A Component Head Injury Criteria Tester for Aerospace Applications

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Problem Statement

- The compliance with the Head Injury Criteria (HIC) poses a significant problem for aerospace industry

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

Where, a(t) is the head resultant acceleration of the Part 572 Hybrid II ATD in g's and t_1 and t_2 are the response times to maximize the function.

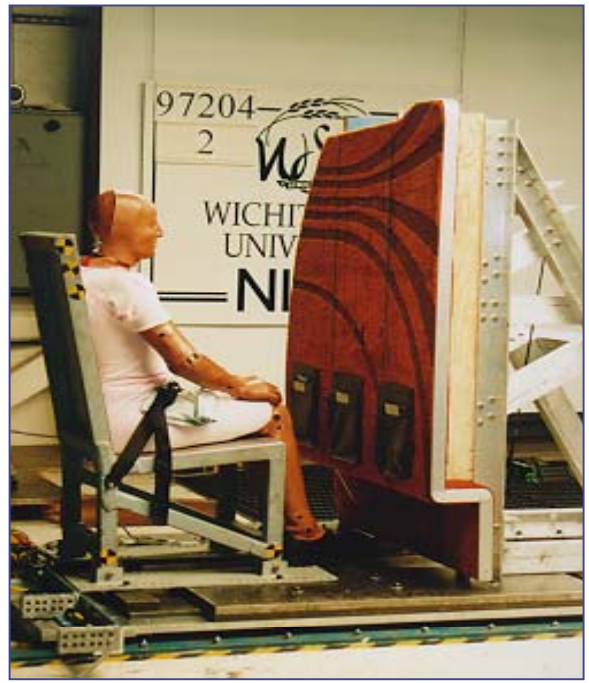
Non injurious if: HIC < 1000

- HIC problem encountered in:

Bulkhead	Class Dividers
Cabin Furnishings	Cockpit Glare Shields
Cabin Side Walls	Row-to-Row
Instrument Panel	Entry Door Steps
Wind Screen Posts/Side Posts	

Problems Related To Dynamic Full-scale Sled Tests

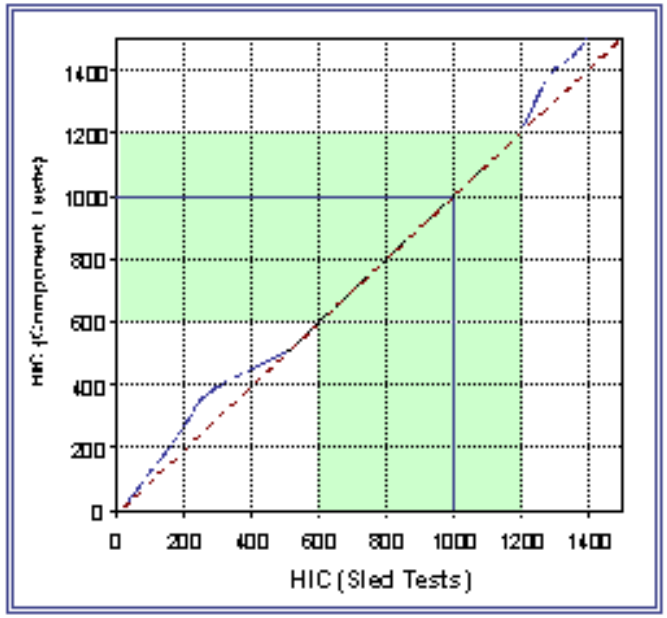
- Difficult to identify and test the critical conditions
- Several test articles are destroyed to certify one test condition
- Require large flow time
- Inherent variations in sled test data may result in excessive HIC scatter
- Associated with significant cost



Component Level Testers

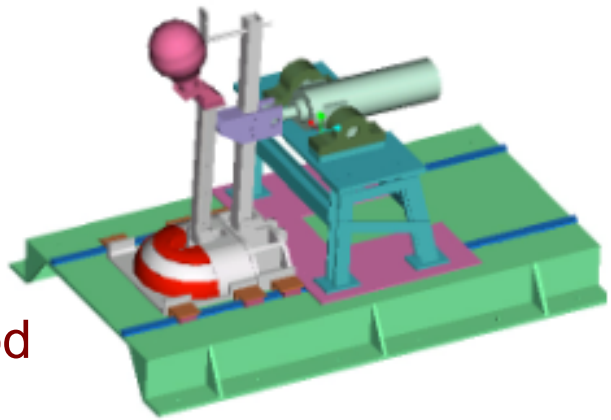
Advantages

- Easier to setup
- Shorter flow time
- Effective product development tool
- Cost effective
- Appropriate for identifying critical impact location(s)



Validation Criteria

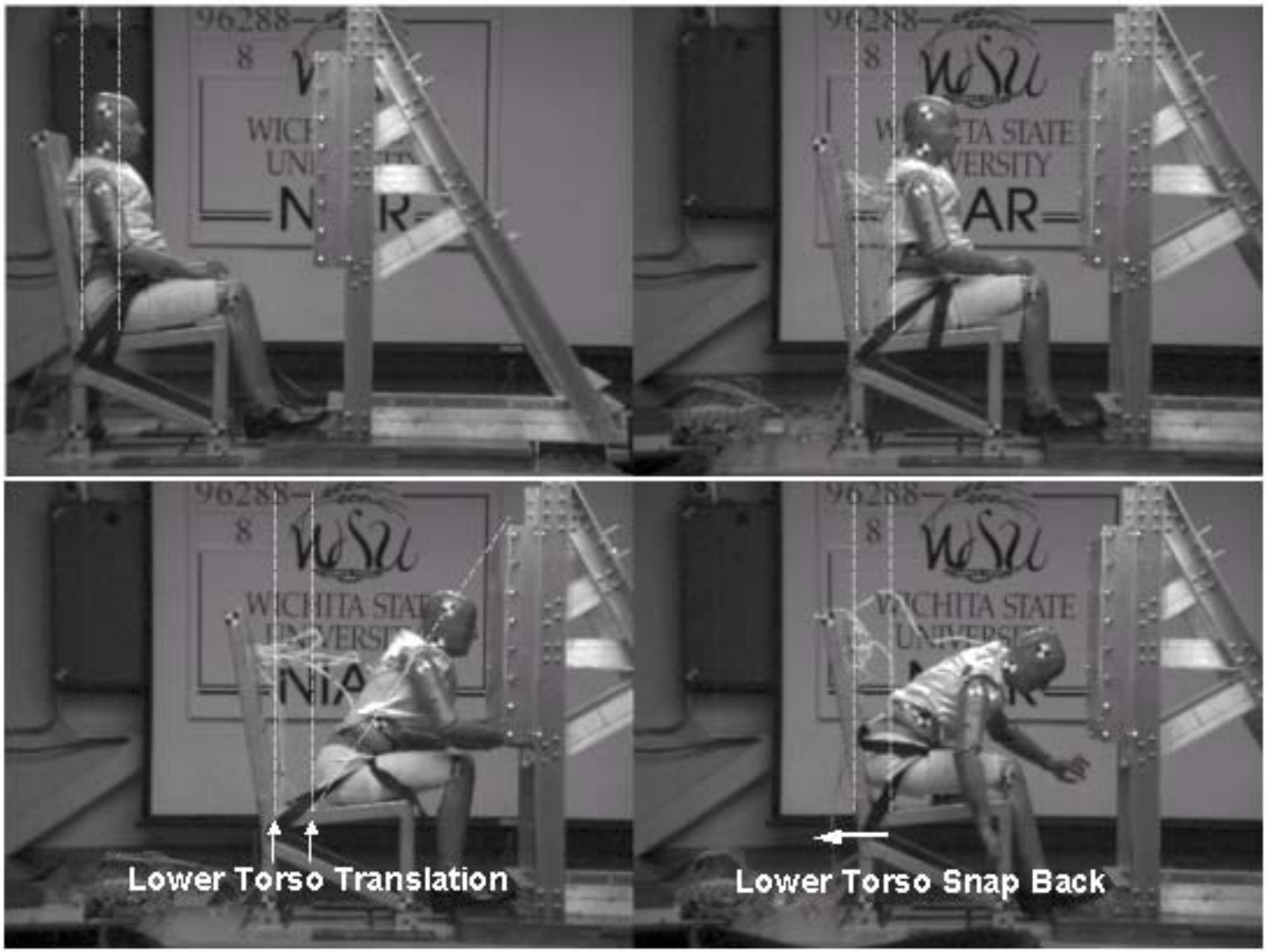
- HIC
- HIC window, $\Delta t = t_2 - t_1$
- Average head C.G. acceleration
- General form of the head acceleration time history



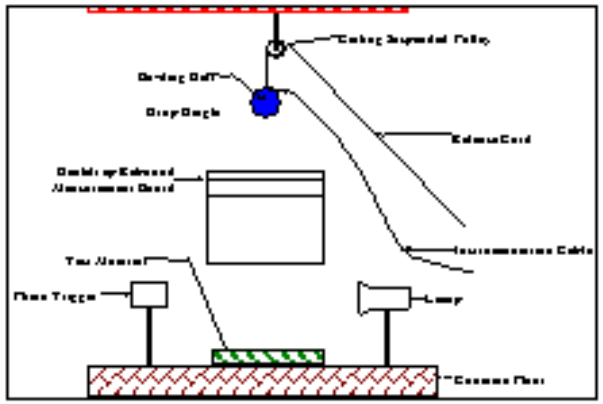
Goal

- Develop an enhanced component test method as an alternate procedure to support HIC compliance for front row bulkhead seating

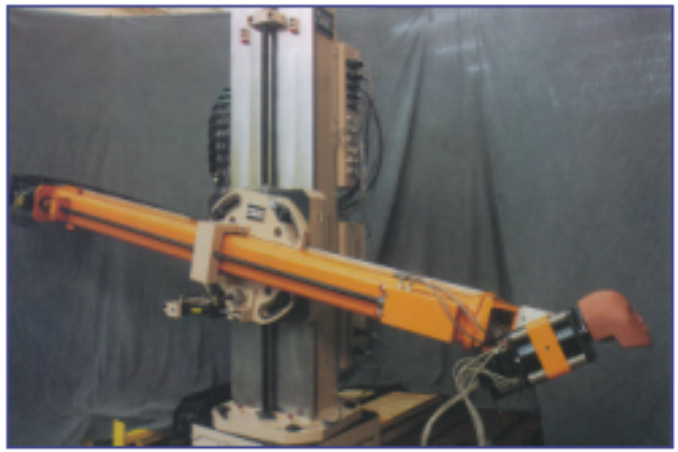
ATD Kinematics During a 16g Dynamic Test



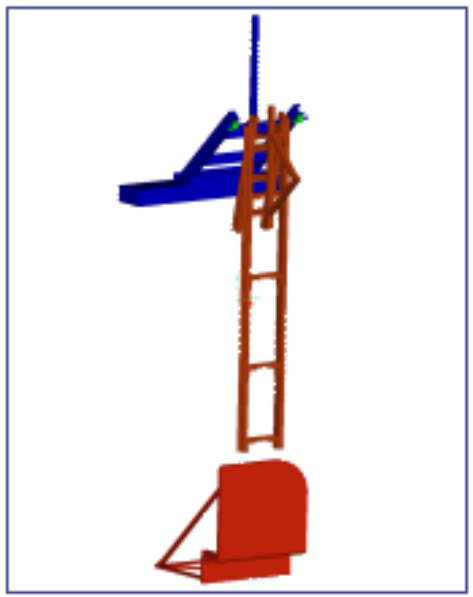
Component HIC Test Devices



Bowling Ball Tester



Free Motion Head Form



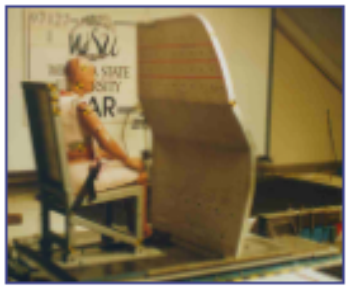
NIAR's Pendulum Test Rig

MGA Head/Neck Impactor

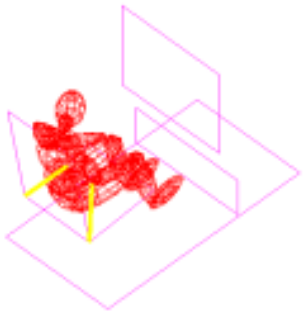
Evaluation of Component HIC Test Devices

- The component HIC test devices provide reasonable correlation compared with the 16g dynamic full-scale sled tests only for
  - Configurations with dominantly normal head impact velocity (short distances to impact surface)
  - Relatively short duration impacts(relatively hard surfaces)
  - Properly utilized system effective masses
- Factors affecting these differences may include:
  - articulation of other body segments for the ATD
  - belt compliance & motion (translation) of the pelvis
  - friction of the pelvic/seat and head/frontal-structure
- The HIC window $\triangle t = t_2 - t_1$ is usually much smaller for all the component HIC testers compared to the results from dynamic sled tests

Methodology

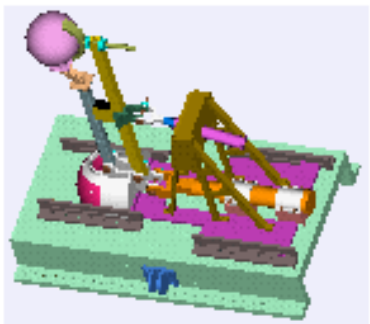


Analyze full-scale sled test data

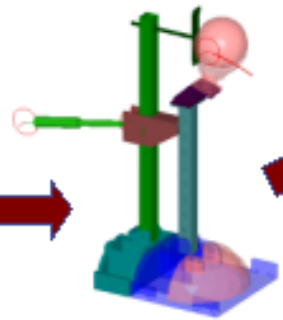


Analyze ATD kinematics through biodynamic simulations

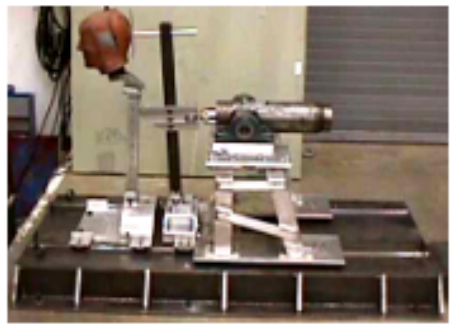
Create biodynamic model and refine the design



Design the component HIC Tester



Analytical Modeling

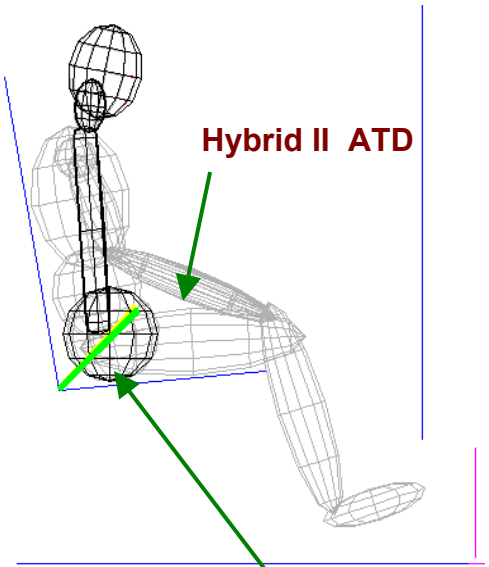


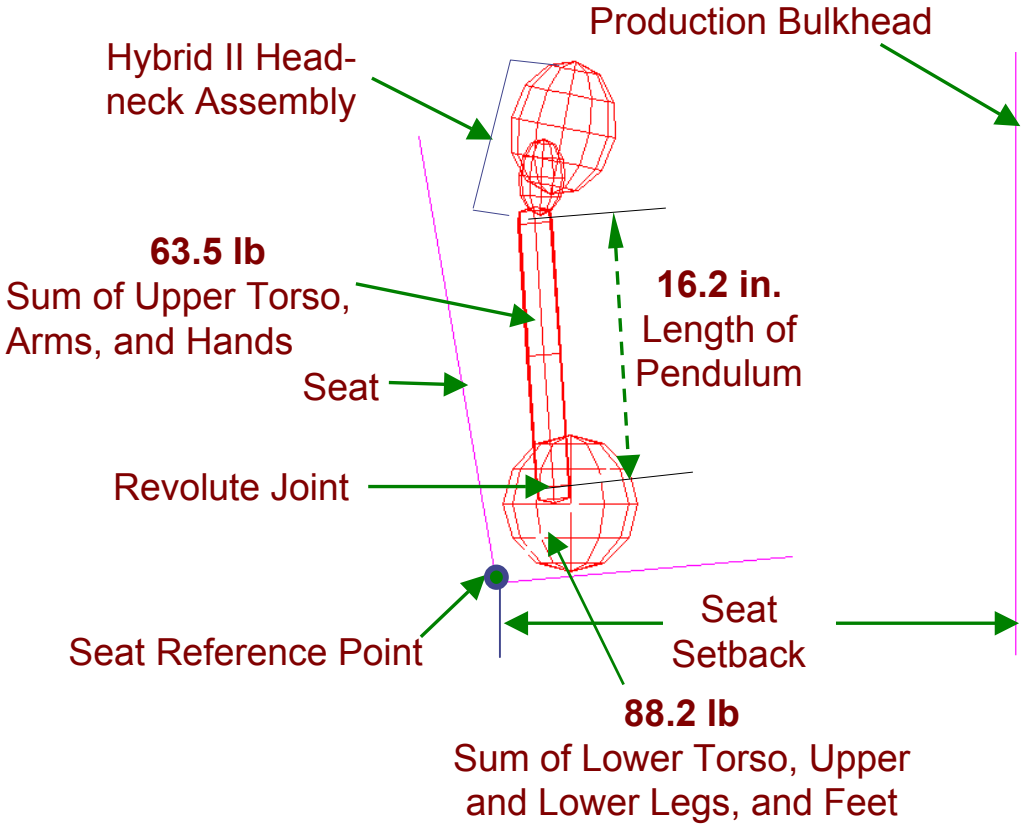
Fabricate Component HIC Tester

Develop a Propulsion System

Test and Validate the Component Tester

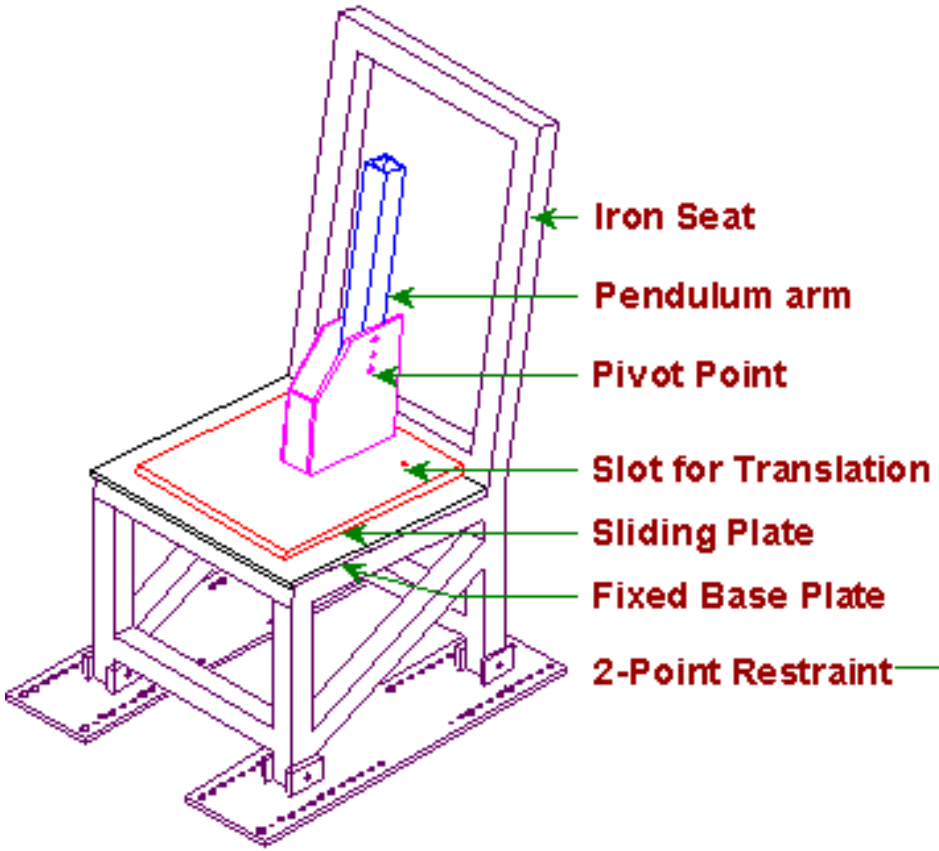
Design of an Inverted Pendulum Device

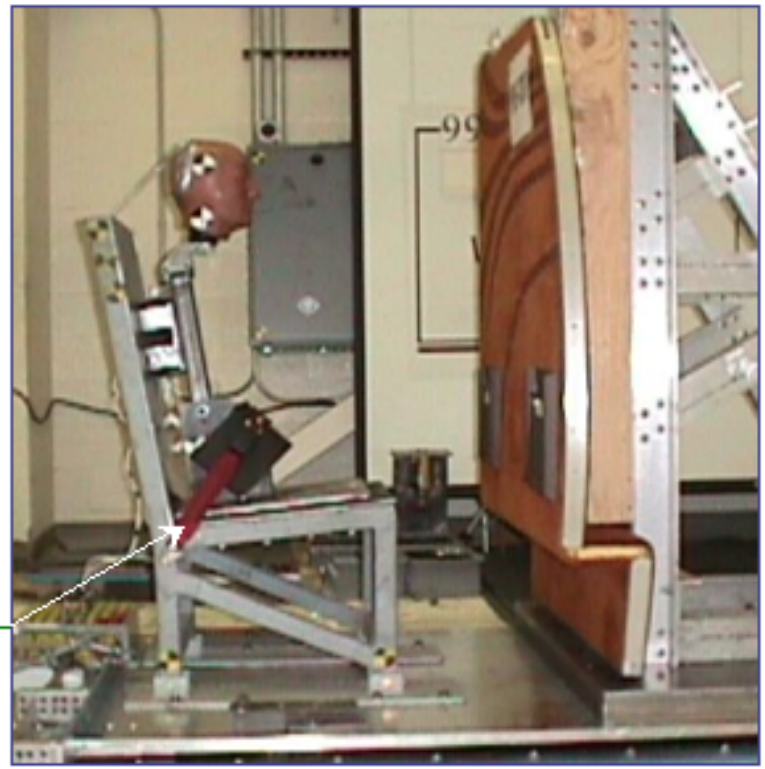




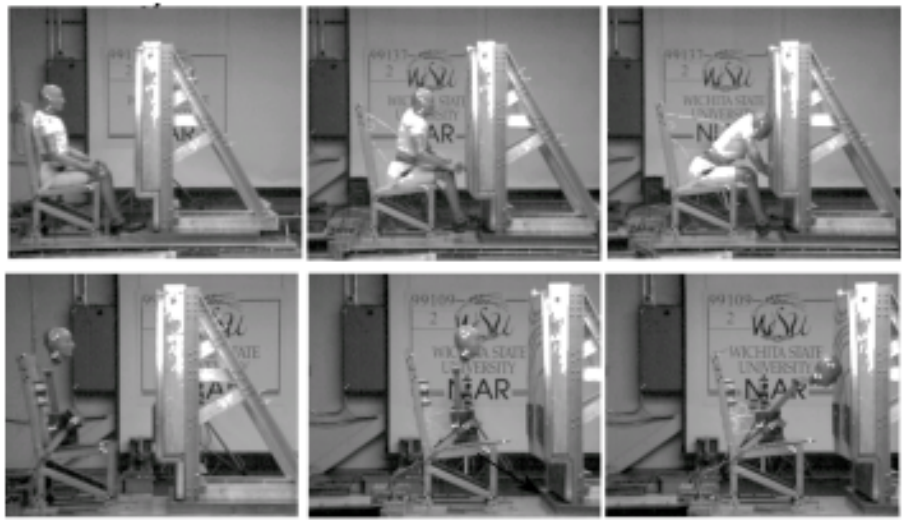
Full-scale Model → **Inverted Pendulum Model**

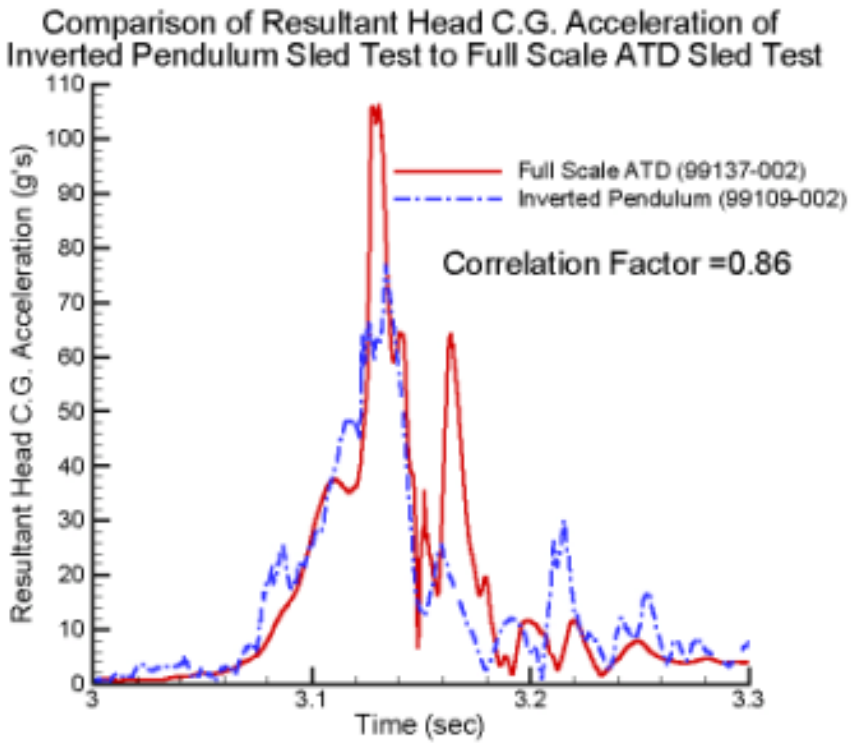
Qualification Test with Inverted Pendulum Setup





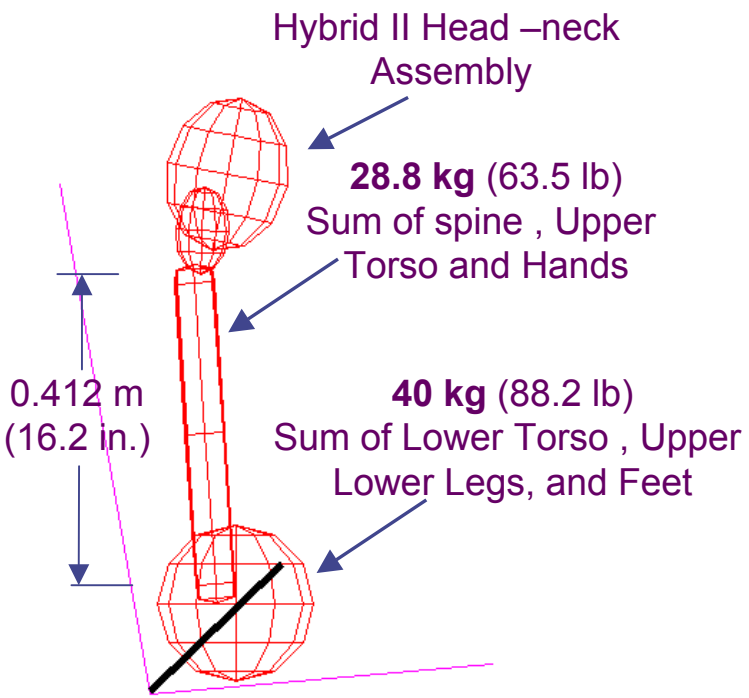
Comparison of Results



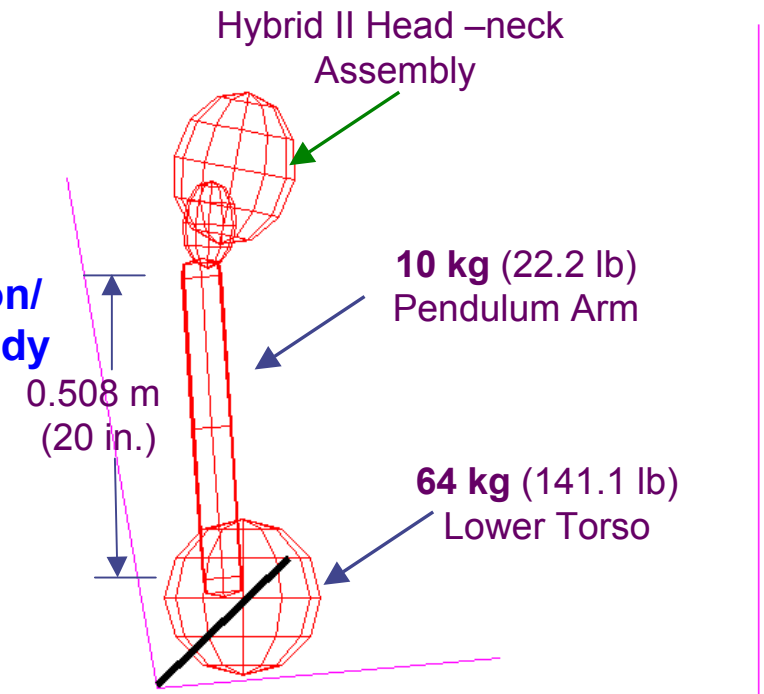


Results	Inverted Pendulum	Hybrid II
Head Impact Angle (deg)	52	50
Head Velocity at Time of Impact (ft/sec)	46.2	41.7
Head Peak Resultant acceleration (g's)	77	106
Average Acceleration (g's)	41	47
HIC	810	1088
Δt (ms)	38	70

Adjustments in Design Based on Madymo Analysis



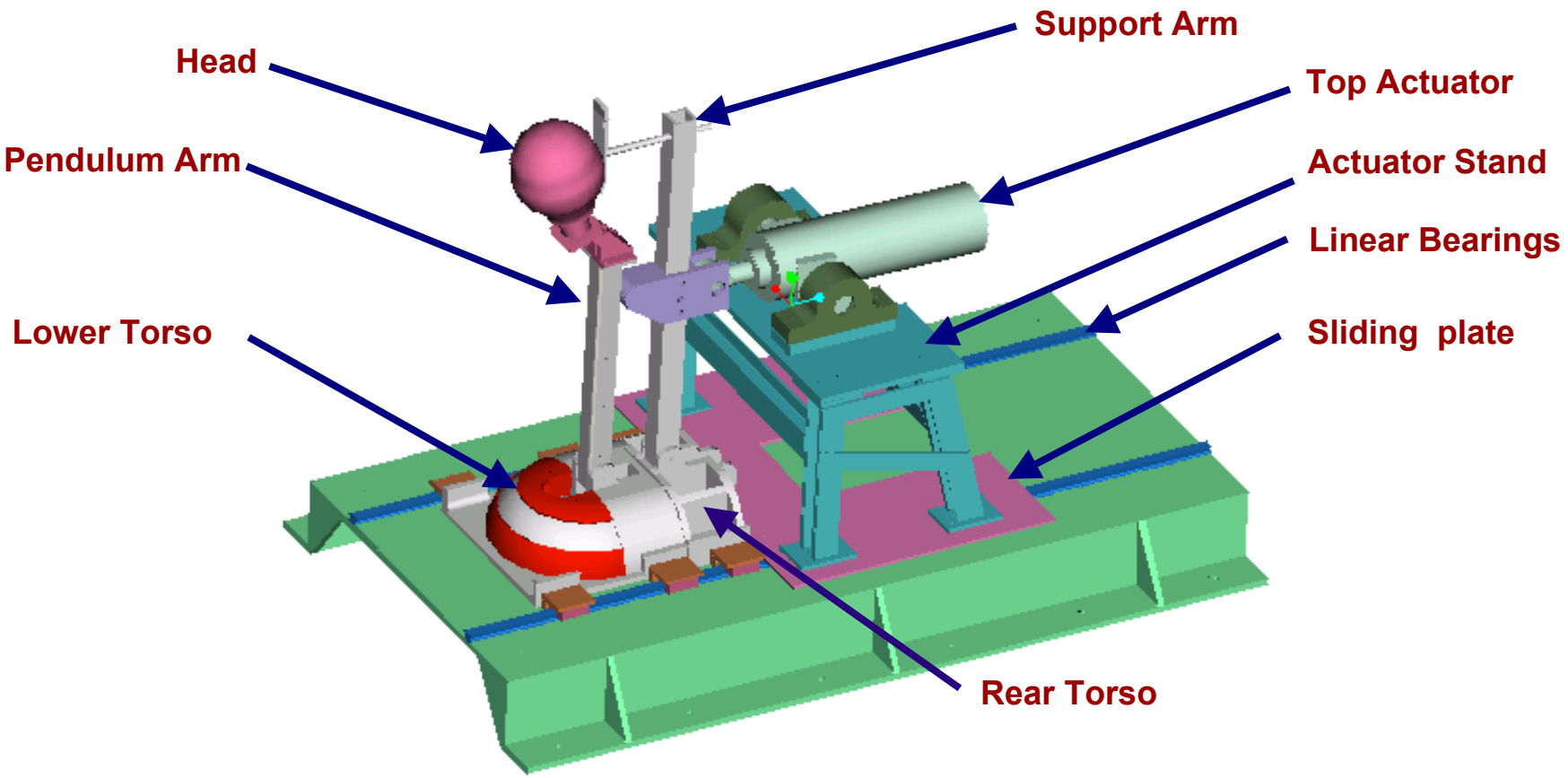
Design Iteration/ Parametric Study



Initial design based on ATD weight distribution.

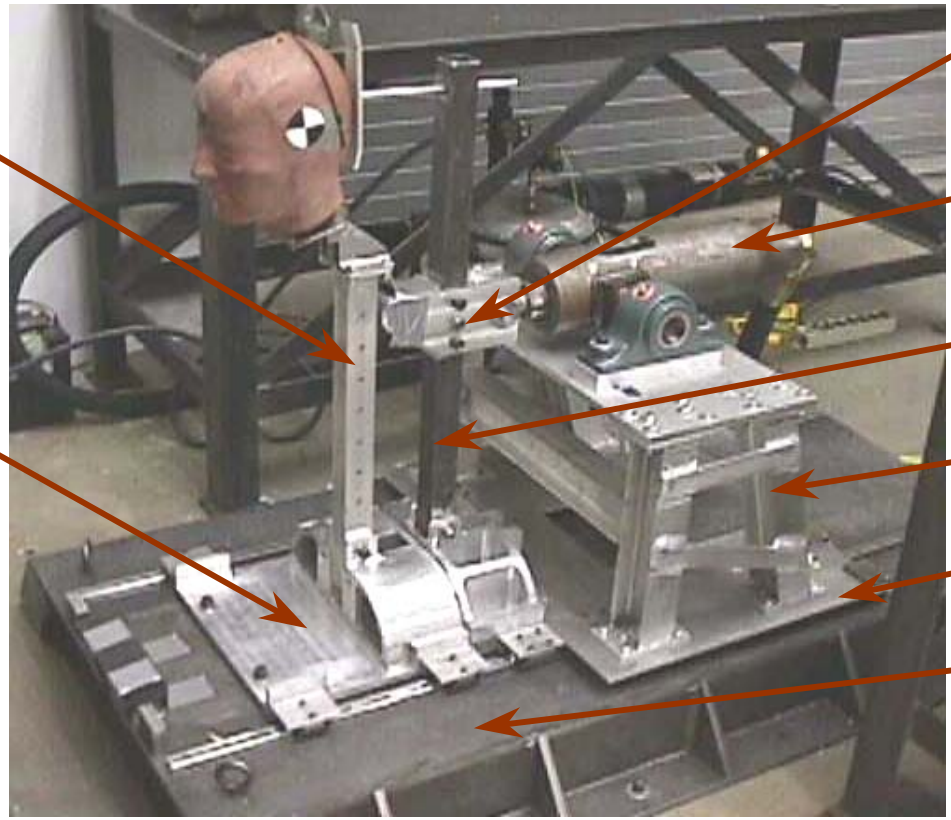
Weight distribution based on Madymo analysis.

Final Design of the Component HIC Tester

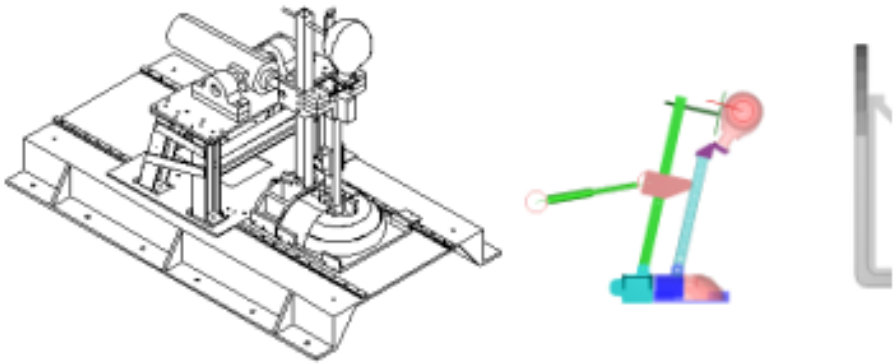


ProEngineer Model of Component HIC Tester

Fabricated Component HIC Tester

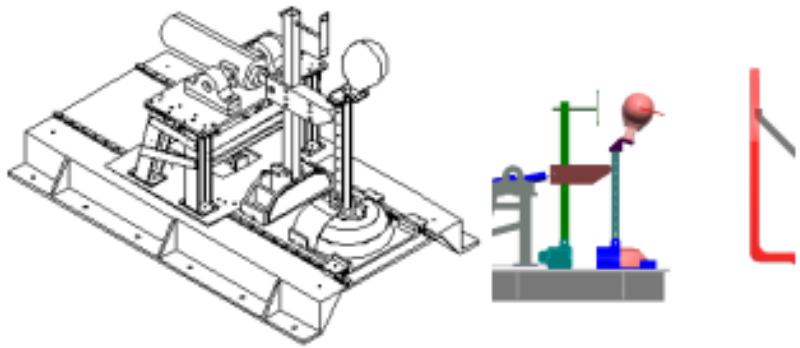


Operation of NIAR's Component HIC Tester



Mode:1

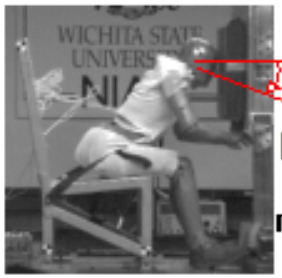
- Fixed lower torso (similar to MGA device)
- Operated only by top actuator



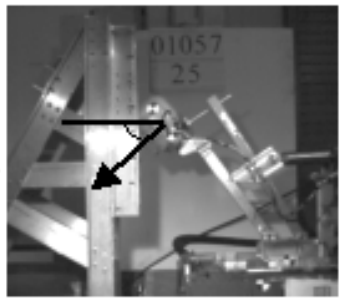
Mode:2

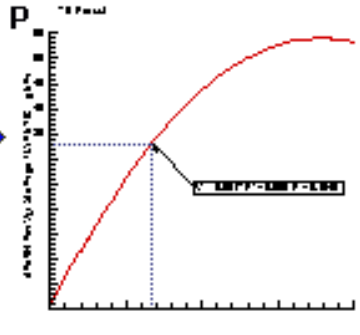
- Lower torso constrained in the forward direction
- Lower torso allowed to snap backward at the time of impact and resisted by springs/dampers, or crushable honeycomb
- Operated only by top actuator

Operating Methodology of Component HIC Tester

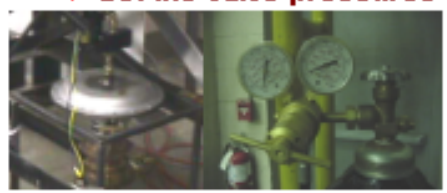


Obtain required data





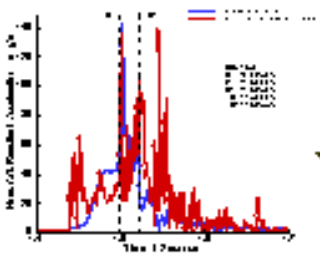
- Conduct baseline dynamic sled test
- Fix the required bulkhead and set the required head impact angle and impact location
- Select the actuator pressure for the required head velocity from the calibration chart
- Set the pressure in nitrogen bottle
- Set the valve pressures



- Set the data acquisition system(DAS) and video capturing devices

Data Transmission

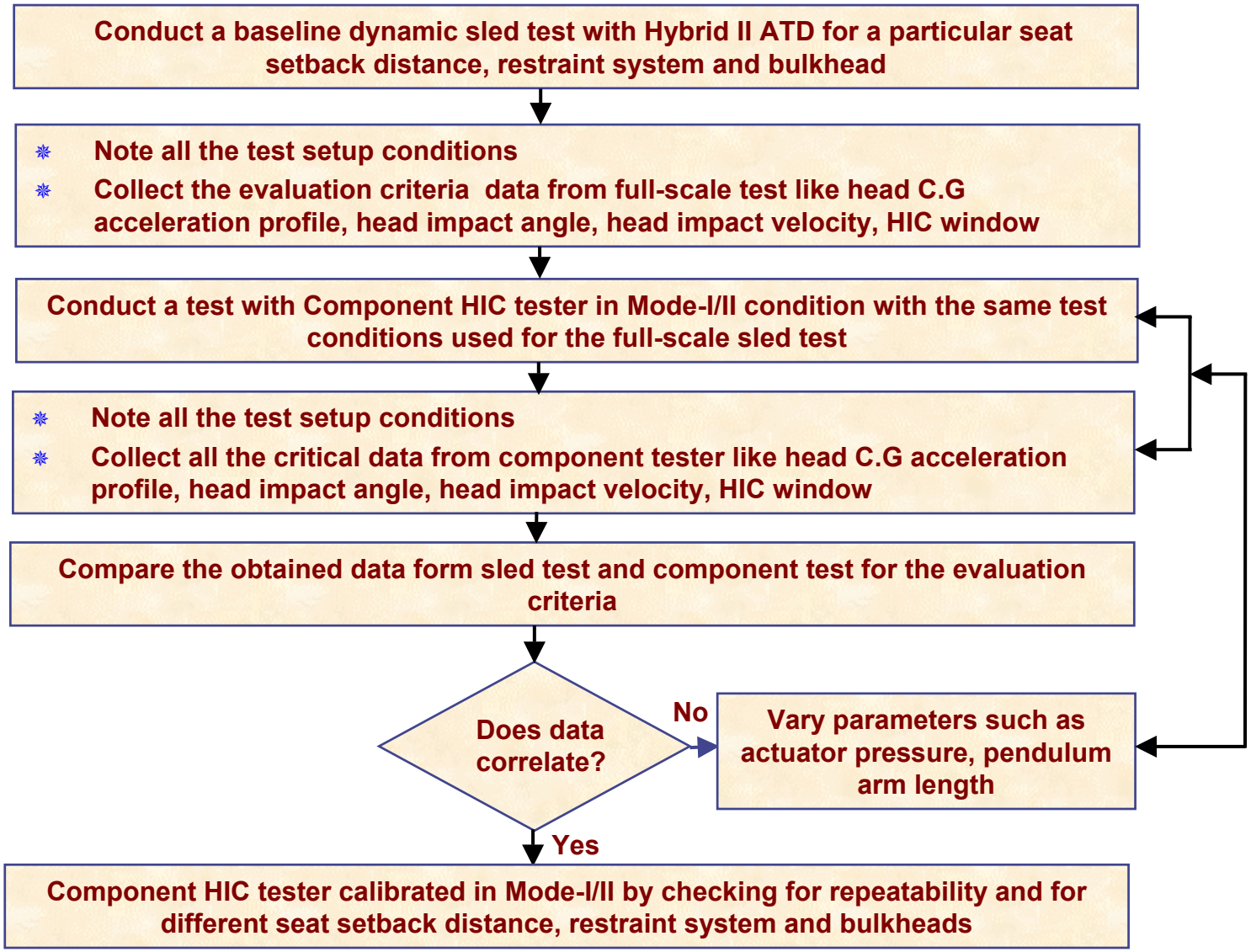
- Generate a trigger and perform the test



Obtain results from DAS

Correlate with full-scale sled test

Component HIC Test Methodology – Flow Chart

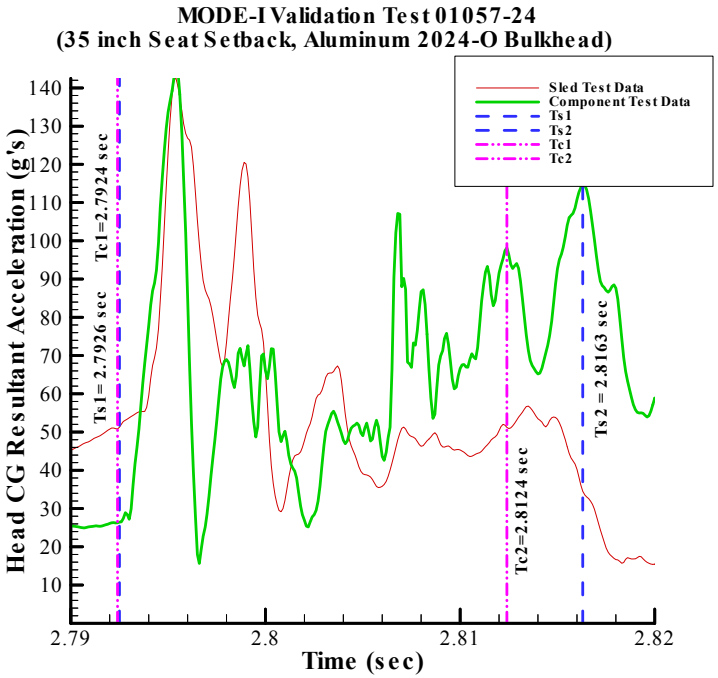


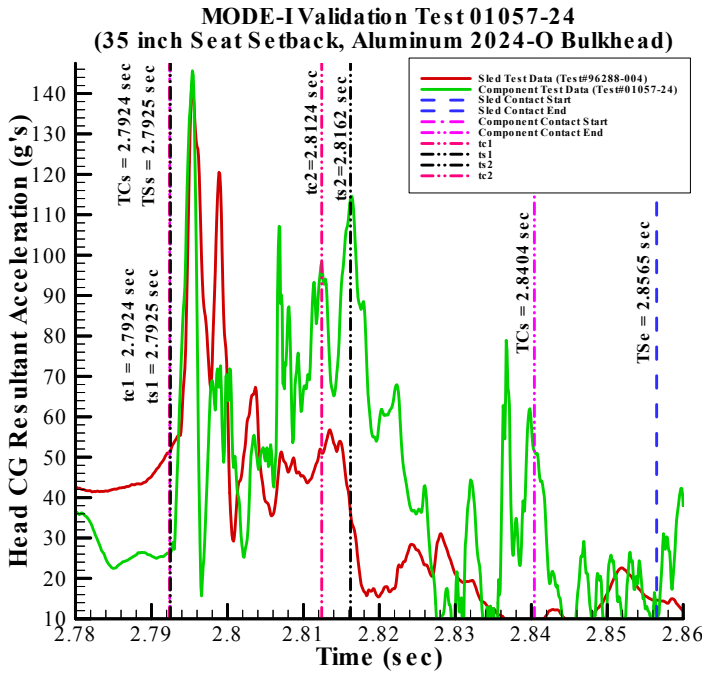
MODE-I: Calibration Tests with Aluminum Bulkhead

Full-Scale Sled Test#96288-004

Calibration Test#01057-25

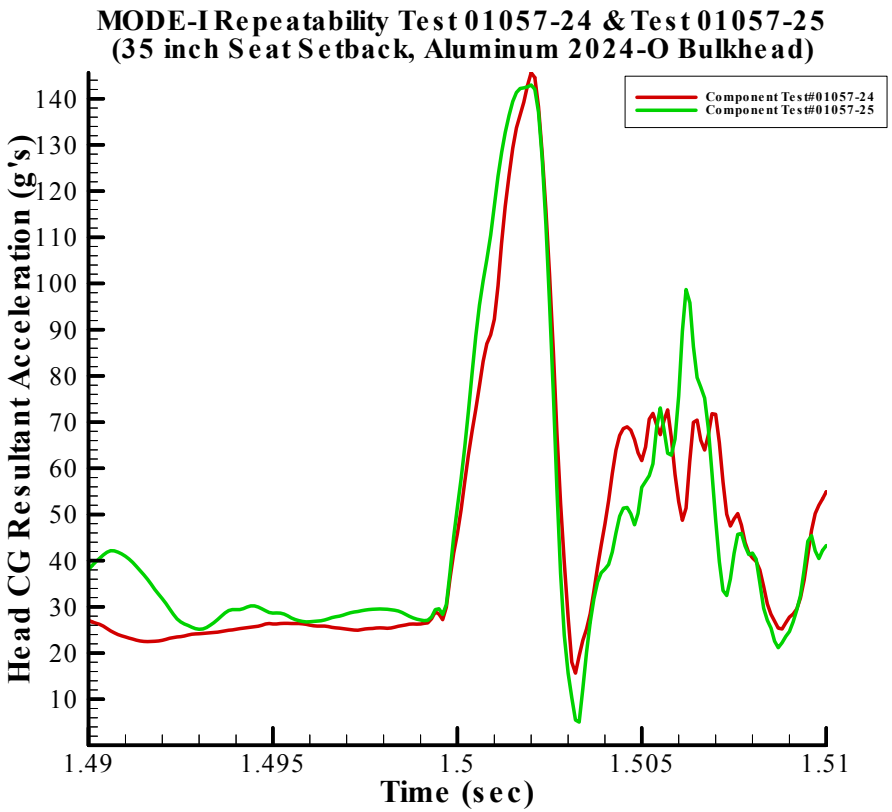
Calibration of MODE-I Tests with Full-Scale Sled Test

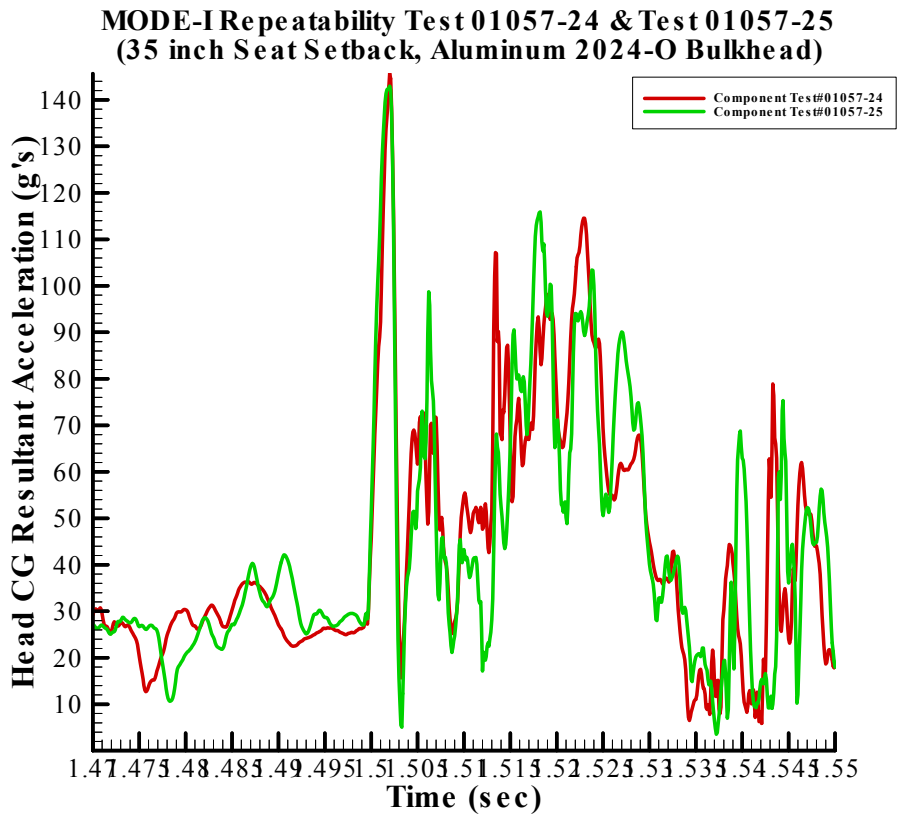




Description	Full-Scale Test#96288-004	Comp*HIC* Test#01057-24	Comp*HIC* Test#01057-25
HIC	694	676	703
Head impact angle (deg)	38	37	37.5
Head impact velocity (fps)	45.1	41.0	44.0
HIC window (ms)	23.7	20.0	22.5
Head CG peak acceleration (g's)	142.5	145.0	142.9
Head CG average acceleration (g's)	61.0	64.0	62.5

MODE-I Repeatability





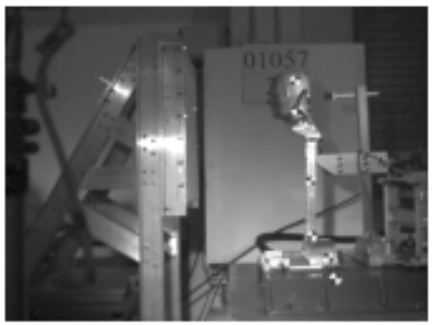
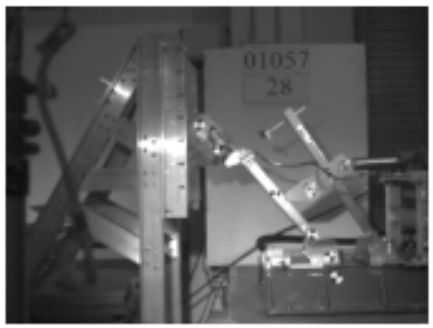
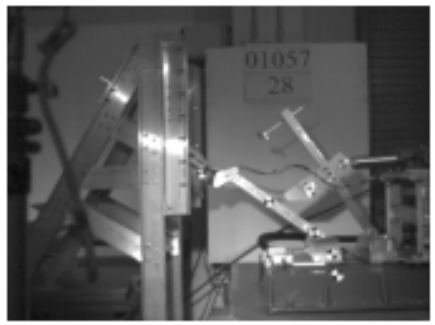
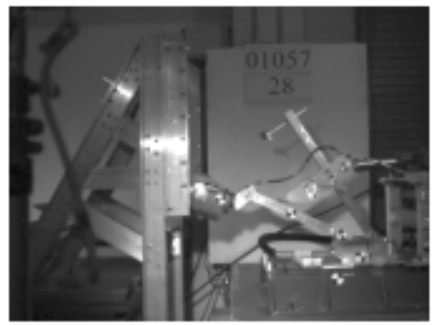
Repeatability Plot

MODE-II: Calibration Tests with Aluminum Bulkhead

Full-Scale Sled Test#96288-004

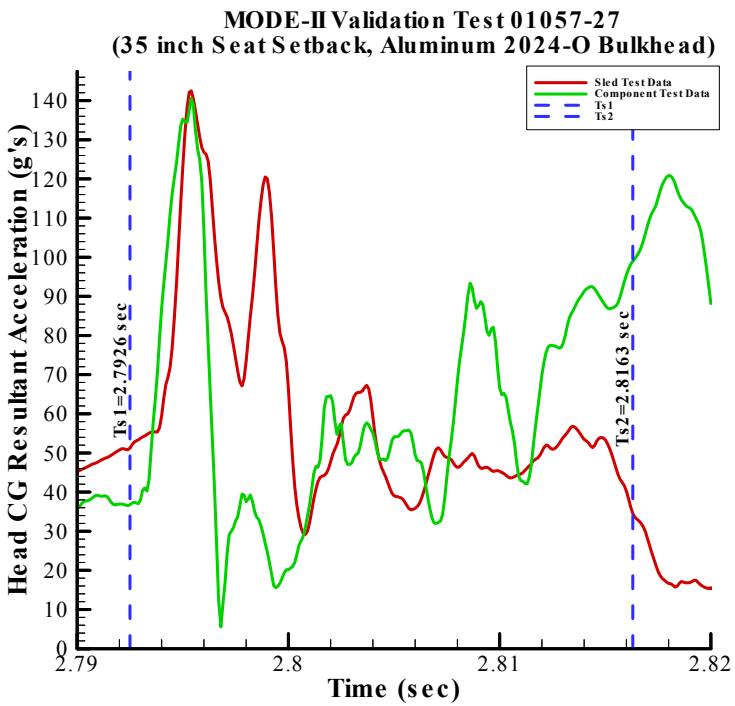


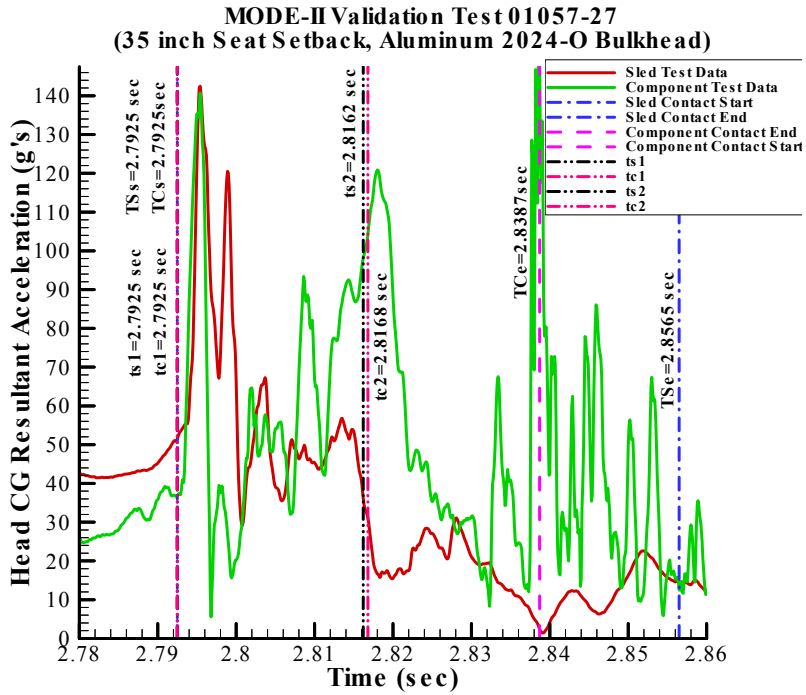


Calibration Test#01057-28

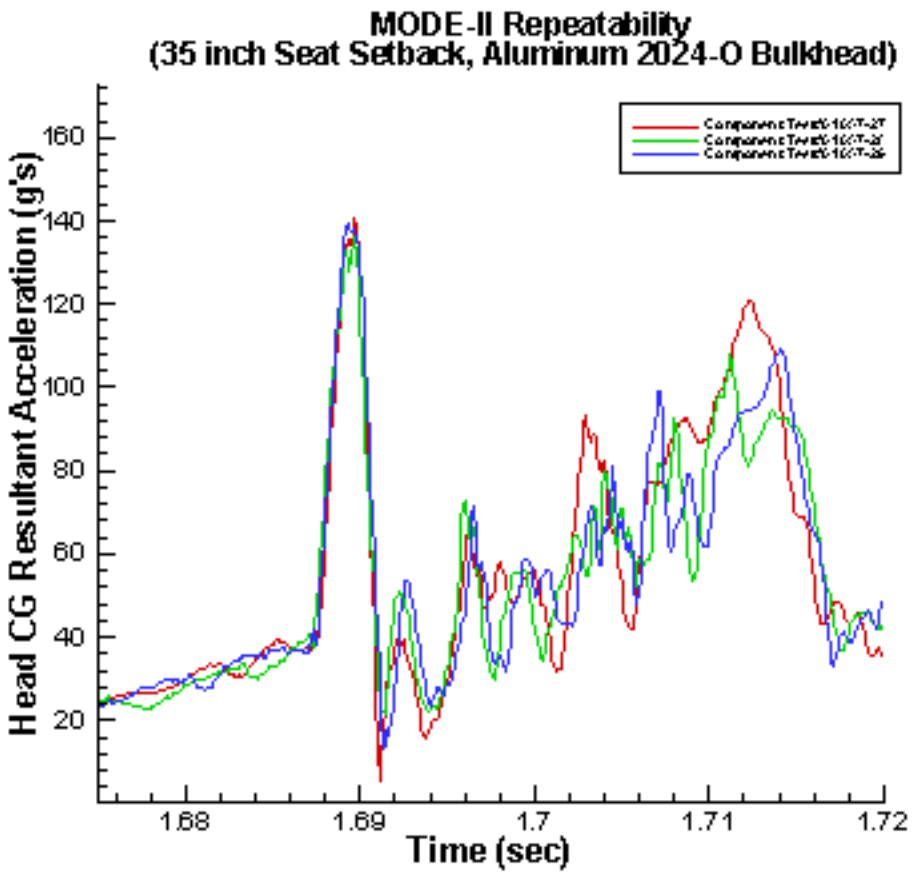
Calibration of MODE-II Tests with Full-Scale Sled Test

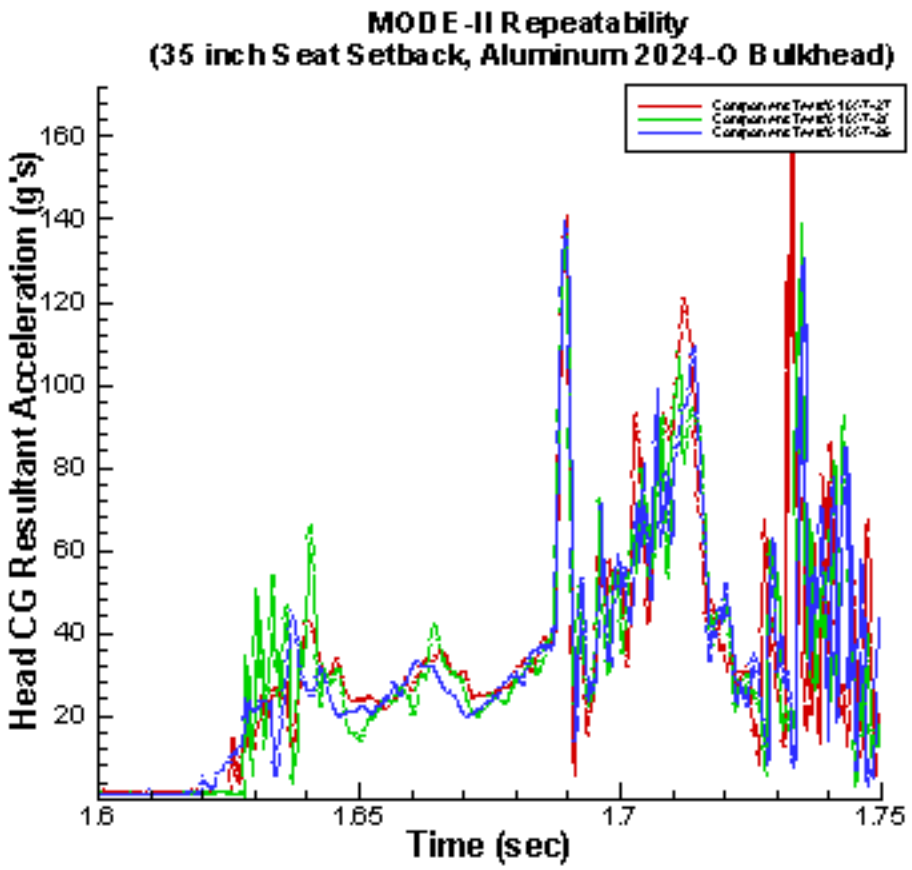




Description	Full-Scale Test#96288-004	Comp*HIC* Test#01057-27	Comp*HIC* Test#01057-29
HIC	694	677	700
Head impact angle (deg)	38	38	37
Head impact velocity (fps)	45	46	46
HIC window (ms)	23.7	24.3	29
Head CG peak acceleration (g's)	142.5	142	139
Head CG average acceleration (g's)	61 g	65.7	60

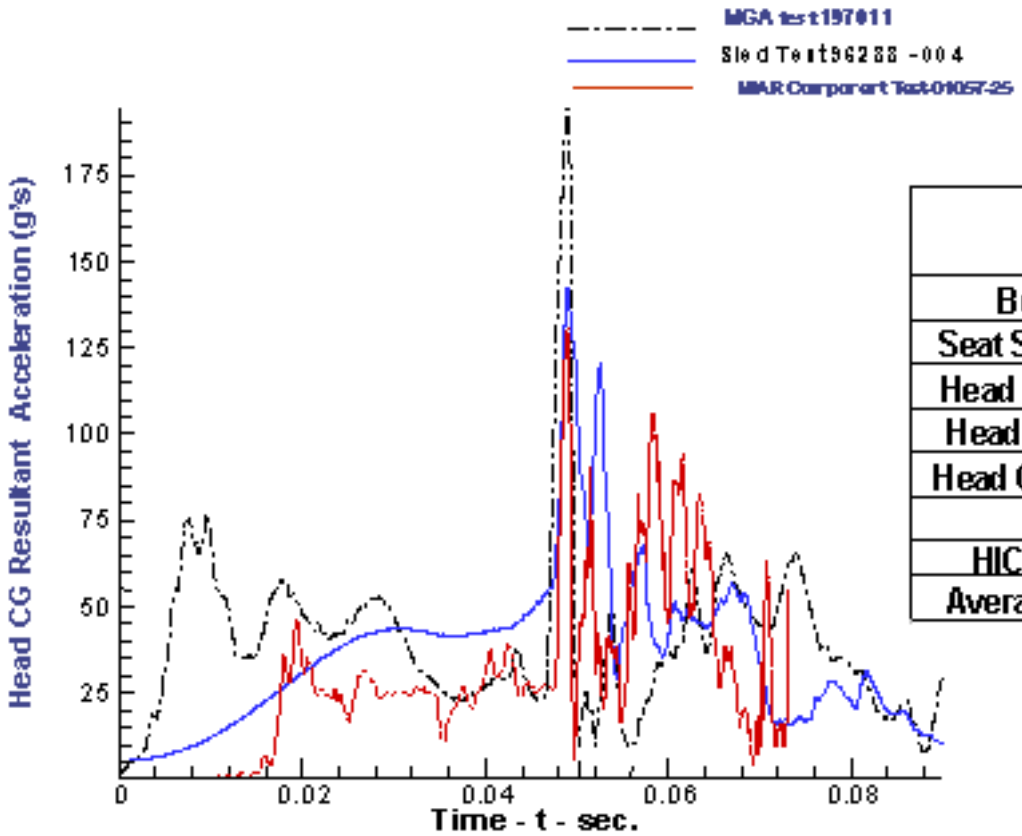
MODE-II Repeatability

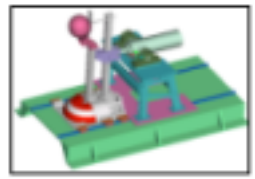


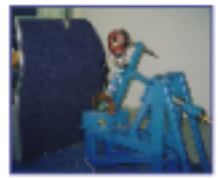


Repeatability Plot

Comparison Of The Component HIC Test Data With MGA Test





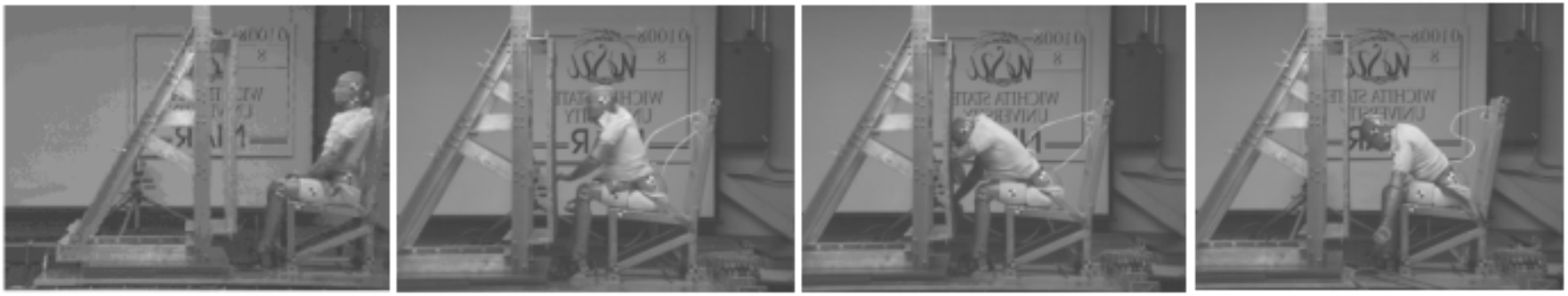


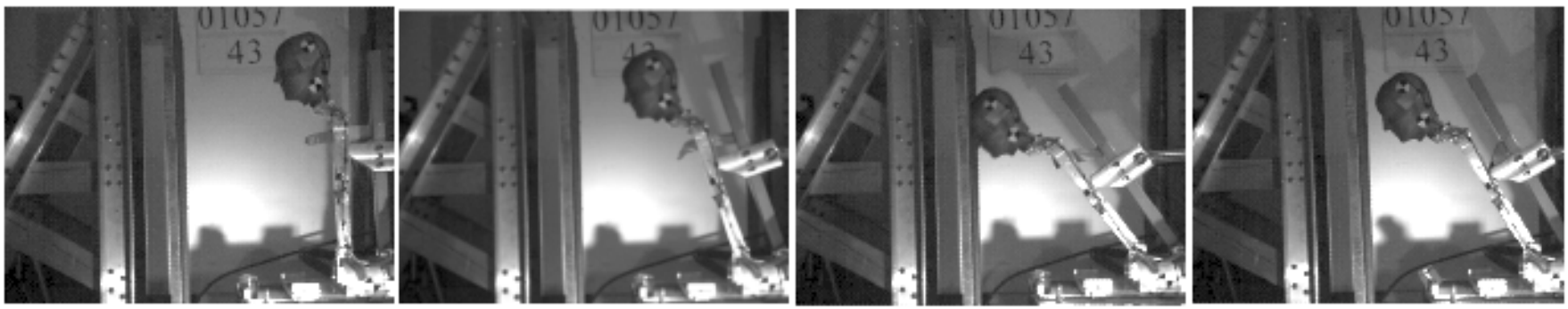
PARAMETER	SLED 96288-04	01057-25 Model	197011 MGA
Bulkhead Material	AL2024 -O	AL2024-O	AL2024-O
Seat Setback Distance - in	35	35	35
Head Impact Velocity –ft/s	45.1	44.0	42.9
Head Impact Angle – deg	38	38	38
Head C.G. Peak Accel – g's	142.5	142.9	204.0
HIC	694	685	783
HIC Window (Dt) - ms	23.7	21.4	2.2
Average Head Accel –g's	61	63	NA

CORRELATION OF MGA TEST 197011 AND NIAR ENHANCED COMPONENT HIC TEST 01057-25 WITH SLED TEST

MODE-I: Calibration Tests with Honeycomb Bulkhead

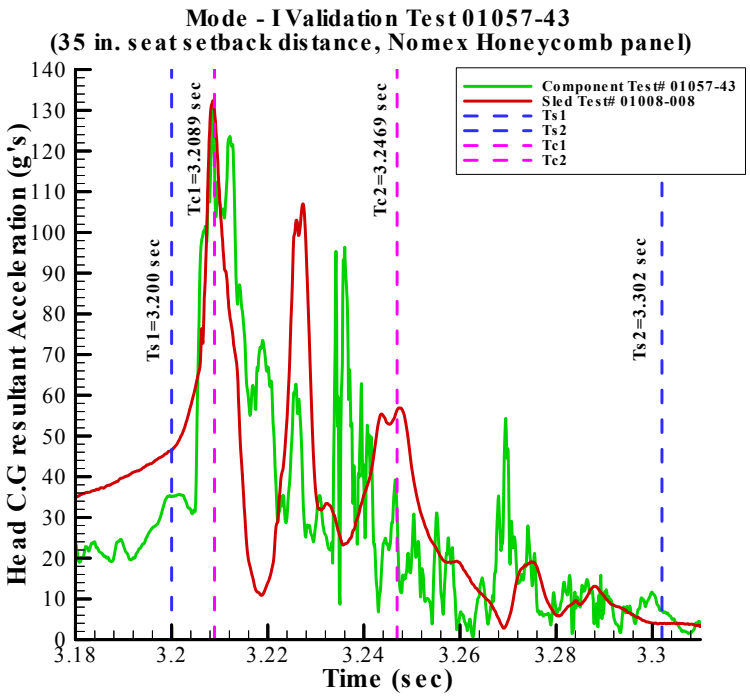
Full-Scale Sled Test# 01008-008

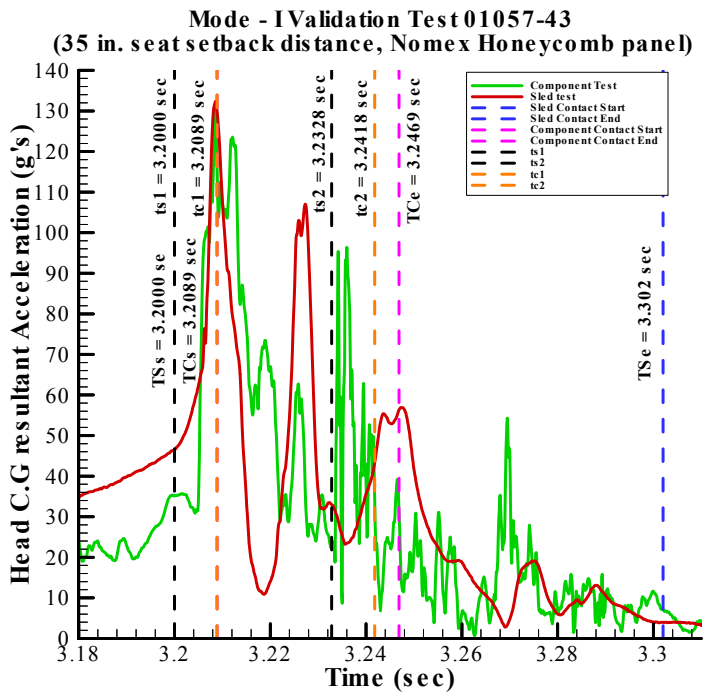




Calibration Test# 01057-43

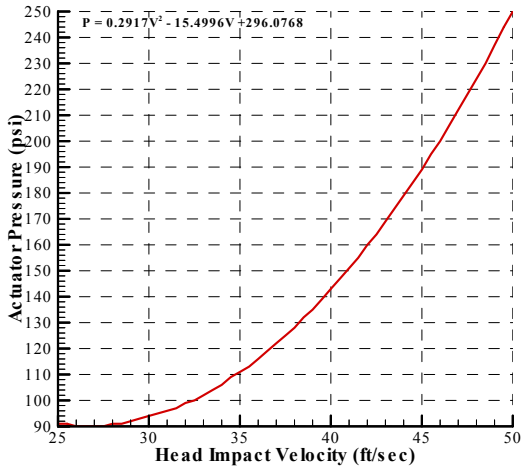
MODE-I: Calibration Tests with Honeycomb Bulkhead



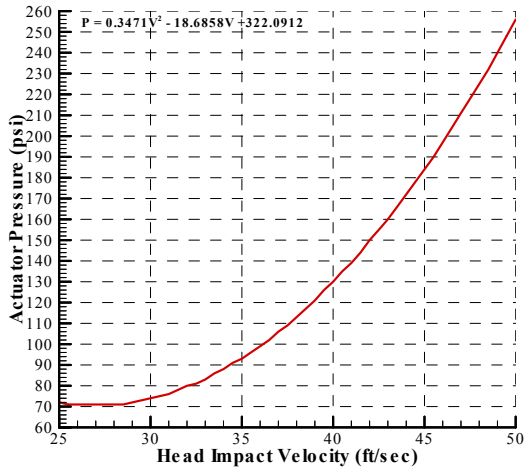


Description	Full-Scale Test#01008-008	Comp*HIC* Test#01057-43	Comp*HIC* Test#01057-44
HIC	862	834	980
Head impact angle (deg)	38	38	38
Head impact velocity (fps)	44.0	40.3	41.0
HIC window (ms)	28.7	32.9	31.8
Head CG peak acceleration (g's)	132.3	131.0	134.0
Head CG average acceleration (g's)	61.0	58.0	62.5

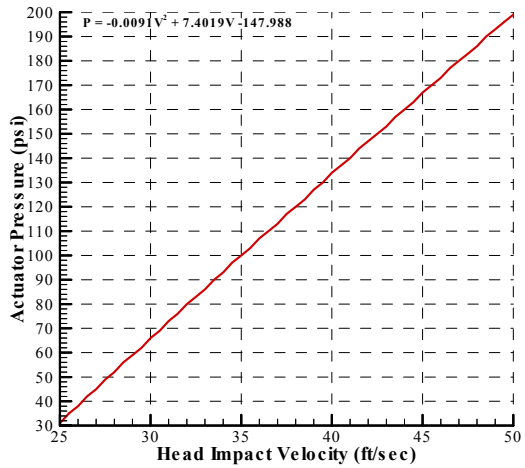
Pressure – Velocity Calibration Charts



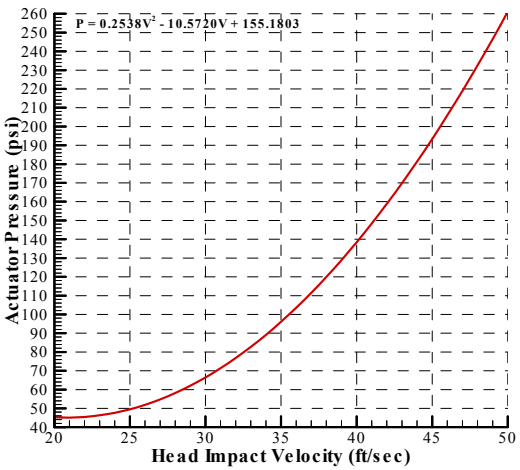
35 degrees



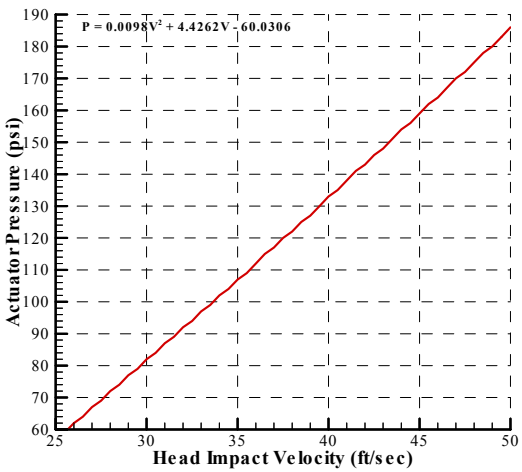
40 degrees



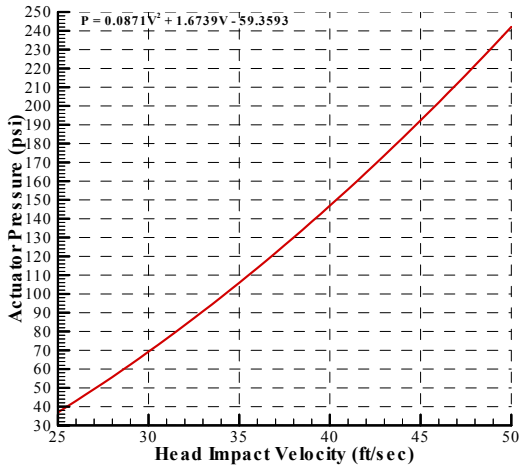
45 degrees



50 degrees



55 degrees



60 degrees

Concluding Remarks

- A component HIC tester was designed, fabricated and tested for aerospace applications.
- Calibration of the device was conducted for aluminum and honeycomb-type bulkheads.
- Preliminary tests of the NIAR component HIC tester have shown promising results.
- Pressure-velocity calibration charts have been developed. The charts are independent of the physical characteristics and surface treatment of the bulkhead.
- Preliminary tests with aluminum bulkheads at small and large seat setback distances have indicated that the device can be used with reasonably good correlation in Mode-1 for small head impact angles (less than 40 degrees) and in Mode-II for high head impact angles (greater than 40 degrees).
- The system will be enhanced to have a representation of the upper torso restraint system or at least calibrated for the presence of the upper torso system.

Concluding Remarks

- A range of impact angles and velocities from the dynamic sled tests will be used for calibration of the device.
- The system will also be evaluated for the seating configurations utilizing typical airline seats rather than iron seats.
- Other bulkhead types and surface treatments will also be considered and the system will be evaluated for these bulkhead types.
- The system will also be calibrated for Part 23 applications.
- Project will deliver a tool that can be utilized to easily identify potential solutions for bulkhead HIC problem.
- The component HIC tester will offer the capability of evaluating different designs and/or test conditions at relatively low cost and short period of time.
- Detailed test methodology and guidelines for the use of the system as an eventual compliance test method is being developed.