ANALYSIS OF COMPONENT HIC TESTING

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ABSTRACT

The Head Injury Criteria (HIC) represents a significant challenge to engineers designing cabin interior furnishings for all classes of aircraft. The dynamic seat tests required for the evaluation of this injury measure are costly, time consuming and provide too much scatter on HIC. Many segments of the aerospace industry have expressed the desire for an effective component test with which to address this problem. This paper documents an evaluation of the Boeing/MGA Component HIC test apparatus for front-row bulkhead tests. The project included both full-scale deceleration sled tests of rigid seats with a two-point pelvic restraint performed at the National Institute for Aviation Research in Wichita, Kansas and component tests performed at the MGA Research facility in Burlington, Wisconsin. The evaluation concluded that the component test is particularly effective for problems with short duration head impact events but is less effective for problems producing longer responses involving interactions of the head, neck, and upper torso especially at larger seat setback distances.

INTRODUCTION

The compliance with the Head Injury Criteria (HIC), specified in 14 CFR Parts 23.562, 25.562, and 27.562 (Federal regulations, 1988) poses a significant problem for many segments of the aerospace industry. The HIC is an empirical measure that is generally accepted as an indicator of severe head injury (Gurdjian *et.al*, 1953, 1964). It is evaluated as

$$HIC = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)dt \right\}^{2.5} \right]_{max} \quad (1)$$

where a(t) is the resultant acceleration of the CG position of a 49 CFR Part 572 Hybrid II anthropomorphic test dummy (ATD) head in g's, and t_1 and t_2 are times in the response that maximize the function. The event is considered not to be injurious, if this index is less than 1000. The aerospace industry has encountered problems complying with the HIC requirement in a number of situations including bulkhead and row-to-row seats, and has experienced high costs and significant schedule overruns during the development and certification of the 16g seats. The resolution of HIC problem requires a complete understanding of the system response for the seat, ATD, restraint system, and surrounding cabin furnishings. Dynamic sled tests, as shown in Figure 1, are generally used to evaluate these criteria. Engineering programs to develop HIC compliant systems are expensive since they normally require several tests and a seat is destroyed

Figure 1 - Sled testing of the
ATD-seat-restraint-interior structure

in each one. The tests are also time consuming with four tests per eight hour shift representing a typical rate during a development program. These factors have motivated seat manufacturers, airframe manufactures, the FAA, test labs, as well as research providers to pursue alternative testing procedures. Their goal is to develop an alternate means of HIC compliance, based on a component test that does not consume a seat during each test. Different designs and/or test conditions could be evaluated with these devices at a relatively low cost and in a short period of time. A validated component test device should be simple, but robust, and should reduce the costs and flow time associated with seat certification. Engineer should initially be able to employ the test to certify modifications to an approved "16g seat" by similarity analysis or to use it to complement sled testing data during the certification of new designs.

TEST PROCEDURE

A number of component HIC devices have been developed. Many of these designs, such as the free motion head form tester, address the needs of the automotive industry. However, automotive tests are not always appropriate for aerospace applications since the automotive crash conditions, interior designs, and restraint systems differ significantly from their aerospace counterparts. The free motion head form tests were not considered for the front row bulkhead problem since this device does not generate comparable levels of kinetic energy as produced during sled tests. The bowling ball test developed at the FAA Civil Aeromedical Institute (CAMI) represents one of the first component tests developed for the aerospace industry (Gowdy 1995[a]). Gowdy 1995[b], observed that the HIC level is primarily governed by the change in velocity of the ATD head. Recently MGA and Boeing developed the head/neck impactor shown in Figure 2. It consists of an accelerator, pendulum arm, support arm, rebound brake system, ATD head/neck assembly, and a computerized control and data acquisition system. A schematic diagram of the system is shown in Figure 3, and a description of the components follows.

Figure 2 - MGA’s component HIC test device ‘head/neck impactor’

Accelerator – High-pressure, dry nitrogen gas is used to accelerate the inverted pendulum arm.

Pendulum Arm – The pendulum arm consists of a 17-in-long square steel tube weighing 45 lb.

Support Arm – This arm is an inverted pendulum that transmits the actuation force to the pendulum arm and head/neck assembly. It also supports the head during the initial phase of acceleration so that the head does not go backward due to inertia and that the desired head impact angle is maintained. The support arm guides the ATD head along with the inverted pendulum and retracts, just before the ATD head hits the target.

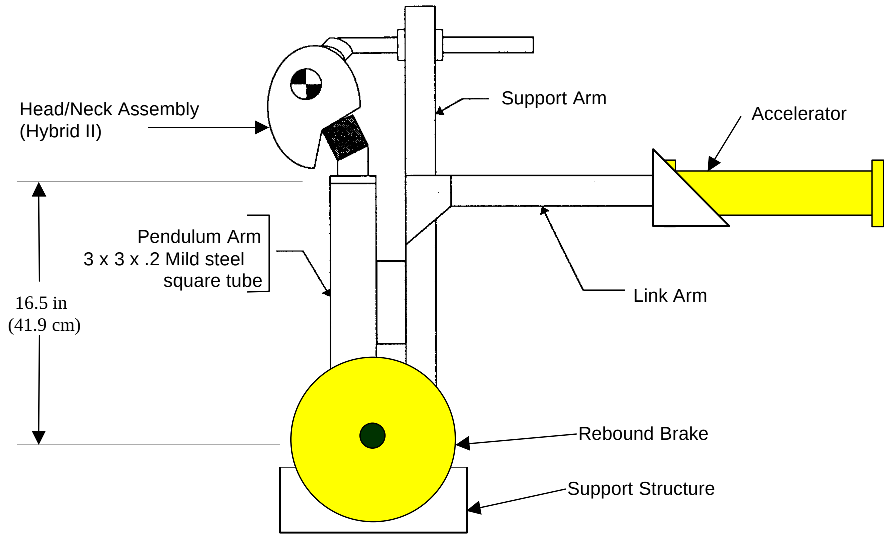


Figure 3 - Schematic diagram of MGA’s head/neck impactor

Rebound Brake System – This is a safety system. It is designed so that the pendulum and head/neck assembly stop just after the impact.

Head/Neck Assembly – A calibrated Hybrid II or Hybrid III head can be mounted on the pendulum arm. The head is instrumented with a set of tri axial accelerometers (a tri axial neck load may be used with Hybrid III head).

Head accelerations (x, y, and z components), neck forces (x, y, and z components), neck moments (x, y, and z components), and pendulum velocity can be recorded. A sampling rate of 10,000 samples per second is used for data acquisition per SAE J 211 (SAE, 1995).

The evaluation of the Boeing/MGA component tester was based on tests performed at the NIAR impact dynamics laboratory and at MGA's Burlington, Wisconsin facility. A series of bulkhead tests using various seat/ATD/bulkhead configurations were performed at the NIAR to generate baseline HIC data. These data were compared with the component HIC data generated during component testing at MGA. The baseline data were generated utilizing both rigid and energy absorbing bulkhead panels per the FAR Part 25.562 Test 2 condition. The head impact velocities and head impact angles were analyzed from the video data acquired during the sled tests. These parameters are the inputs for the MGA component tester. The sign convention for the head impact angle is shown in Figure 4.

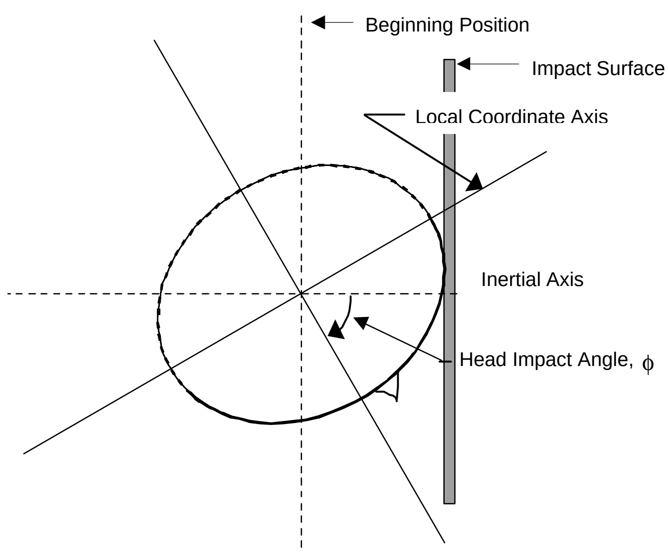


Figure 4 - Convention for head impact angle measurement

Once the baseline sled tests and the component tester were identified, the component test procedure was developed as illustrated in Figure 5. The head impact velocity and head strike angles are extracted from each baseline sled tests. Desired head impact angle was obtained by adjusting distance of the test panel from the impactor. The head impact velocity was obtained by adjusting the nitrogen supplied to the actuator. The head/neck assembly was calibrated in accordance with 49 CFR Part 572. Consecutive tests using an ATD were conducted atleast 30 minutes apart in order to allow the neck rubber sufficient time to dissipate the heat created during a test. This allows the stress strain properties of the neck to return to room temperature levels.

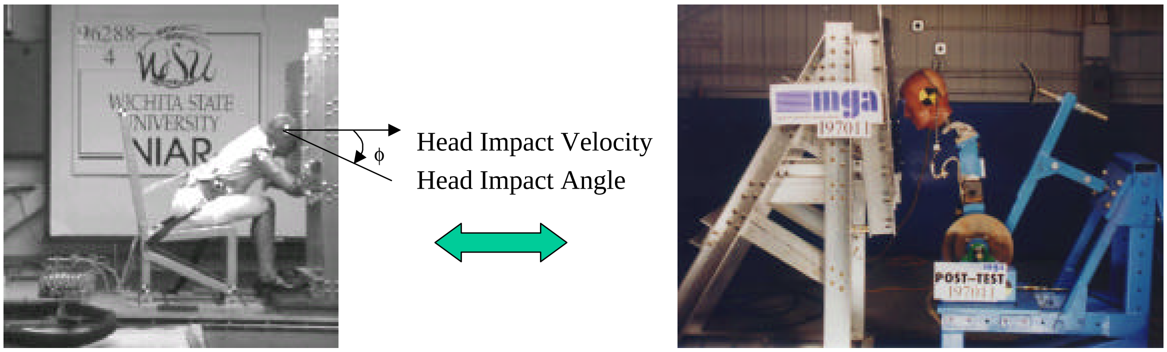


Figure 5 - MGA’s head/neck impactor component test procedure

The ideal component test device should accurately reproduce data from sled tests for a range of HIC values that bracket the injury criteria such as shown in Figure 6.

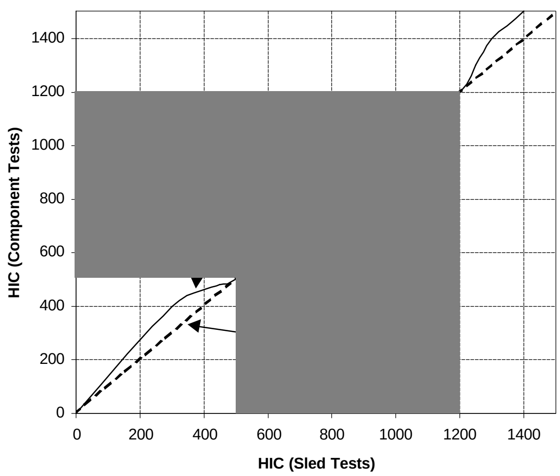


Figure 6 - Target correlation range for the component test device

The SAE-seat-committee established the validation criteria as

1. The component test average head c.g. acceleration should agree with sled test data.
2. The HIC produced by the component tests should agree with sled test data.
1. The HIC window, $\Delta t = t_2 - t_1$, should agree.
4. The general form of the component test head acceleration time history should reproduce the form of the sled test data.

TEST PROGRAM DESCRIPTION

An evaluation of the MGA component tester was initiated with a series of tests conducted at their facility in Burlington, Wisconsin. The baseline data generated from a series of sled tests at NIAR were used to establish the test conditions for the component tests. A front-row bulkhead problem was selected for the baseline study since it is of interest to the aerospace industry and because it was judged to be simpler than a row-to-row test. A test fixture was designed for use, shown in Figure 7, in both the sled tests and the component tests. Thus the conditions measured during the sled tests were exactly reproduced during the component tests.

The same test matrix was used for the component test program as was used for the baseline sled tests conducted at NIAR. This matrix consisted of tests with seat setback distances of 33-in, 35-in and 38-in. The seat setback distance was defined as the distance from the seat reference point (intersection of the seat back and the seat pan) and the outer edge of the bulkhead panel as shown in Figure 7. Bulkheads were fabricated from thin aluminum sheets of thickness 0.063-in.

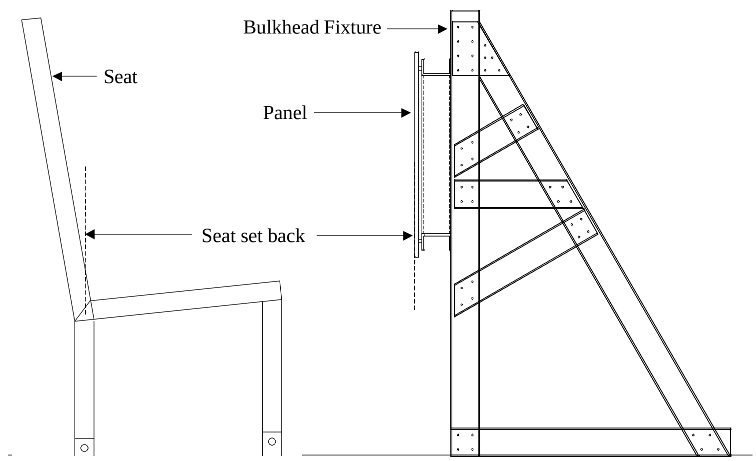


Figure 7 - Seat setback convention for sled tests

For data acquisition in the sled tests, the head accelerometers were mounted in the ATD head c.g, for determining HIC. High-speed video system was triggered prior to the start of sled deceleration for calculating the start and end contact times of the head with the bulkhead. The sled deceleration pulses were captured from two accelerometers that were mounted on the sled. In case of the component testing, head c.g. acceleration, was obtained by mounting the accelerometers in the head. High-speed film was captured for obtaining the contact times of the head with the bulkhead. The MGA pre-test condition is shown in the Figure 8.

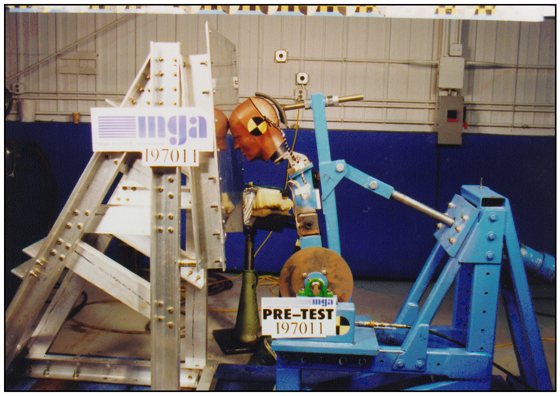


Figure 8 - MGA pre-test condition

DYNAMIC TEST RESULTS

The test results for the component and the sled test are compared in terms of the HIC, peak resultant head acceleration, average head acceleration, and HIC window. Figures 9 to 11 show the frame by frame pictures of the event for the three seat setback distances from the high-speed video data. Head strike paths for the tests were digitized from the video data as shown in the Figure 12.

Time - 0 msec

Time - 100 msec

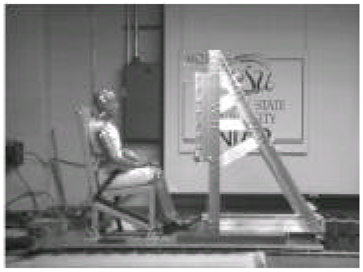
Time - 112 msec

Time - 134 msec

Time - 160 msec

Time - 220 msec

Figure 9 - Sled test frames for seat setback of 33-in.



Time - 0 msec

Time - 80 msec

Time - 102 msec

Time - 120 msec

Time - 142 msec

Time - 172 msec

Figure 10 - Sled test frames for seat setback of 35-in.

Time - 0 msec

Time - 100 msec

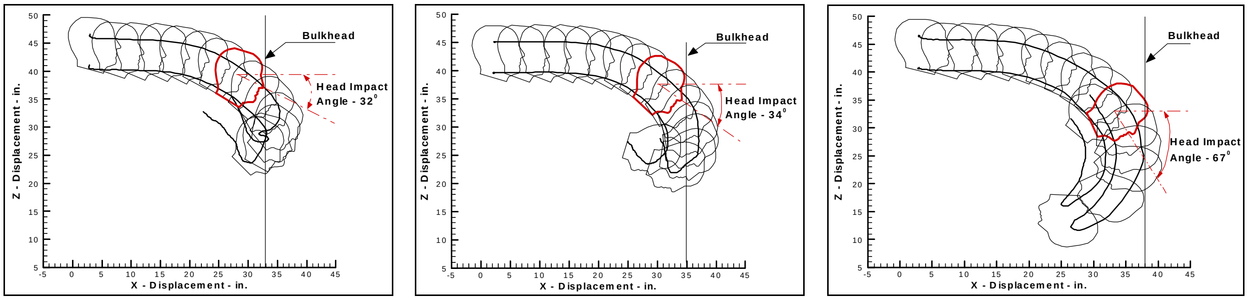
Time - 122 msec

Time - 140 msec

Time - 160 msec

Time - 200 msec

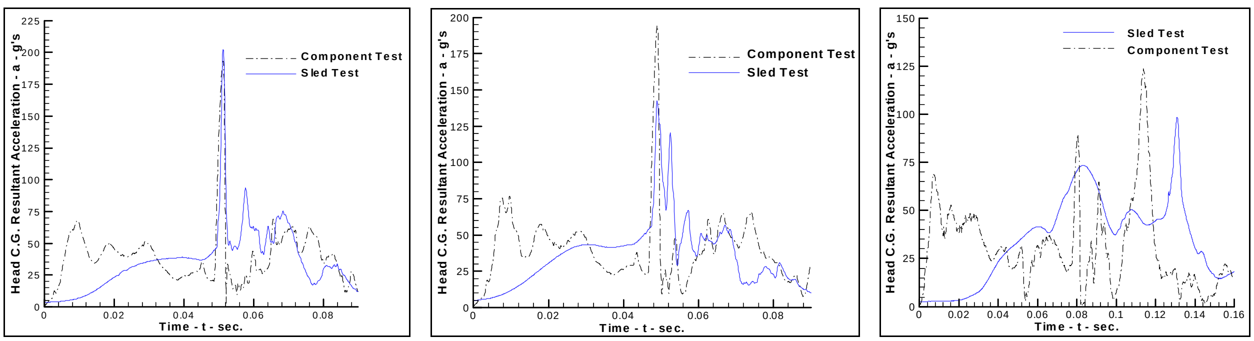
Figure 11 - Sled test frames for seat setback of 38-in.



Seat setback 33-in. Seat setback 35-in. Seat setback 38-in.

Figure 12 - Head path for sled tests of different seat setbacks

The corresponding head c.g. peak acceleration profiles for the sled and the component tests are shown in Figure 13 and the resulting HIC values are presented in Figure 14.



33-in. seat setback 35-in. seat setback 38-in. seat setback

Figure 13 - Comparison of Head c.g. time history for sled and component test

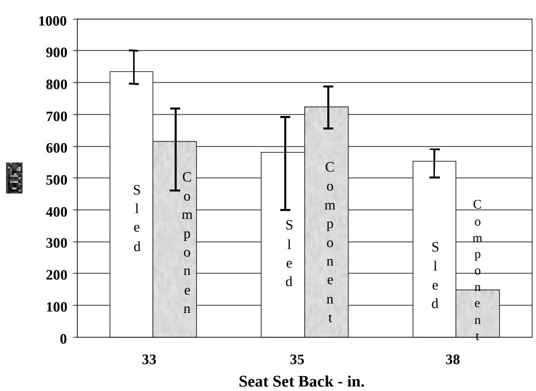


Figure 14 - Comparison of HIC for sled and component tests

The peak and average head acceleration values for the sled and the component test are presented in Figure 15 and 16 respectively. The average values from these tests are represented by the bars while the scatter bands represent variation in the data. By examining these figures, it is seen that the component test head acceleration profile agrees for the 33-in. seat setback and deteriorates as the seat setback distance increases.

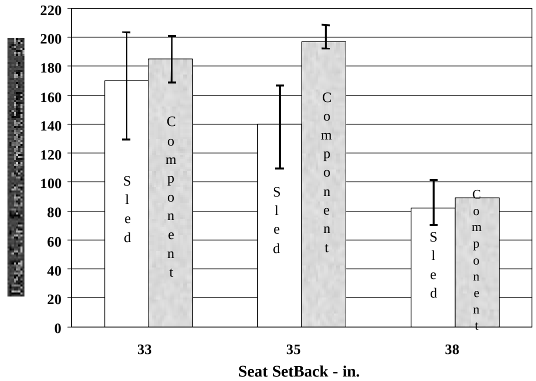


Figure 15 - Comparison of head c.g. peak resultant acceleration for sled tests and component tests

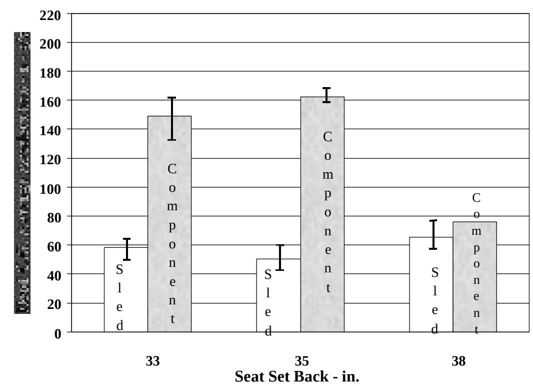


Figure 16 - Comparison of head c.g. average resultant acceleration for sled tests and component tests

The HIC window, $\Delta t = t_2 - t_1$, for the component tests were much less than the corresponding time intervals for the sled data as shown in the Figure 17. This was identified as a significant problem that could contribute to the differences in the HIC values for the shorter seat setback distances. Given the good correlation for the head c.g. peak values, for the shorter set back distances, it certainly explains the differences observed in the average head acceleration data.

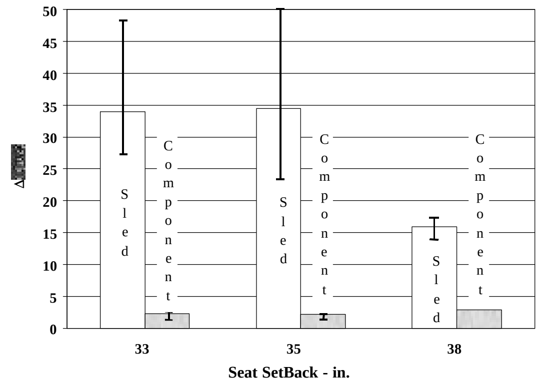
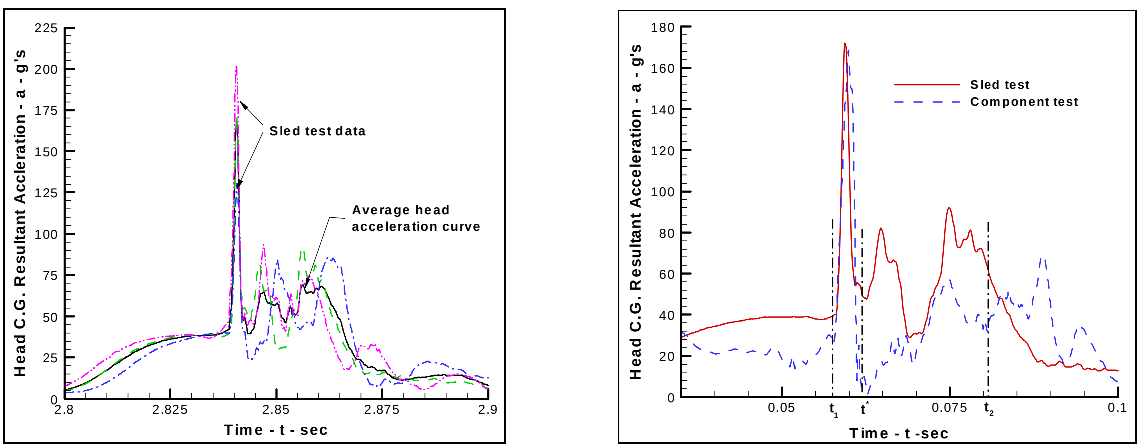


Figure 17 - Comparison of Δt (time window) for sled and component tests

The lack of correlation in the HIC and the head acceleration data is due to longer time intervals identified for the sled tests data. Recall that the time intervals are identified during the maximization of the HIC problem. It can be inferred from the Figure 18, for a seat setback of



Average acceleration function of sled test data Sample head acceleration

Figure 18 - Sample head acceleration plots for 33-in. seat setback

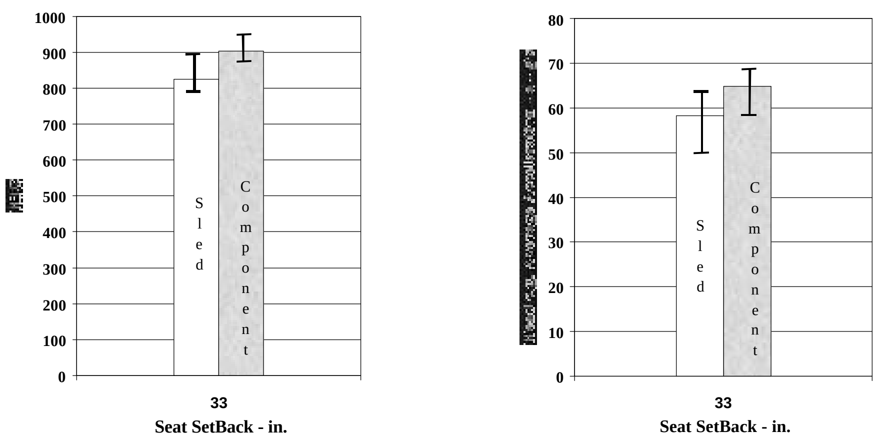
33-in., the character of the acceleration function for the first portion of sled data and the component test data closely agree. Therefore the acceleration function of the sled and the component test data are shifted so that the peak time periods coincide. The average head acceleration for the sled test under similar test conditions is obtained by synchronizing the peak values, as shown in Figure 18. An average of these synchronized functions was then calculated. The HIC for a given component test was then evaluated as

$$\text{HIC} = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \left(\int_{t_1}^{t^*} a(t)dt + \int_{t^*}^{t_2} a_c(t)dt \right) \right\}^{2.5} \right] \tag{2}$$

where t_1 is the initial contact time, t^* is based on engineering judgment followings analysis of the data from each component test, and t_2 is the maximization time from the sled test. The second part of the equation represented by $\int_{t^*}^{t2} a_c(t)dt$ is the component HIC correction factor. The average acceleration is computed by using the expression,

$$\text{Head average acceleration} = \left\{ \frac{1}{(t_2 - t_1)} \left(\int_{t_1}^{t^*} a(t)dt + \int_{t^*}^{t_2} a_c(t)dt \right) \right\} \tag{3}$$

The time intervals for each individual component test are estimated separately for t_1 and t^*. Results for the component tester, computed using this procedure are presented in Figure 19 and are seen to be in agreement with the results from the sled tests.

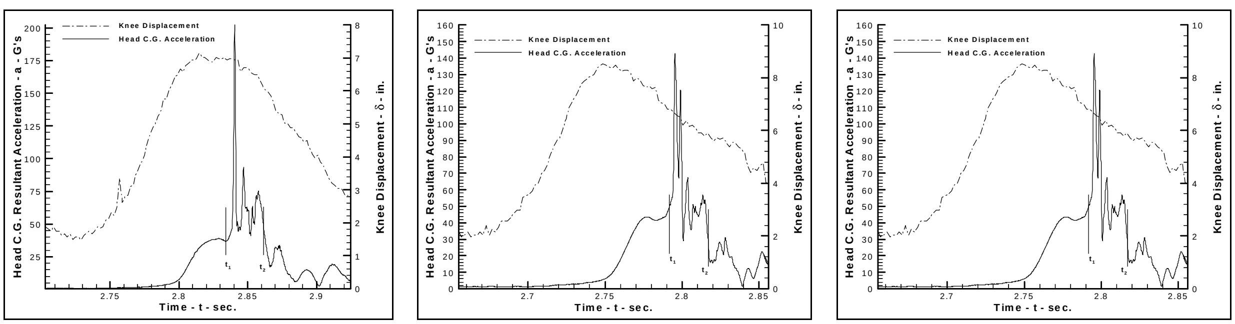


HIC Head average acceleration

Figure 19 - HIC and Head average acceleration for sled and component tests

HIC values measured during a test are sensitive to the orientation of the head during the contact time. This is evident if one compares the head accelerations presented in Figure 13 with the video data for the same time presented in Figures 9 to 11. It was found that the head impact angles for the 33-in., 35-in., and 38-in. seat setbacks averaged 32°, 34°, and 67° respectively. The head impact angles measured from the video data for the sled tests were almost same for both 33-in. and 35-in. seat setbacks. It can be inferred from the Figure 12, that the head struck the bulkhead almost flat, when the seat setback was 33-in. The head impact angle is around 32° in this case. The head contact area is larger but applied to one region of bulkhead, whereas, the head contact occurs over a large area of the bulkhead at the larger seat setback distances. This results in high head deceleration. In case of a larger seat setback, i.e. 38-in., the head of the ATD struck the bulkhead at an angle of 67°. Hence the head contact area is smaller than the corresponding case and the impact energy is not transferred to the bulkhead normally. The head underwent a sliding or glancing motion that helped to dissipate some energy.

The head/neck impactor results for the sled tests and component tests largely agree for the tests with seat setback distances of 33-in and 35-in., but the acceleration profiles for the component test results do not agree with a seat distance of 38-in. A careful review of the video data for these tests revealed a significant difference of the lower torso motion between 7-in to 8-in. Since there was no target point on the lower torso, the knee displacement time history in the longitudinal direction was analyzed. In view of the stiffness of the ATD's femur, their motion was nearly the same. The time history plots of both the knee motion as well as the head acceleration time history for the three seat setbacks are shown in the Figure 20.



33-in. seat setback 35-in. seat setback 38-in. seat setback

Figure 20 - Head and Lower torso motion for different seat setbacks

It can be inferred from these plots that the knee or lower torso moves almost 7-in. to 8-in. in the forward direction. This is also evident in Figures 9 to 11. It is significant to note that there is a phase shift between head acceleration and the knee (lower torso) displacement as the seat setback distance increases. This leads to the possibility that the degradation in the correlation between the component and sled test was due to the fact that the torso and pelvis motion are not accurately reproduced by the component tester.

CONCLUSIONS

The HIC component tester study evaluated the Boeing/MGA Component HIC test apparatus for front-row bulkhead seating configurations. It was shown that the component tester faithfully reproduces the HIC values obtained during dynamic seat tests at 33-in. seat setback distance. The time windows for the HIC calculations are however quite different even though the head acceleration profiles from the sled and component tests are similar at this seat setback distance. A correction factor, based on the baseline sled data, was introduced to address the deficiencies. This correction factor not only improved the correlation for the time interval, but improved the HIC values as well. The component test appears to be a reasonable replacement sled test for shorter setback distances if it is used in conjunction with related sled test data and if the data are reduced using the correction factor identified in the paper. The correlation between the component test results and the sled test results deteriorate as the setback distance increases to 35-in. and is unacceptable at 38-in. It was concluded from analyses of these data that the degradation in component test performance was due to the effect of the torso and pelvis motion of the ATD during the sled tests, whereas in the component tests, the pelvis is fixed at one point and the lower translation is fixed. It is clear from the results of this study that the present component test design is better suited for tests at shorter seat setback distances.

The scope of the current study was limited to HIC problems associated with front-row seating of occupants who are restrained by two-point lap belts and facing soft energy-absorbing bulkheads. The study also did not address similar problems encountered in the design of smaller aircraft that must use three-point restraints. Similarly, it did not address the row-to-row HIC problem commonly encountered during the certification of airline seats. All of these problems are important and should be considered during future studies. Most importantly, the development of a robust component tester that faithfully reproduces front-row bulkhead and row-to-row transport seating problem should be pursued.

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