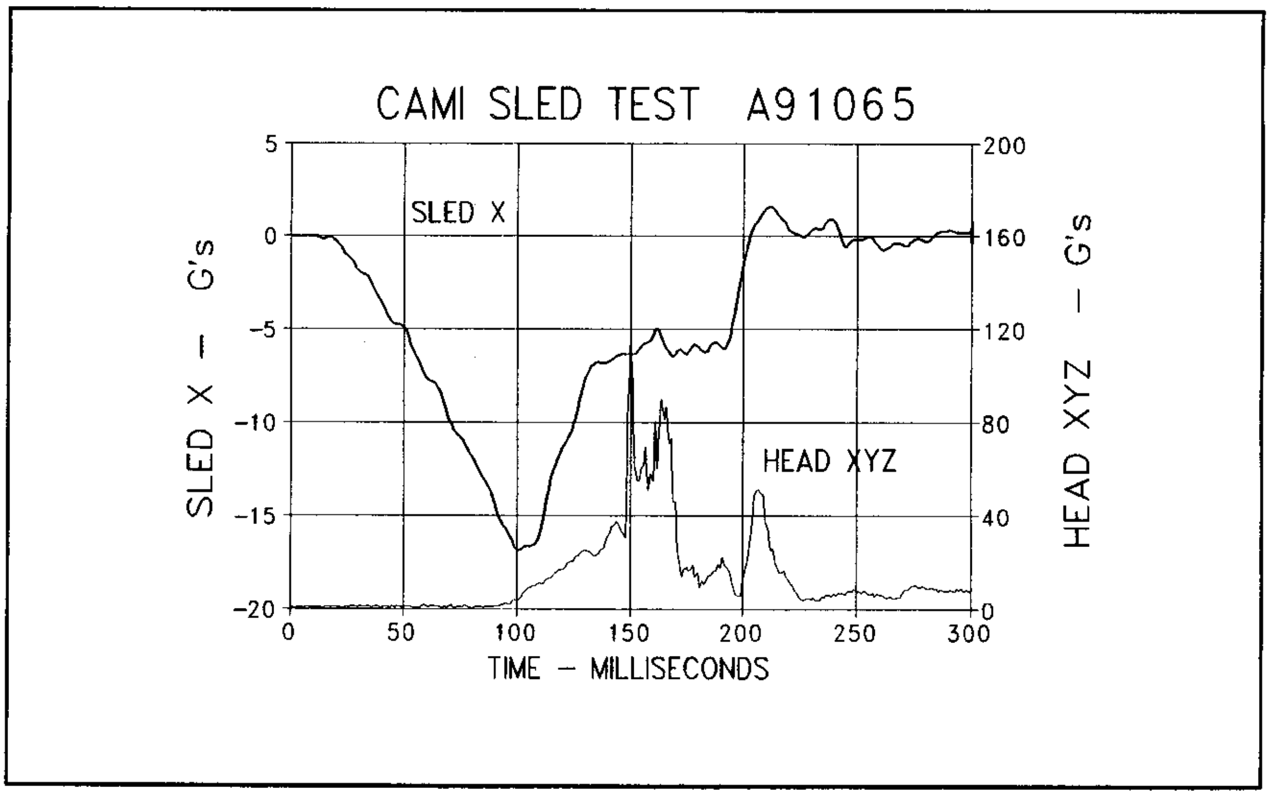

Figure 10.

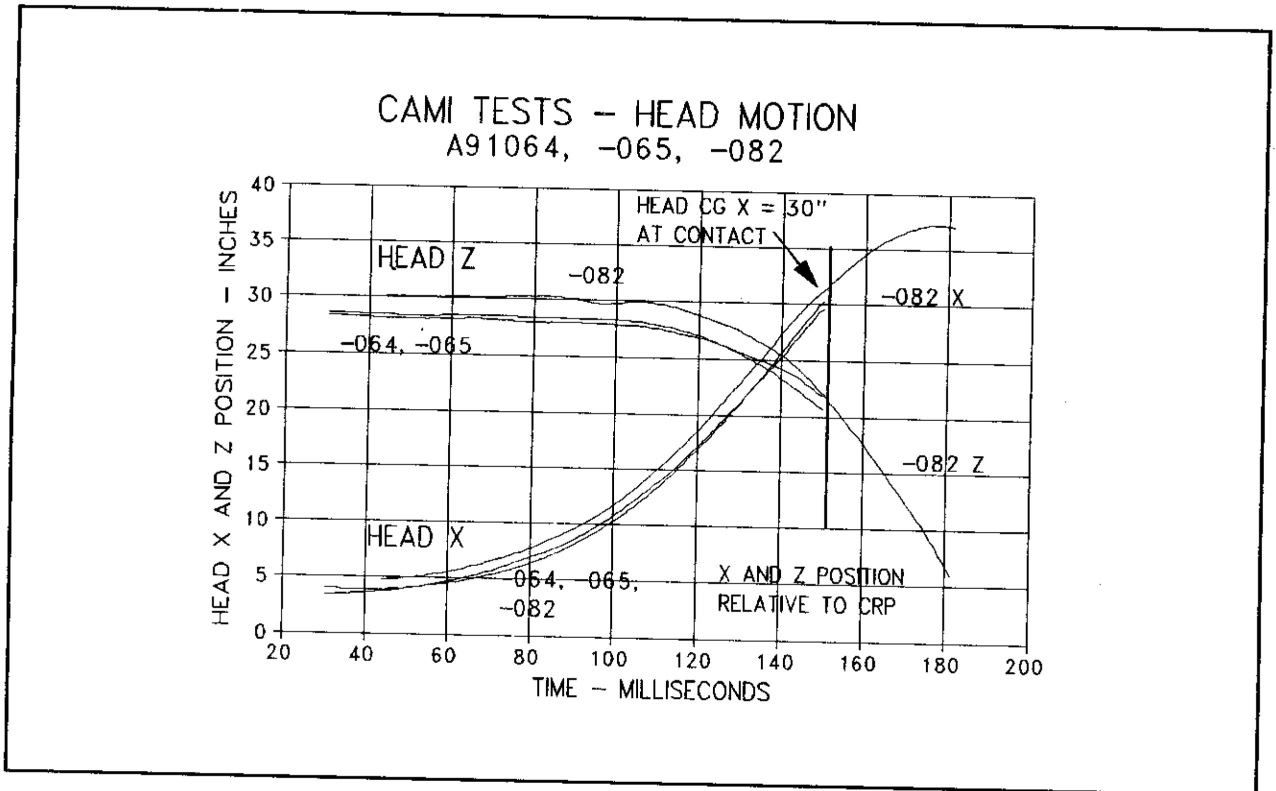

Figure 11.

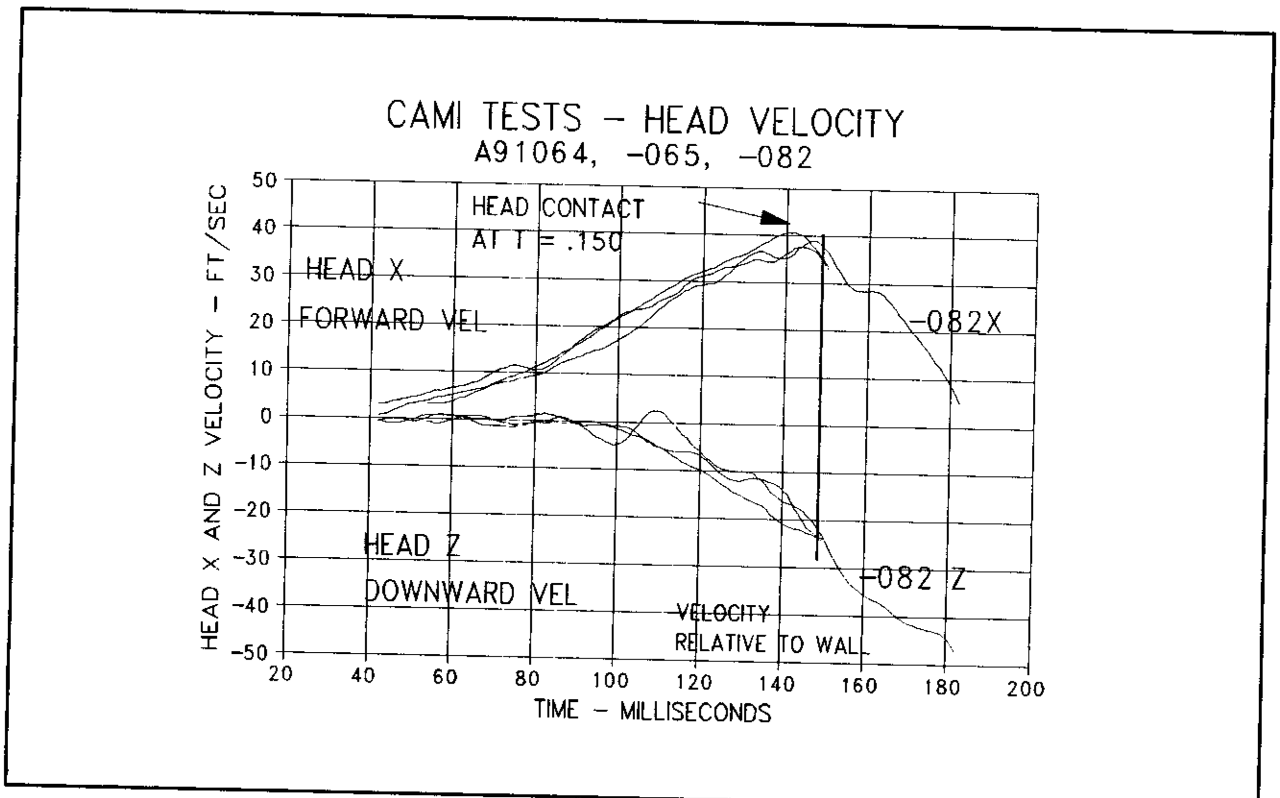

Figure 12.