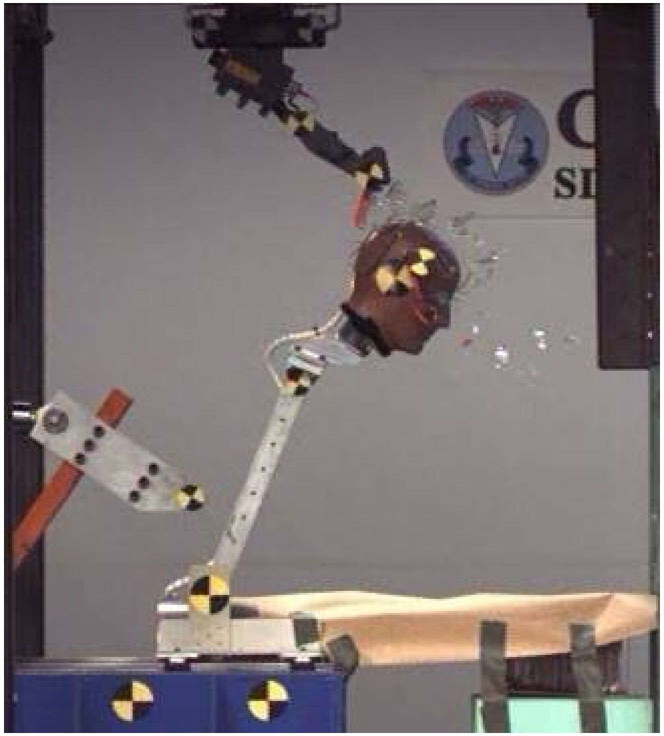
Use of a Head Component Tester to Evaluate the Injury Potential of an Aircraft Head-Up Display

Federal Aviation Administration



Presented to: **The Sixth Triennial International Aviation Fire and Cabin Safety Research Conference**

By: **Rick DeWeese**

FAA Civil Aerospace Medical Institute

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Introduction

14 CFR 25.785 contains several very broadly defined safety requirements. In one part, it requires that seats:

"(b) …must be designed so that a person making proper use of these facilities will not suffer serious injury in an emergency landing as a result of the inertia forces specified in §§ 25.561 and 25.562."

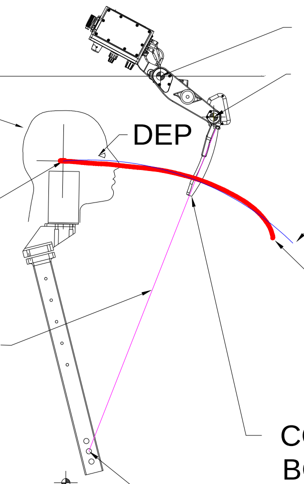
And that each occupant:

"(d) …must be protected from head injury by a safety belt and …. (2) The elimination of any injurious object within striking radius of the head."

Introduction

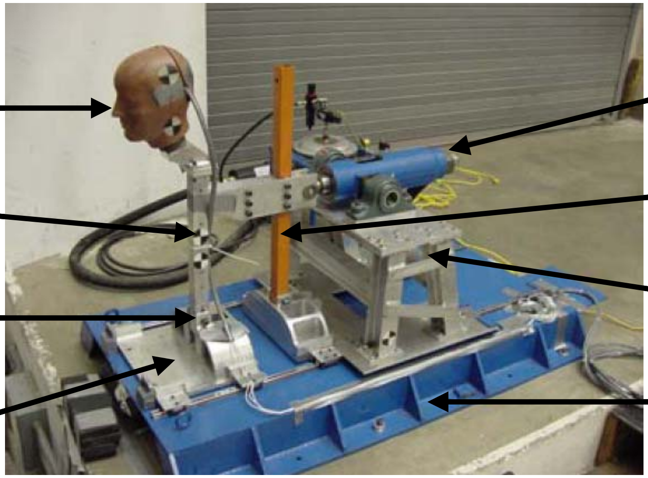
- **Advisory Circular 25-17A provides guidance for showing compliance with the crashworthiness regulations affecting cabin interiors. It provides:**
  - A general definition of head strike radius
  - Padding requirements for items within that radius.
  - If not padded, several test methods provided to determine whether item is injurious. Procedures focus on evaluation of seat back mounted accessories.

HUD Installation Evaluation



- **Combiner glass is only 10” in front of the pilot’s face, clearly within head strike radius**
- **Padding is obviously out of the question**

HUD Installation Evaluation



- **HCT method selected because:**
  - The HCT head travel arc is very similar to the head path observed in forward impact tests of pilot seats
  - Configuration allowed normal orientation of HUD
  - Availability of NIAR developed test equipment at CAMI

HCT Background

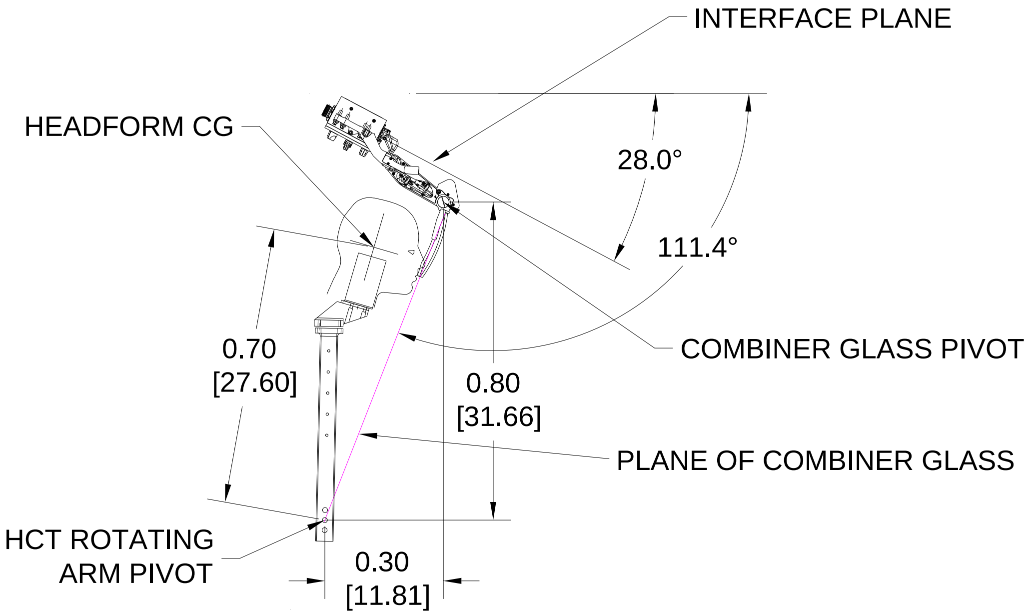
- **Compliance with the Head Injury Criteria is required for seats meeting 14 CFR 25.562.**
  - Evaluated during full scale dynamic tests.
  - Compliance has proven challenging for industry.
- **HCT developed with the goal of providing a more efficient way of evaluating the head injury potential of aircraft interior components.**
- **NIAR HCT performance:**
  - The HCT correlated well with sled test data for impacts with relatively soft items like passenger seat backs, but not as well for impacts with relatively stiff items like bulkhead walls.
  - Modifications have been identified for further development that could provide improved correlation for all impact scenarios.

Test Procedure Development

- **AC25-17A, Appendix 13: Test requirements originally developed for evaluation of seat back mounted accessories were adapted for the HUD tests as follows:**
  - ***Item must be mounted in a representative or rigid fashion:*** **HUD mounted to rigid test fixtures in the aircraft normal orientation. This ensured that any affect that gravity could have on the performance of the HUD would be accounted for.**

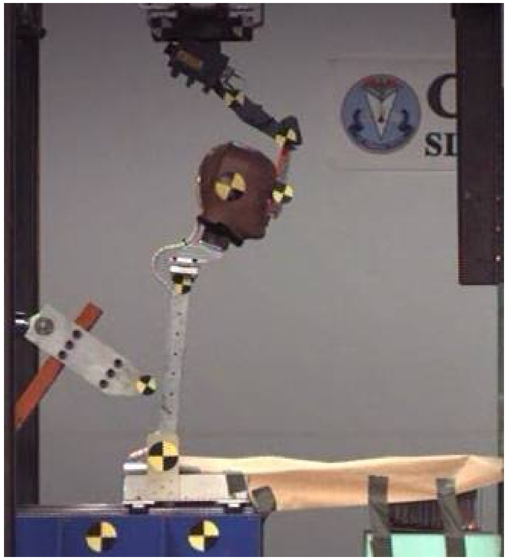
Test Procedure Development

- **HUD test requirements (continued):**
  - ***Impact vector must be perpendicular to item surface and impact point must be at center of item:*** **Produced by HCT relative position with respect to HUD**



Test Procedure Development

- **HUD test requirements (continued):**
  - ***Forehead of headform must be initial point of contact:*** **Geometry of test setup results in the nose contacting just before the forehead. Contact disregarded since nose of Hybrid-II headform is so soft.**

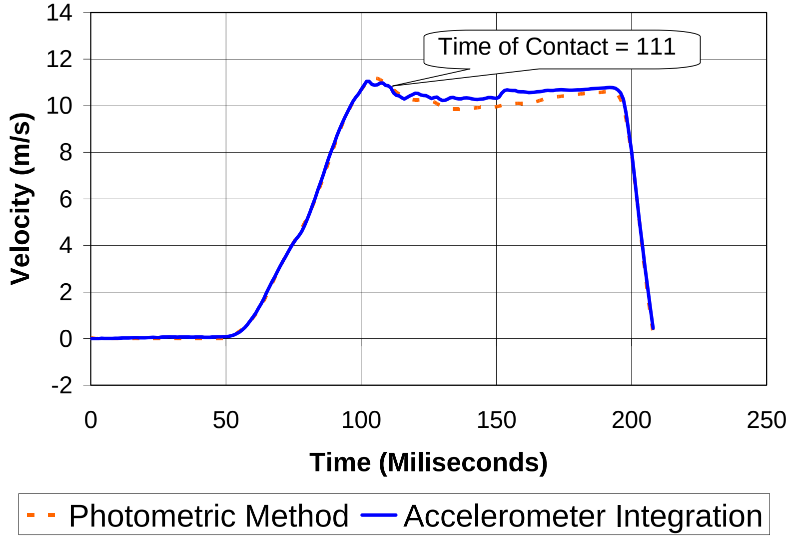


Test Procedure Development

- **HUD test requirements (continued):**
  - ***Impact velocity must be 34 ft/s:*** **Velocity measured at head CG for consistency with other test methods.**
  - ***Peak head accelerations < 200g's; accelerations in excess of 80g's shall not exceed a cumulative duration of 3.0 milliseconds. The impact shall not cause the formation of any sharp or injurious edges or features that may impede egress:*** **Only duration of contact with HUD considered.**

Tests Conducted

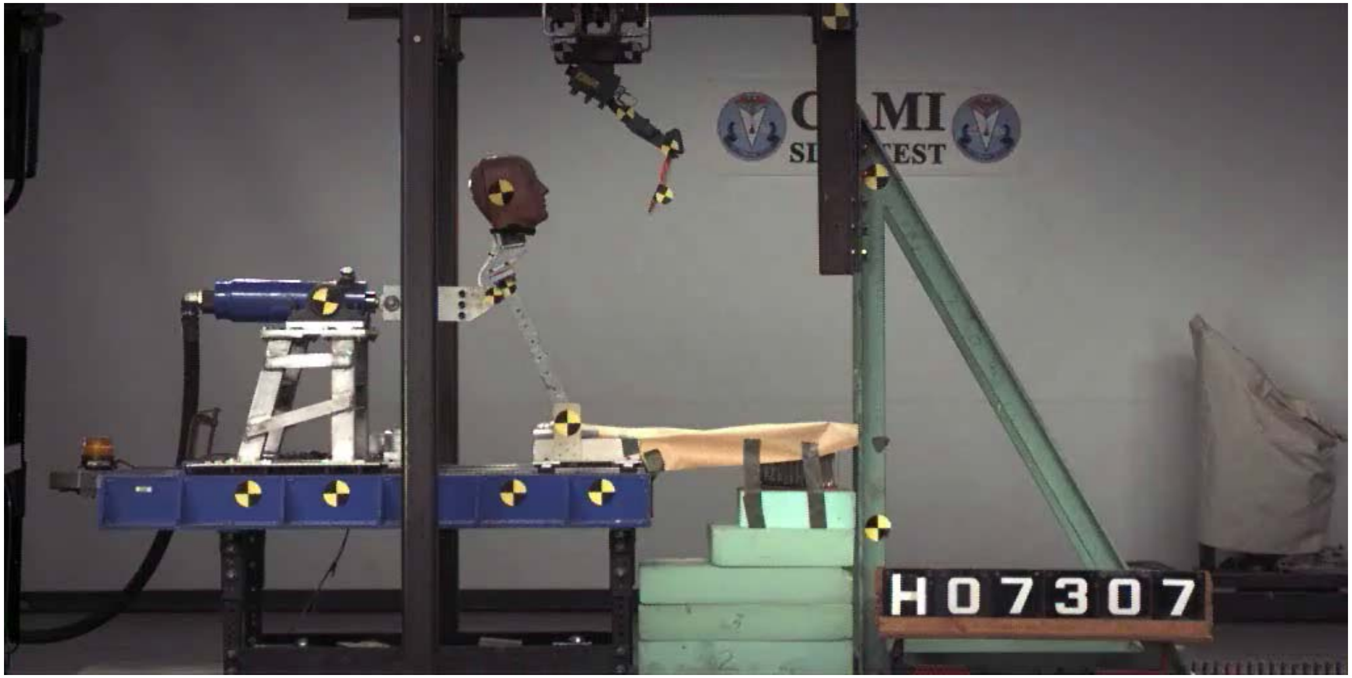
- **Instrumentation and Data Analysis**
  - Axyz at Head CG (normal ATD position)
  - High-speed video (1000 fr/s)
  - Velocity derived by:
    - Differentiating Head CG position from video
    - Integrating tangential head acceleration vector.
  - Setup geometry verified by measuring initial position of HUD and HCT



Resultant Head CG Velocity

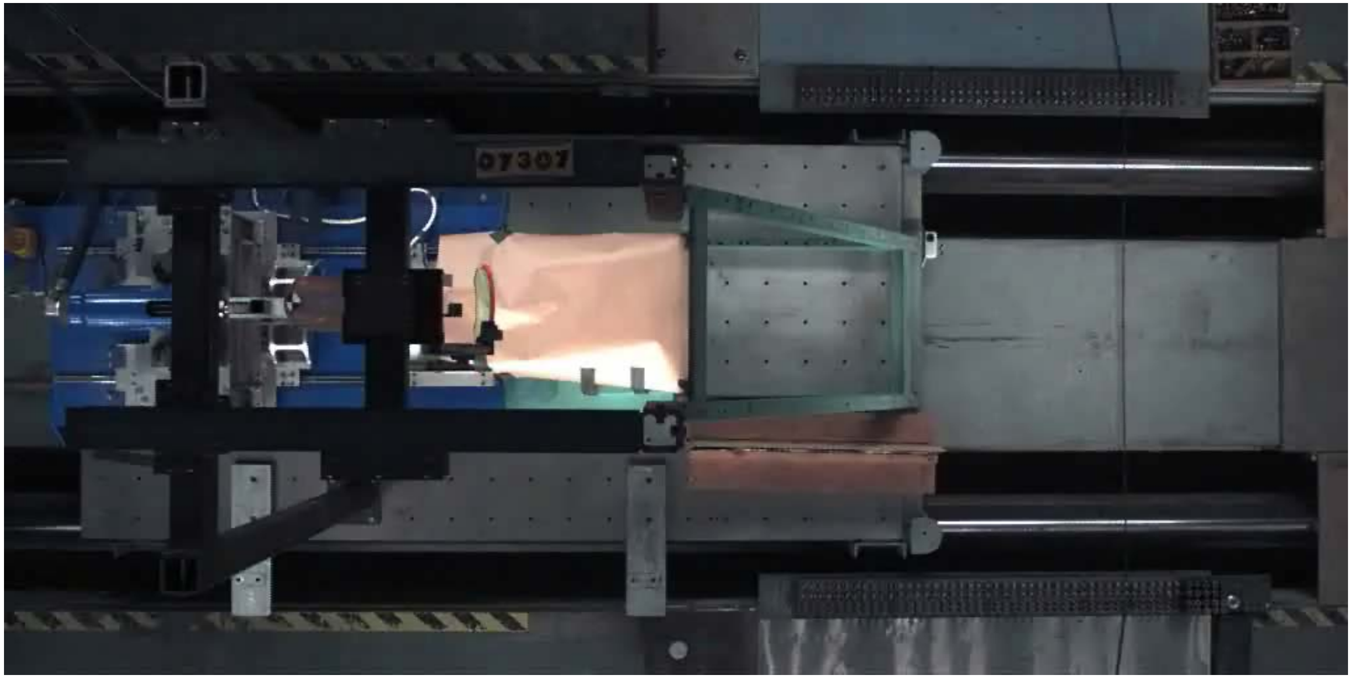
Tests Conducted

- **Test H07307 Results**
  - Velocity: 37.3 ft/s (3.3 f/sec higher than test minimum)
  - Glass shatters immediately upon contact



Tests Conducted

- **Test H07307 Results (cont)**
  - No HUD Frame Flexure Noted.

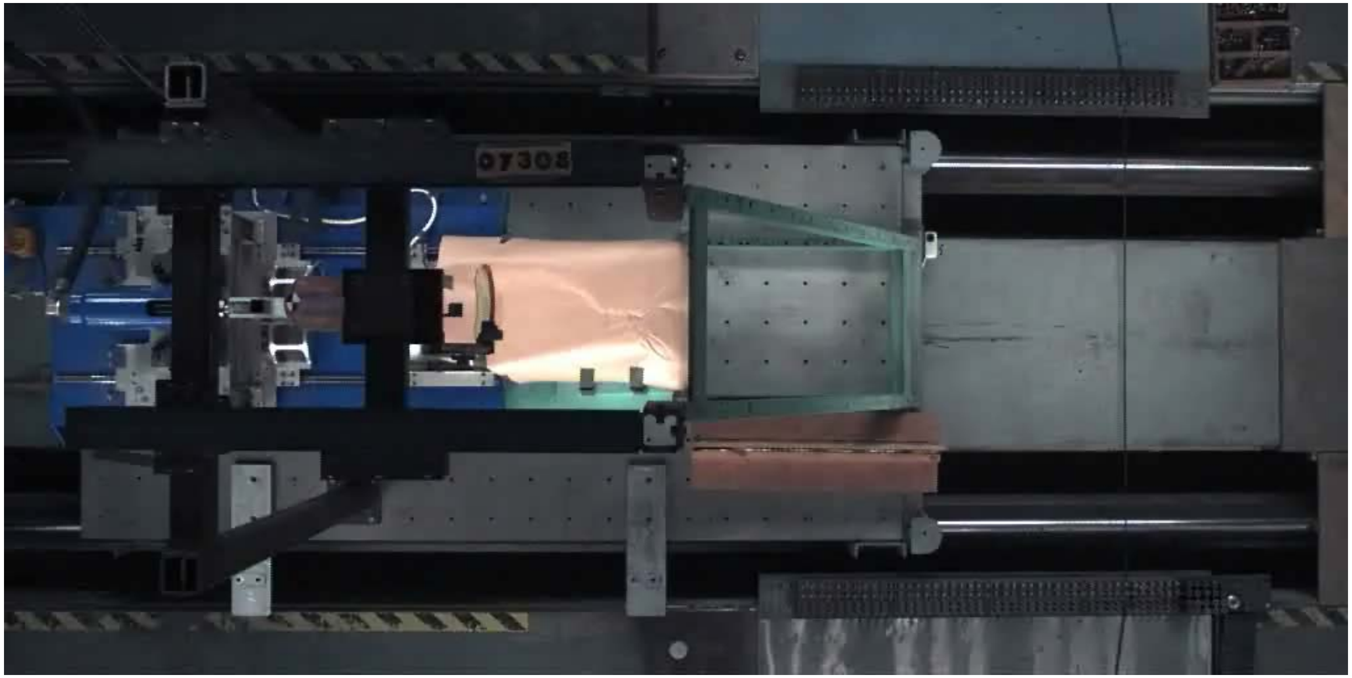


Tests Conducted

- **Test H07308 Results**
  - Velocity: 36 ft/s
  - Head pushed glass forward and upward then passed underneath. Glass remained intact (no sharp edges)

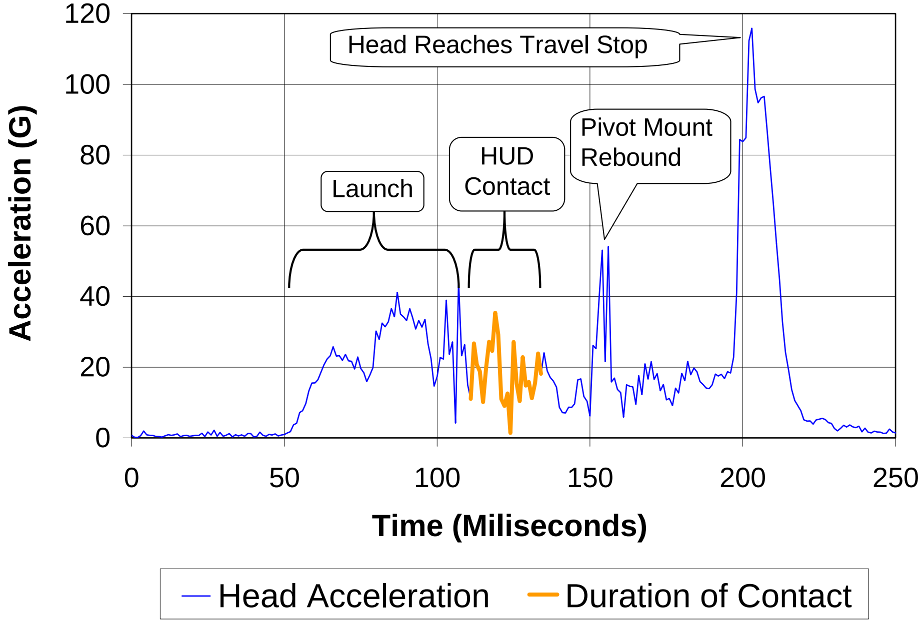
Tests Conducted

- **Test H07308 Results (cont)**
  - Some HUD frame lateral flexure observed.
  - HUD glass remained in forward position post-test.



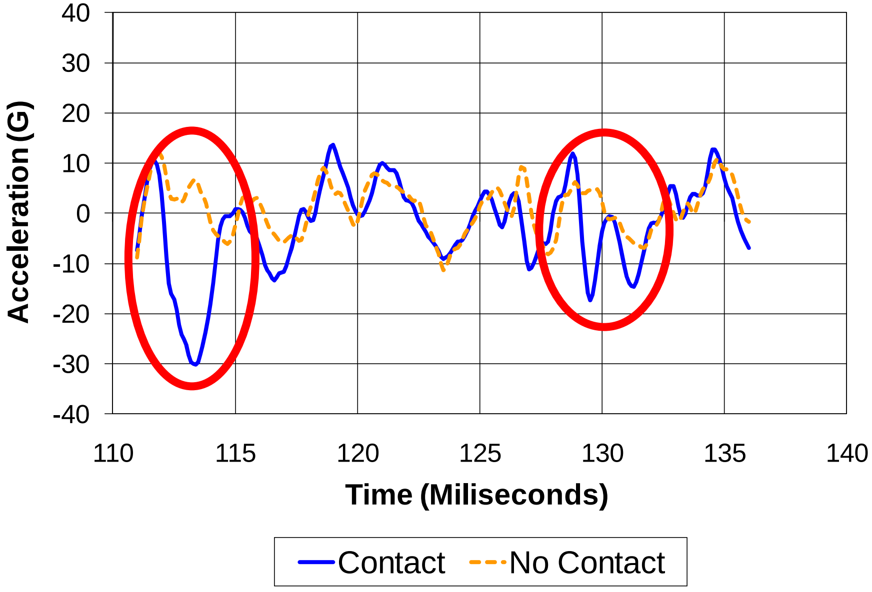
Tests Conducted

- **Test H07308 Results**
  - Acceleration levels during head contact with HUD were well below limits. Although not a pass/fail criteria, HIC during the contact was calculated for reference and was only 42.

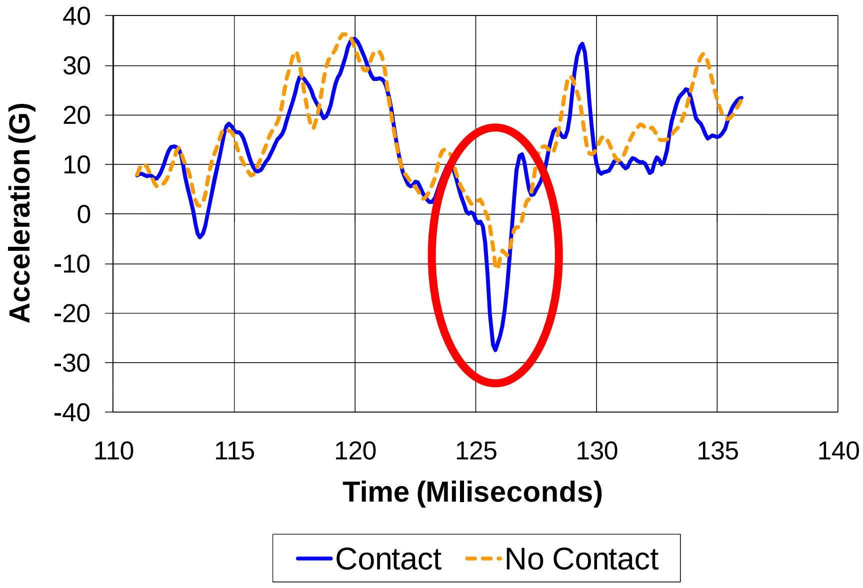


Tests Conducted

- **HCT Response**
  - The HCT's high-rate launch produces a low level oscillation in the measured HCT headform acceleration.
  - Comparison between impact and no-contact cases illustrates the affect due to impact with HUD (areas highlighted in red oval)



Headform X Accel



Headform Z Accel

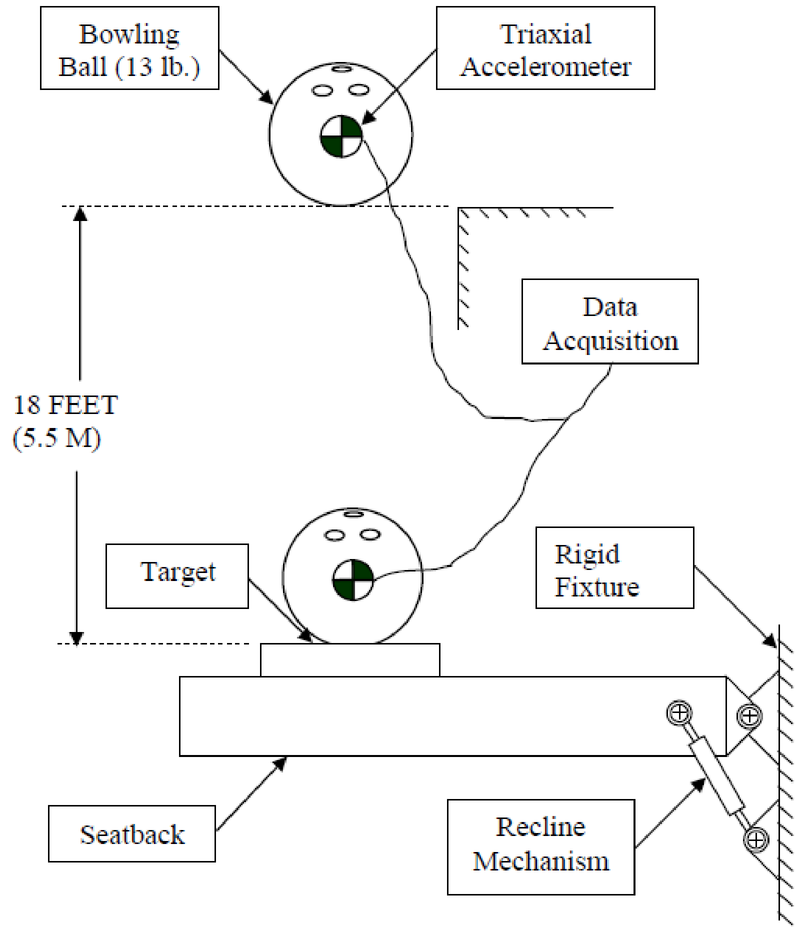
Alternate Test Methods

- **Free Motion Headform (FMH)**
  - Similar rational applied to the HCT may be used to adapt procedures for use with the FMH.
  - Requirements for initial forehead contact must also be addressed with this device since the chin may impact a flat surface slightly before the forehead does. (Nose is removed)

Alternate Test Methods

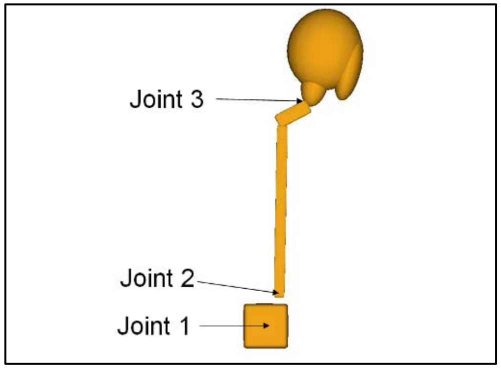
- **Bowling Ball**

  Not best choice for HUD application due to:
  - Imprecise guidance
  - Gravity propulsion does not allow mounting test articles in normal orientation
  - Very rigid (overly conservative) contact surface will increase peak acceleration and potential for glass breakage

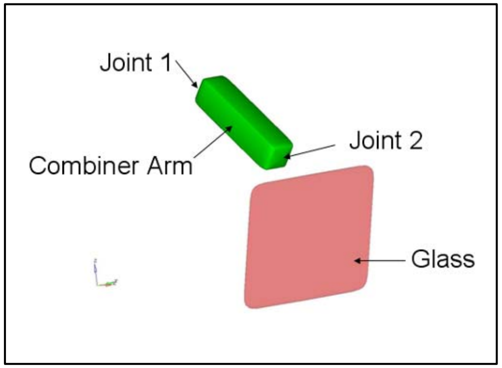


Model Development

- **Model Description**
  - MADYMO rigid body type model
  - Model parameters based on measured mass and dimensions of both items. HUD dynamic pivot (Joint 2) stiffness based on measured F/D characteristics.



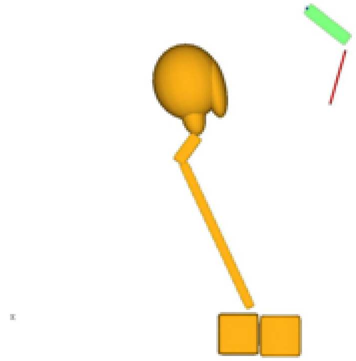
HCT Model



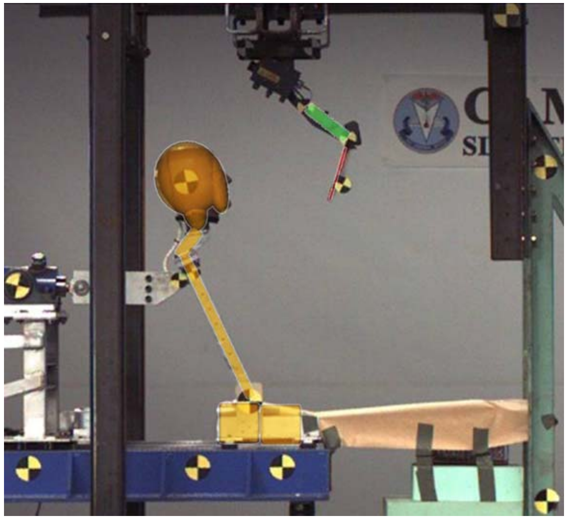
HUD Model

Model Development

- **Model Description**
  - Models combined to emulate entire system.
  - Joint stiffness of HUD static pivot (Joint 1) was calibrated to produce observed kinematics



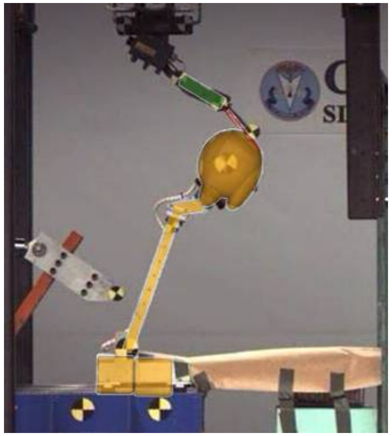
System Model



Overlay of Model and Test Setup

Model Development

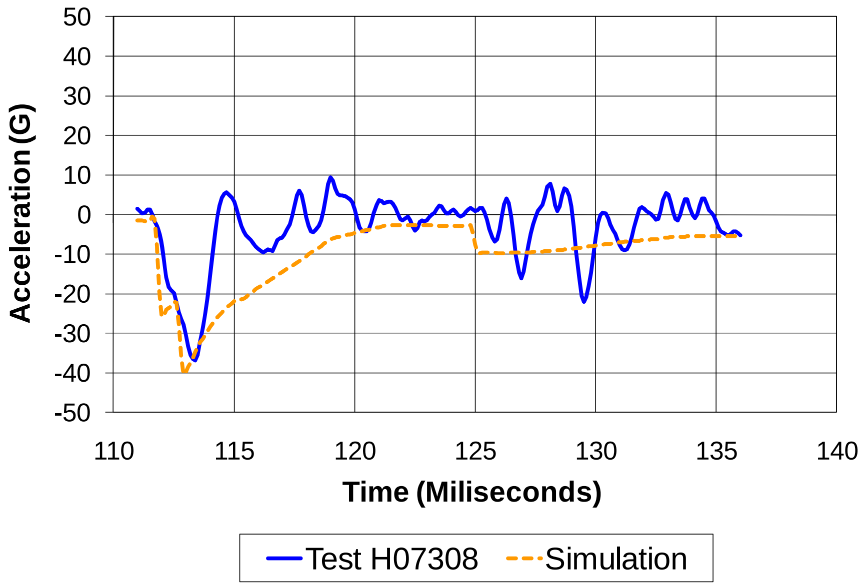
- **Simulation Output**
  - Overall kinematics and phasing of response very similar to test results

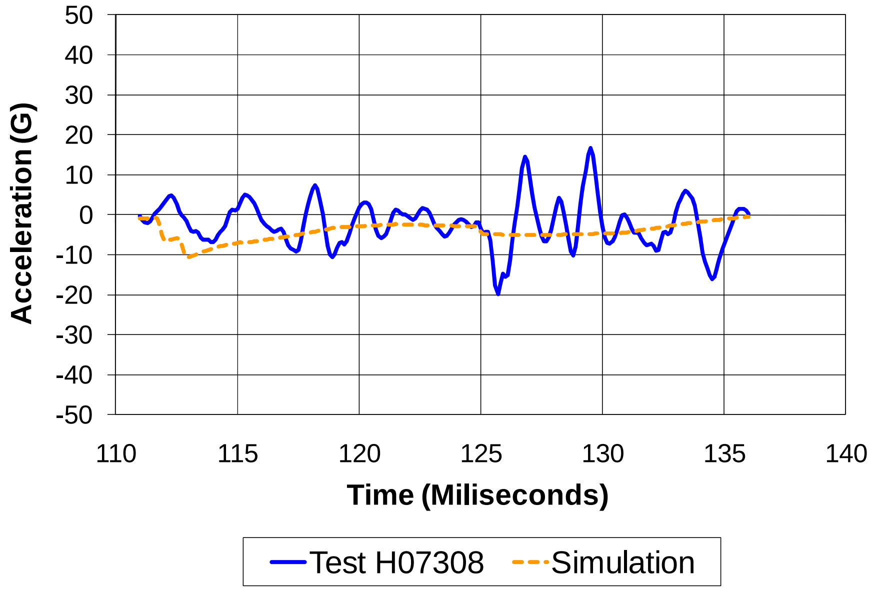


Initial Contact **Max Combiner Rotation** **End of Contact**

Model Development

- **Simulation Output (cont)**
  - Head accel from simulation compares well to test data with underlying oscillatory response removed.

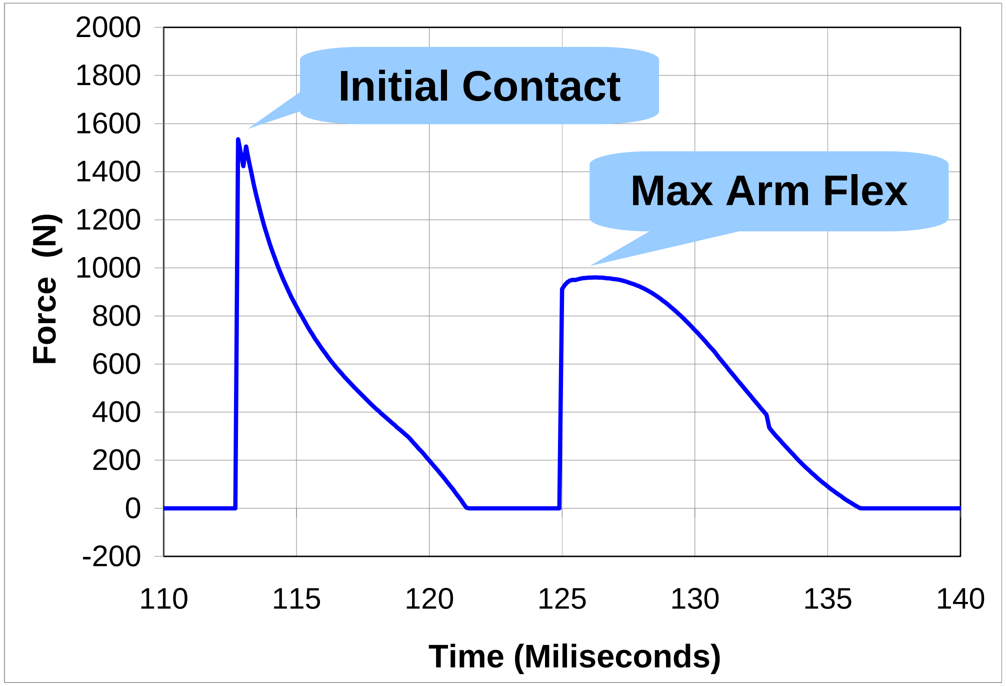




Differential Head X Accel **Differential Head Z Accel**

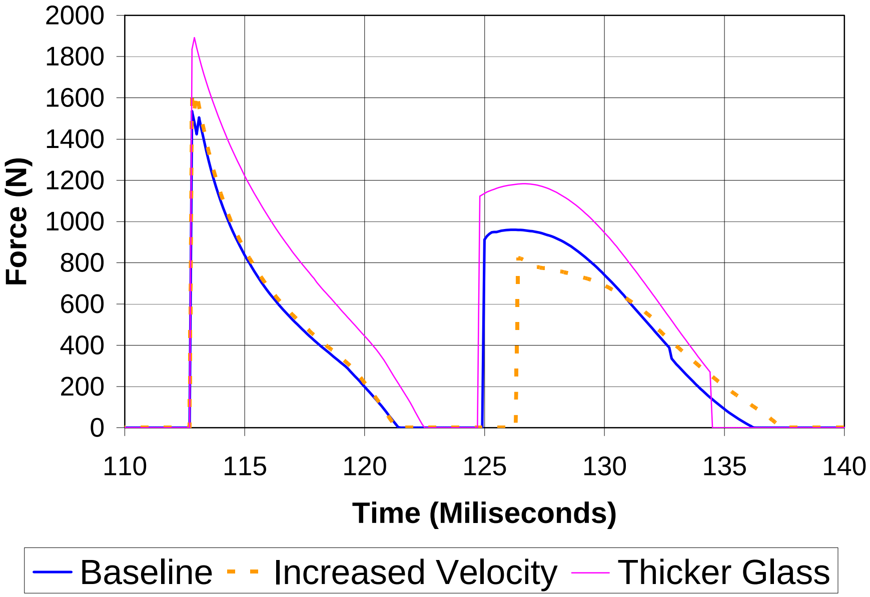
Model Development

- **Simulation Output (cont)**
  - Contact force between Head and Glass was much less than the skull fracture injury threshold (50% risk) of 2670 N.



Parametric Studies

- **4% Higher Velocity (to match glass breakage case)**
  - Force increased by 7 % (simulation assumes glass remains intact)
- **Thicker Glass**
  - Glass contact force predicted was 23% higher, but was still well below injury threshold.



Contact Force Between Head and Glass

Conclusions

- A procedure was developed to use an HCT to evaluate whether a head-up display unit is an injurious object per §25.785.
- The rationale used may be useful when adapting the general test methods contained in FAA policy to other applications.
- A computer model of the HCT and HUD was developed that correlated well with experimental data.
- The model can be used to evaluate the effect of certain design parameters on HUD injury potential.

Acknowledgment

Co-authors:

David Moorcroft
Civil Aerospace Medical Institute
Federal Aviation Administration

Chandrashekhar K. Thorbole
The Engineering Institute, Inc.

Hamid M. Lankarani
Mechanical Engineering Department
Wichita State University

Reference

A report containing the details of this project will be published in the proceedings of the 2010 ICRASH Conference:

"*Use of a Head Component Tester to Evaluate the Injury Potential of an Aircraft Head-Up Display*", ICRASH 2010 Conference, Washington, DC, Sept 22-24, Paper No. 2010-039.