Numerical Crashworthiness Analysis of ISOFIX and LATCH Automotive Child Restraints in Transport Category Aircraft

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Introduction

- Objectives:
  - Use CASA physical tests as the basis for a numerical model
  - Validate model against CASA data
  - Use model for further investigation into ISOFIX/LATCH child restraints in transport category aircraft

Dynamic Model

- Variables of interest identified by CASA and others:
  - Restraint installation method (lap belt, ISOFIX, LATCH)
  - Child occupant size
  - Adult occupant size
  - Seat pitch
  - Anchorage stiffness (ISOFIX and LATCH)
  - Webbing stiffness (LATCH)

Dynamic Model

- Output variables of interest:
  - Adult and child head acceleration
  - Adult and child neck axial force and moment
  - Child head CG position
  - Adult femur and tibia loads
  - Child restraint anchor loads
  - Aircraft seat anchor loads
- MADYMO was chosen for its emphasis on occupant safety analysis and range of included ATD models

Dynamic Model

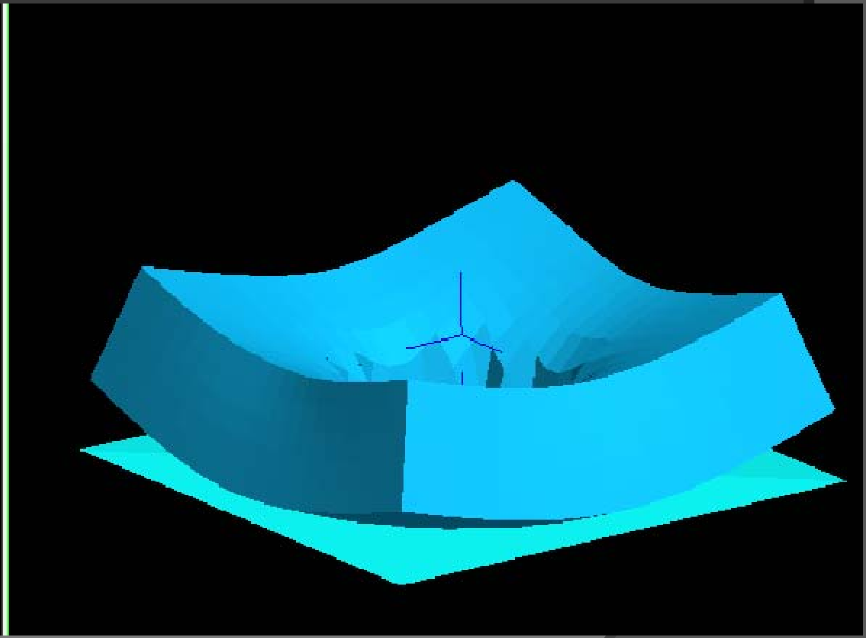
- Required model capabilities:
  - able to be validated across a range of configurations
  - allow for simple manipulation of all input variables as well as possible introduction of new ones
- Multibody model would not be appropriate
- Result is a model constructed mostly of finite elements
- Basis for model:
  - Two rows of two-abreast typical economy class airline seats at 30” pitch
  - Replicates CASA study

Method

- Reverse-engineering
  - Dismantle post-test seats from CASA study
  - Assess seats and high-speed footage from CASA study to determine which components have significant influence on output variables
  - Particular components were identified
    - Tray table
    - Cushion foam
    - Seatback break-over mechanism
  - These were subjected to individual component tests

Component Testing

- Seat base and back cushion
  - Foam samples were tested using a modified version of ASTM D3575 test method
  - Test was replicated in MADYMO to test material behavior.

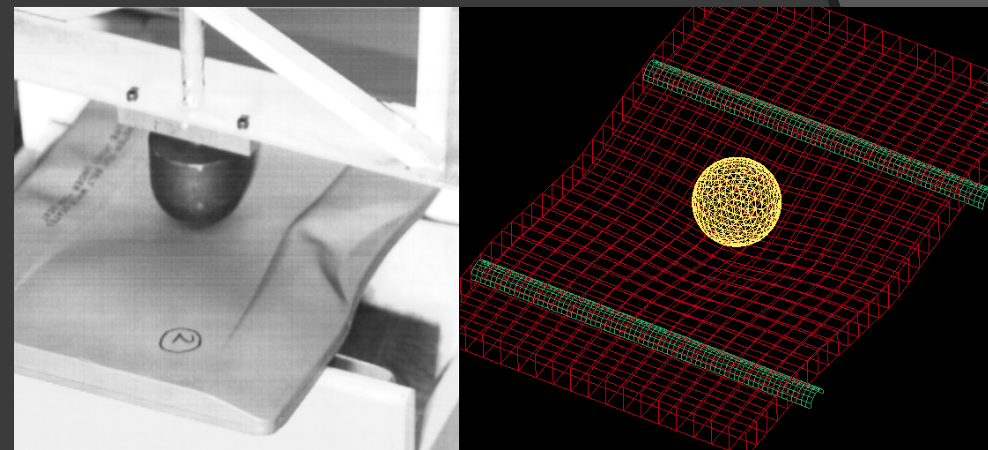


Component Testing

- Tray table

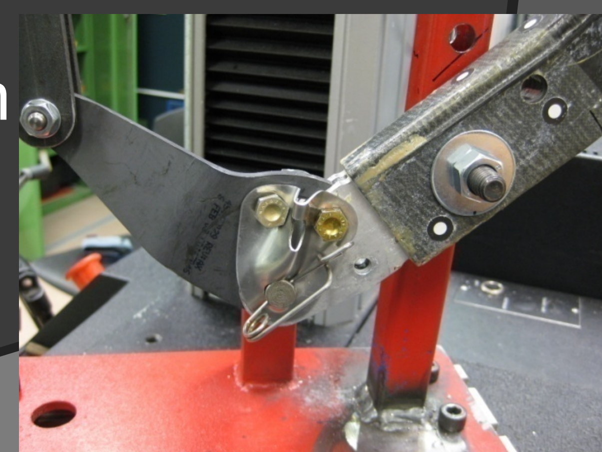
  Left: Physical test

  Right: MADYMO validation



- Seatback break-over mechanism

  (Modeled as a numerical joint, so not directly replicated in MADYMO)



Component Testing

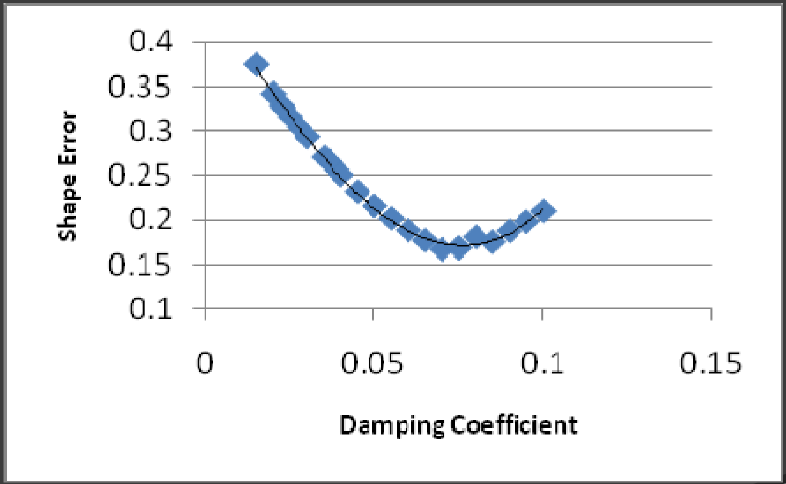
- Issues:
  - Foam testing limited to quasi-static rate (500 mm/min)
    - Need results for a range of dynamic rates to allow for rate effects in foam model
  - Tray table test not as destructive as sled test
    - Need a higher/heavier drop tower capability

Validation

- A validation metric is required in order to compare MADYMO and experiment signals
- The Sprague and Geers metric was chosen
  - Recommended by FAA (Moorcroft 2007)
  - Compares signals based on magnitude as well as phase difference
  - Simple to implement
- This metric was used in validating components and whole model

Foam Model

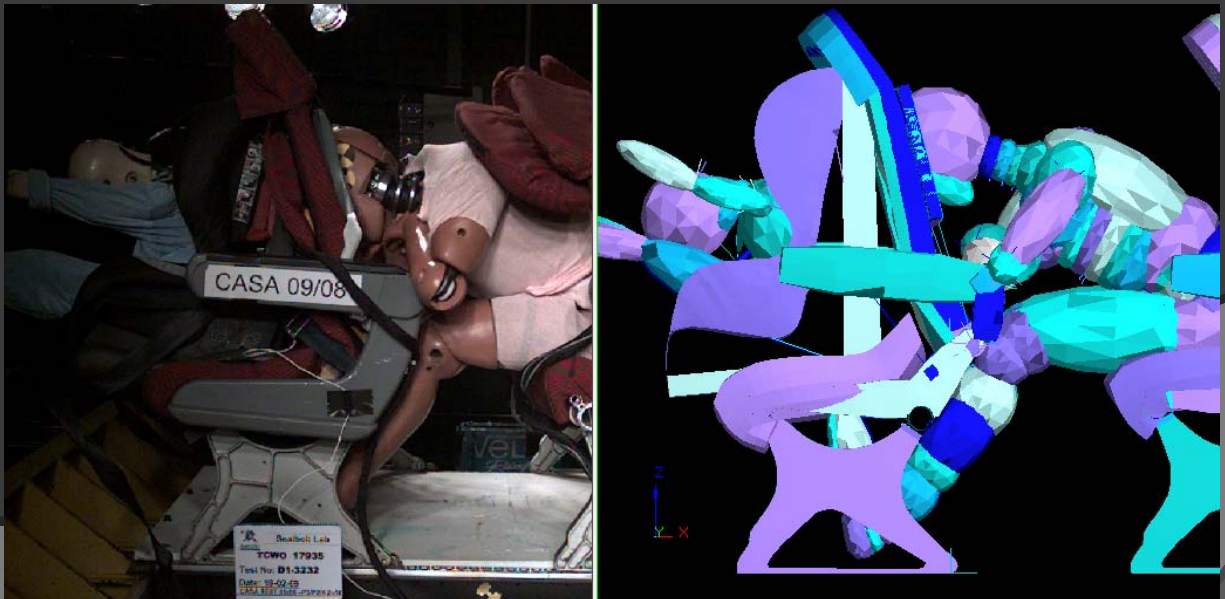
- Foam proved difficult to model
- Stability of foam model is highly sensitive to material damping coefficient and hysteresis



Sprague and Geers shape error was plotted against damping coefficient to find optimum value. (Error value of zero indicates exact match)

Dynamic Model

- Each pair of seats is modeled with approx. 20,000 shell and 1,000 solid elements
- Solver time required on eight 2.3 GHz CPUs is approx. 3 hours



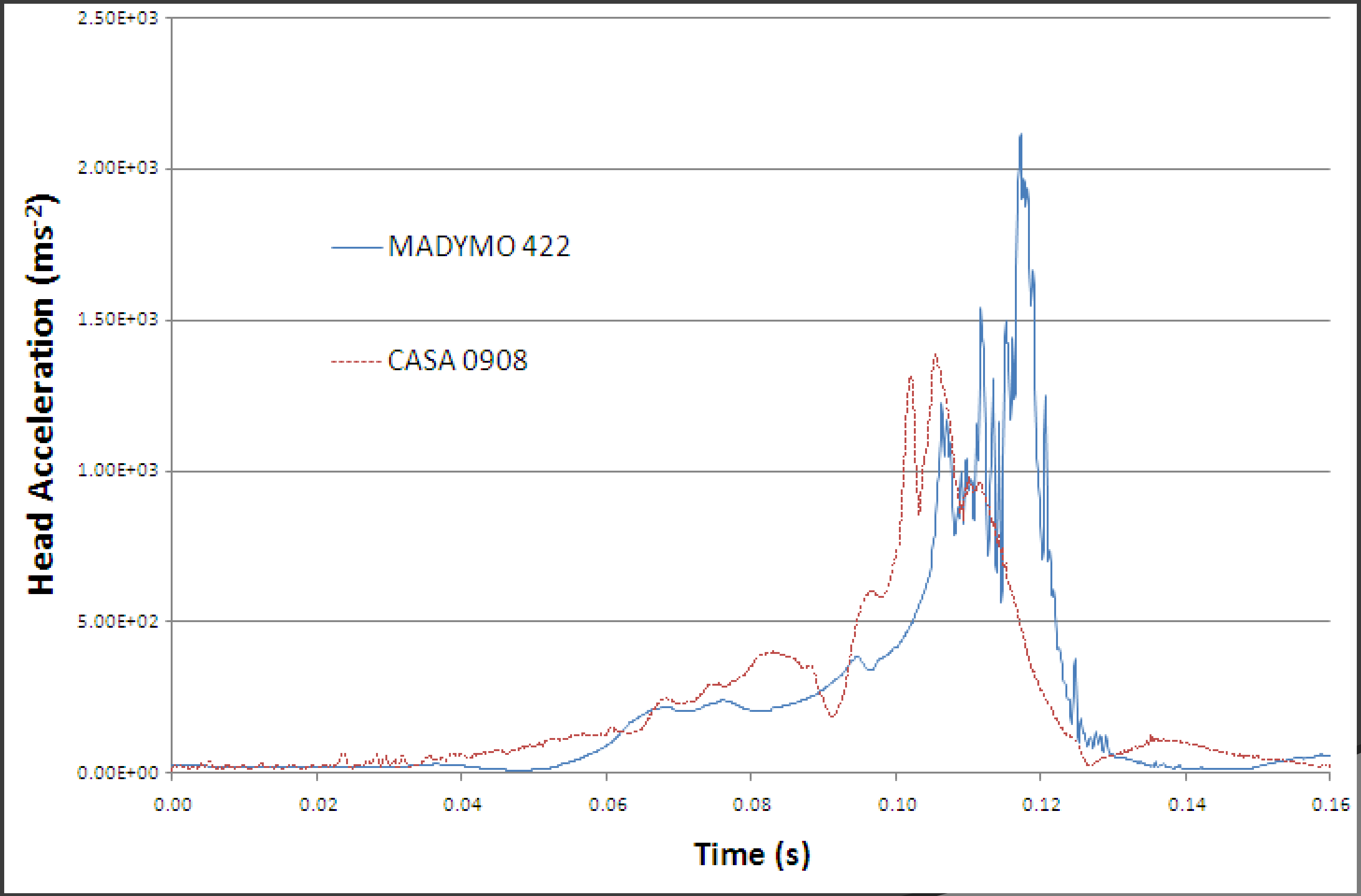
The Fudge Factor

- Sources of error: (Or sources of forced validation?)
  - Belt initial tension (aircraft seat and CRS)
  - ATD positioning
  - Friction curves (dummy/cushion, dummy/tray)
  - Lap belt load curve (which belts were pre-tested?)
- These must be resolved before a ‘validated’ model can be used to test new configurations

Data Filtering

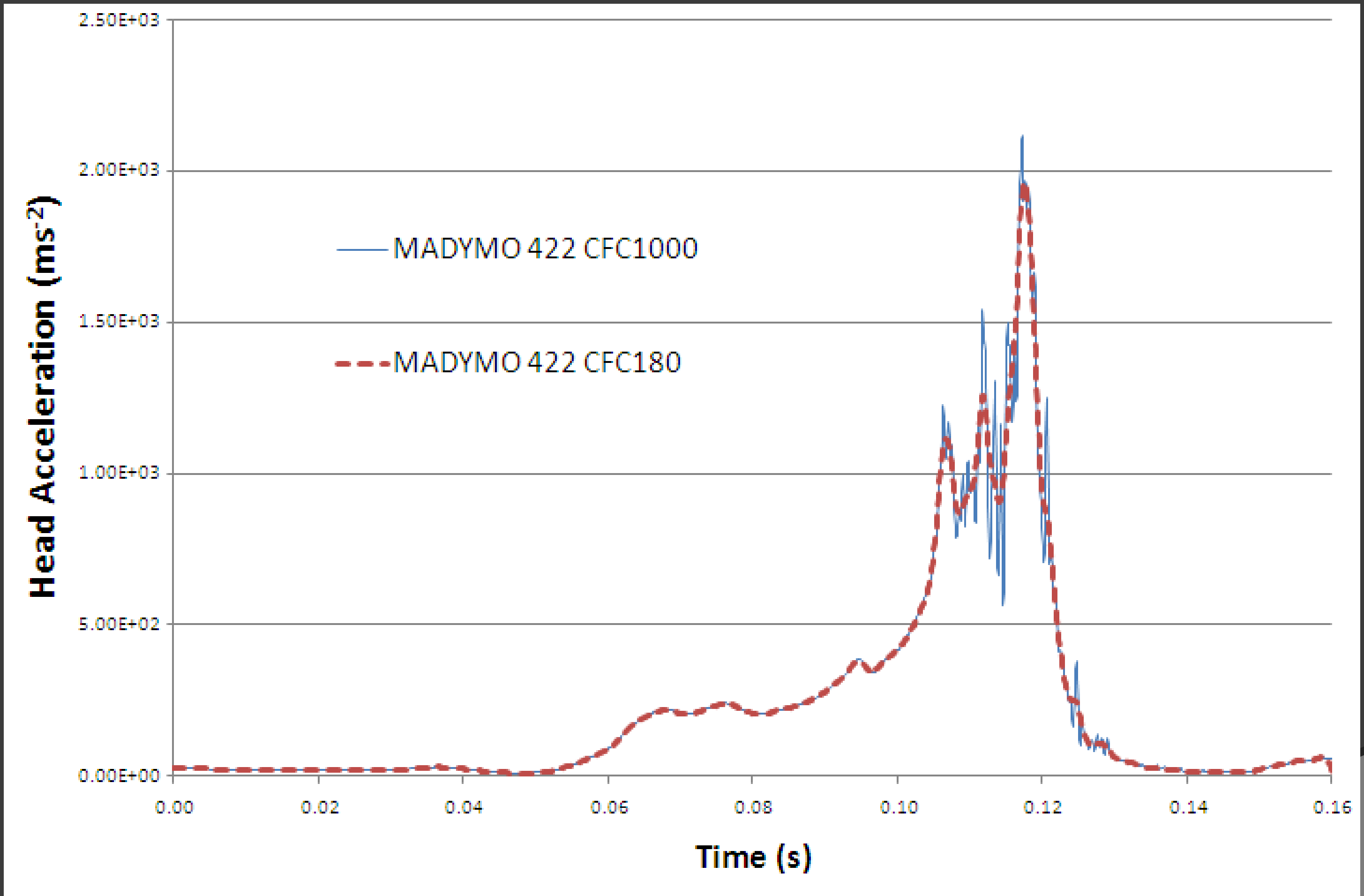
- All physical test data has been filtered to SAE J211 CFC1000
- At this filter level, simulation data was still very noisy
- A CFC180 filter was applied to simulation data to bring noise down to a level similar to test data

Data Filtering



MADYMO head acc. data and test data, CFC1000

Data Filtering



MADYMO head acc. data, CFC1000 and CFC180

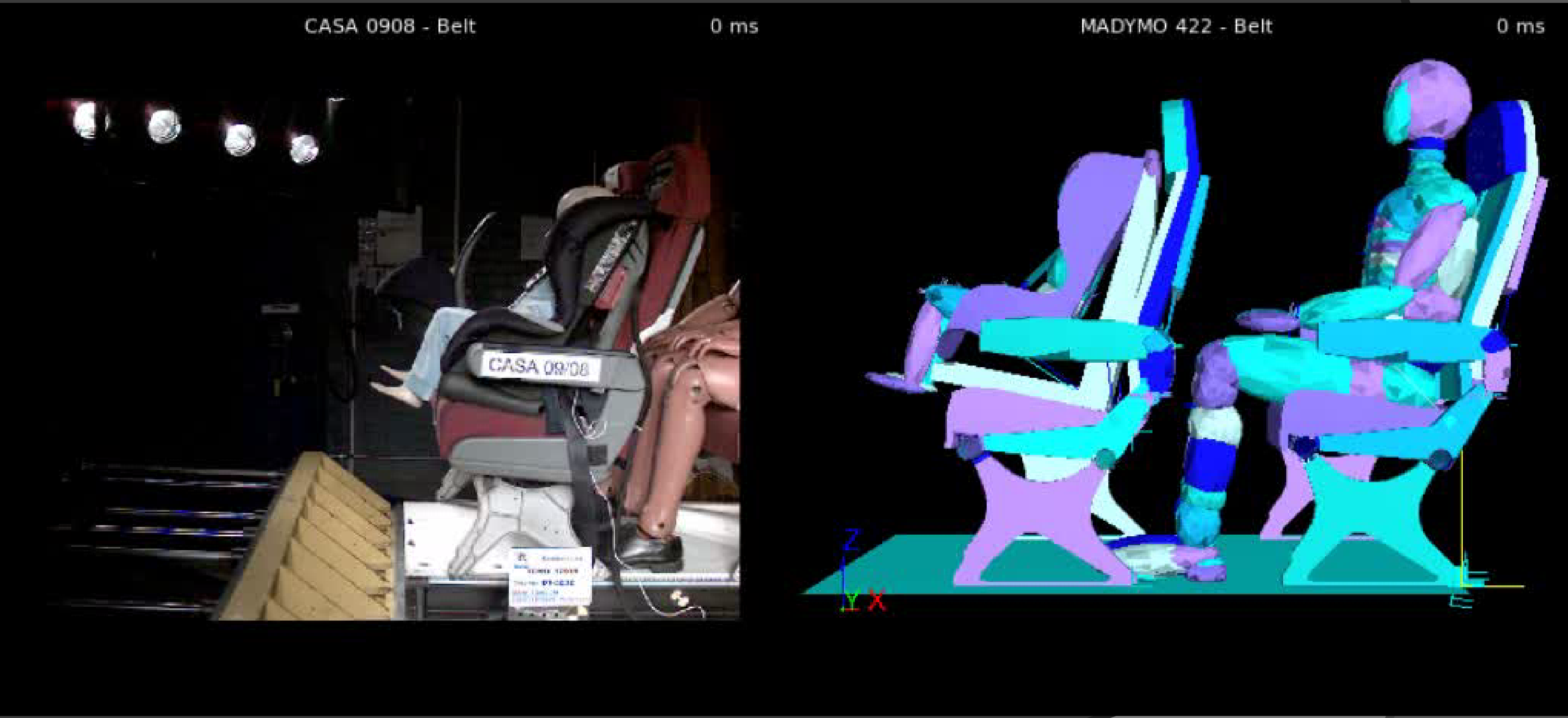
Status of Model

- Early in validation phase
- Results presented henceforth are from an un-validated model
- One CASA test scenario (09/08) was chosen for initial validation
- Modifications were made to improve match between test and simulation
- Same scenario with ISOFIX was then tested (CASA 09/06)

Status of Model

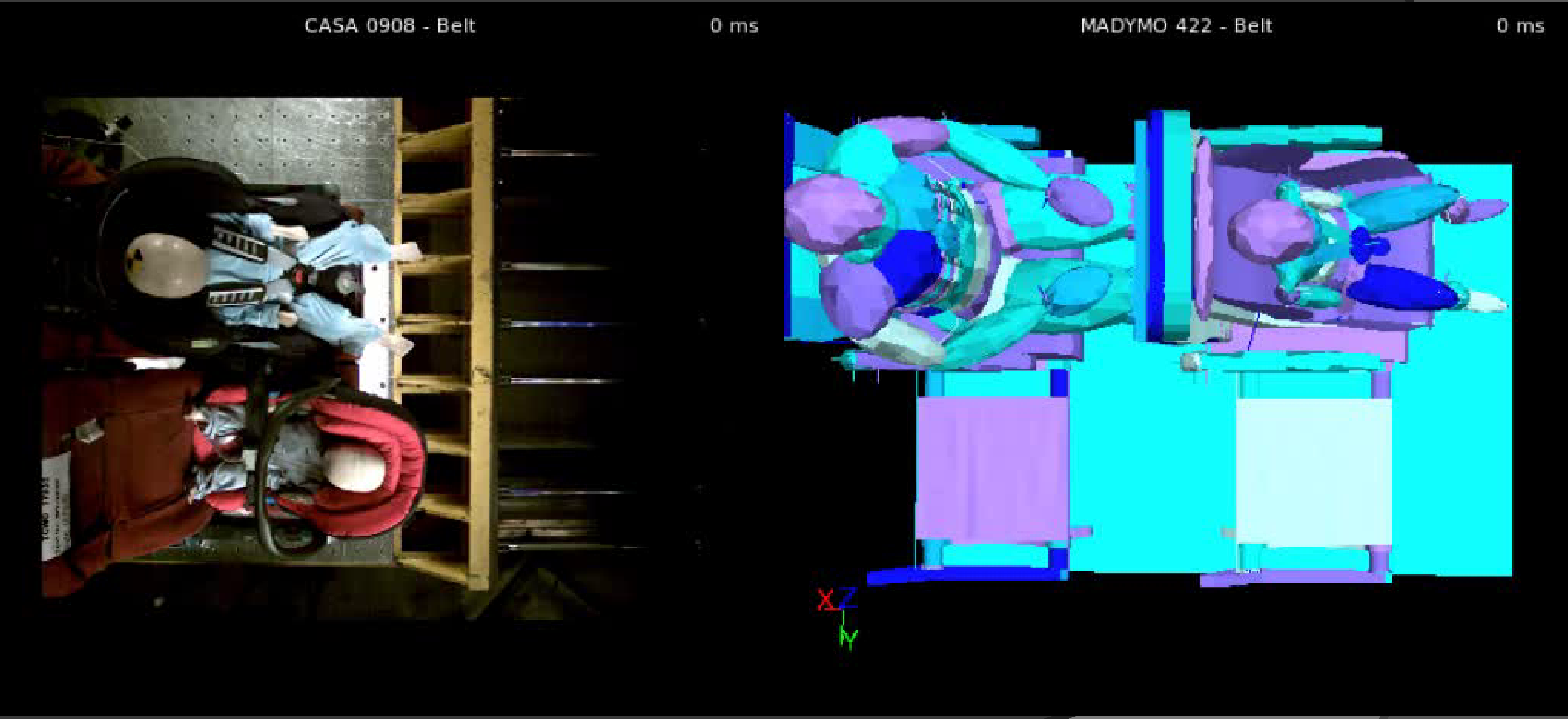
Initial build: H3 50th seated behind TNO P3 in forward-facing CRS installed w/lap belt

Results – Lap Belt



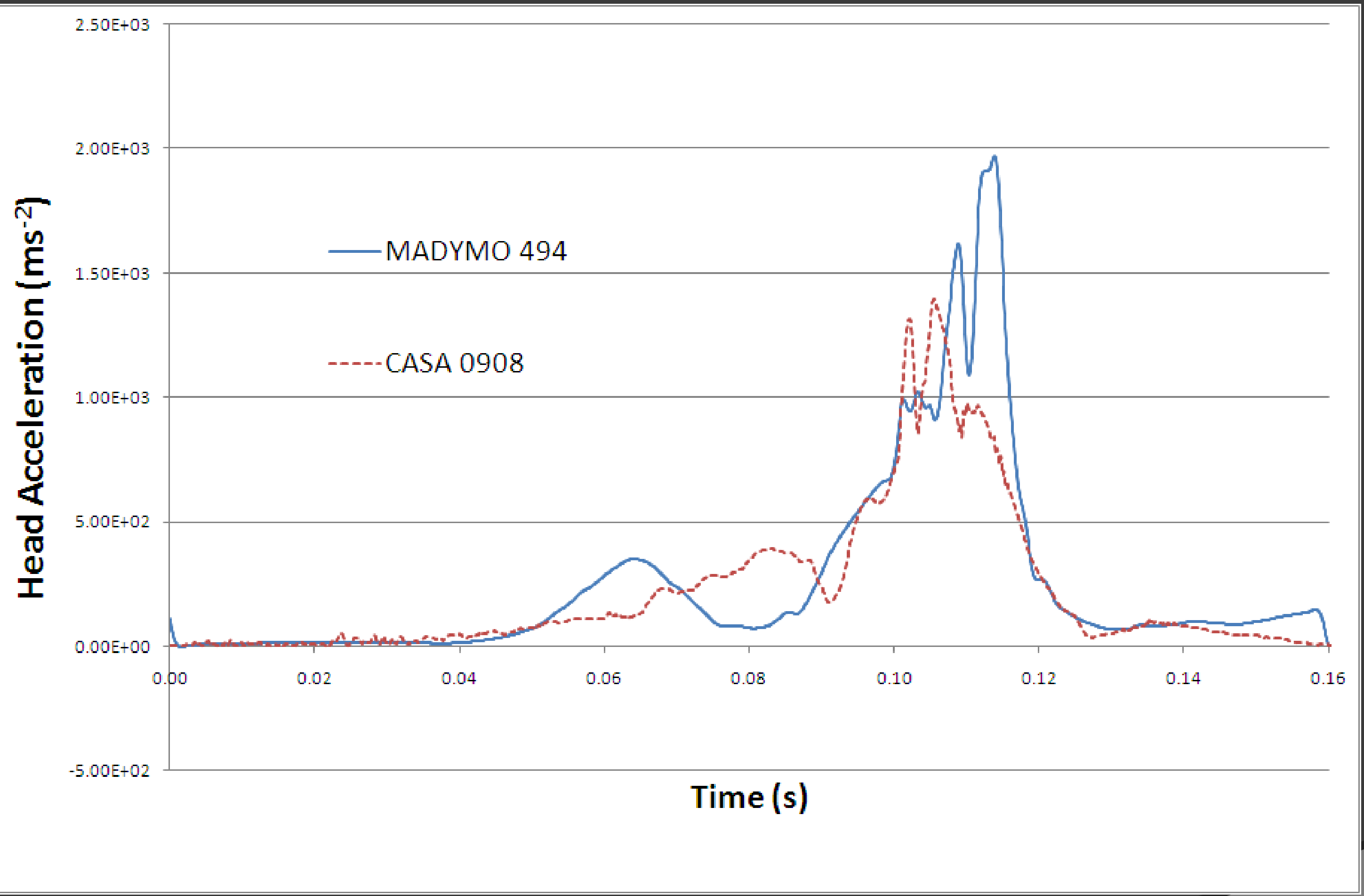
CRS installed with lap belt, P3 and H3 50th occupants

Results – Lap Belt



CRS installed with lap belt, P3 and H3 50th occupants

Results – Lap Belt

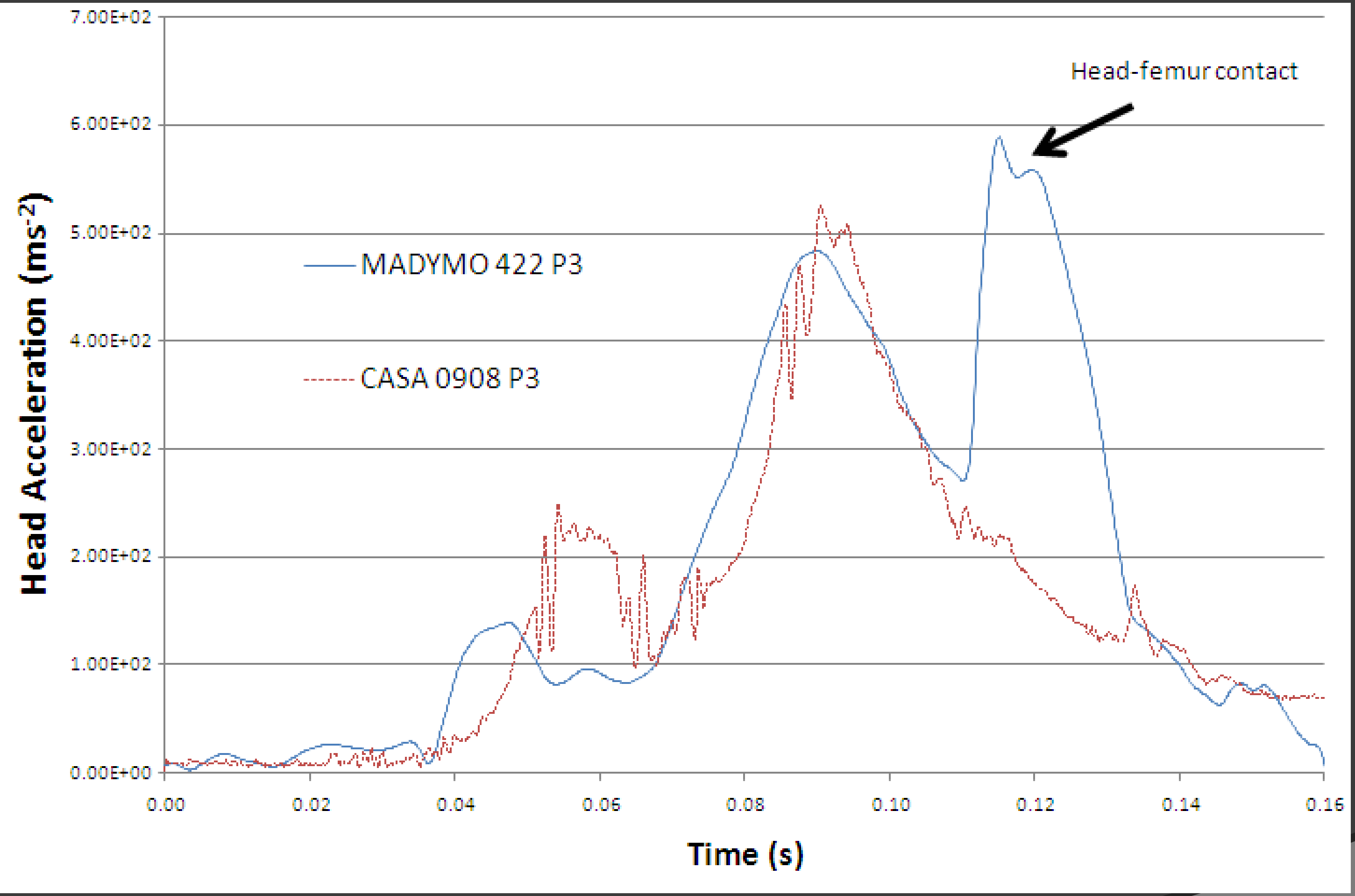


Values of proposed SAE ARP5765 Error Metric:

Delta Error-Max	**-577.1**
Mag. Error-Max	**41.36%**
Delta Error-Min	**2.764**
Mag. Error-Min	**284.1%**
Shape Error	**29.22%**

H3 head acceleration comparison w/ test data
CRS installed with lap belt, P3 and H3 50th occupants

Results – Lap Belt



Values of proposed SAE ARP5765 Error Metric:

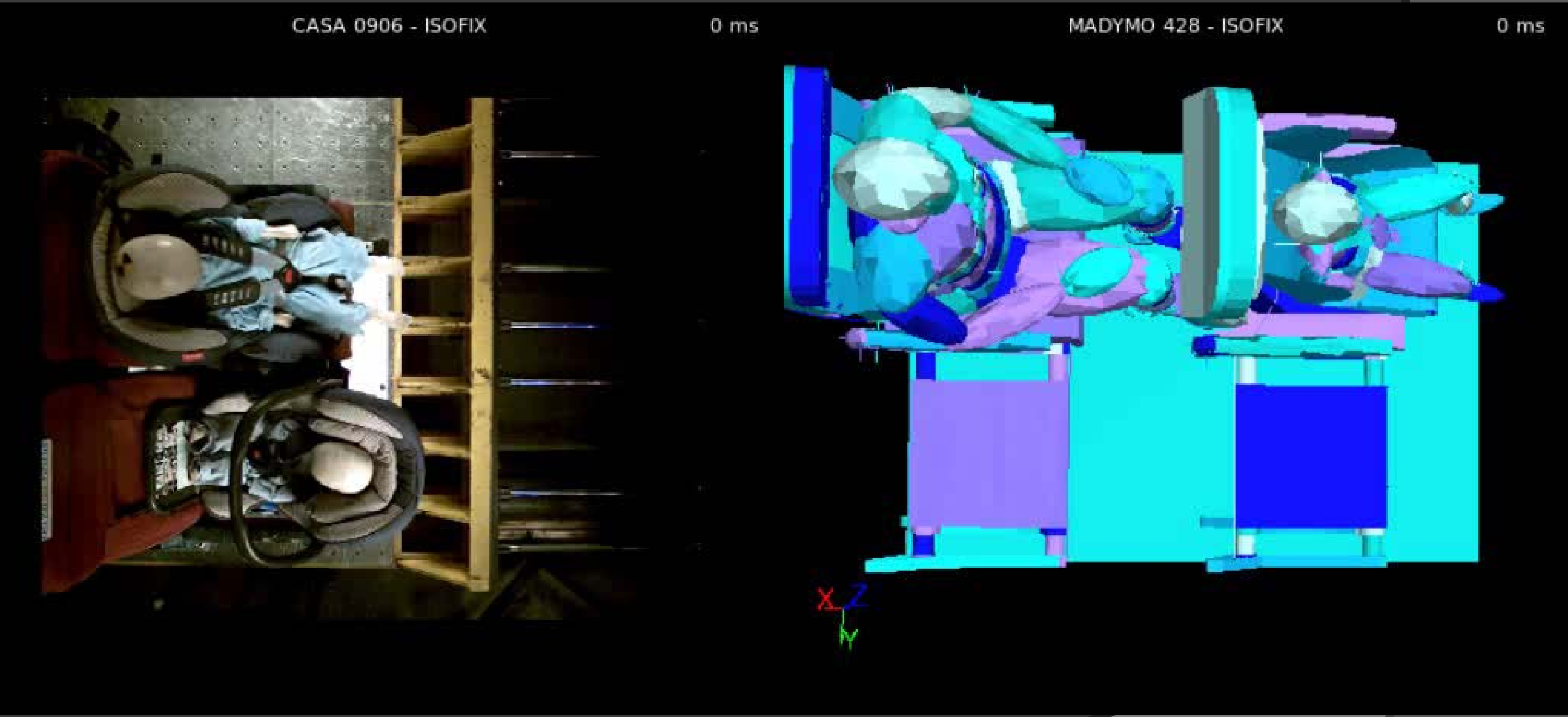
Delta Error-Max	**-64.12**
Mag. Error-Max	**12.22%**
Delta Error-Min	**0.774**
Mag. Error-Min	**34.29%**
Shape Error	**32.67%**

P3 head acceleration comparison w/ test data
CRS installed with lap belt, P3 and H3 50th occupants

Results - ISOFIX

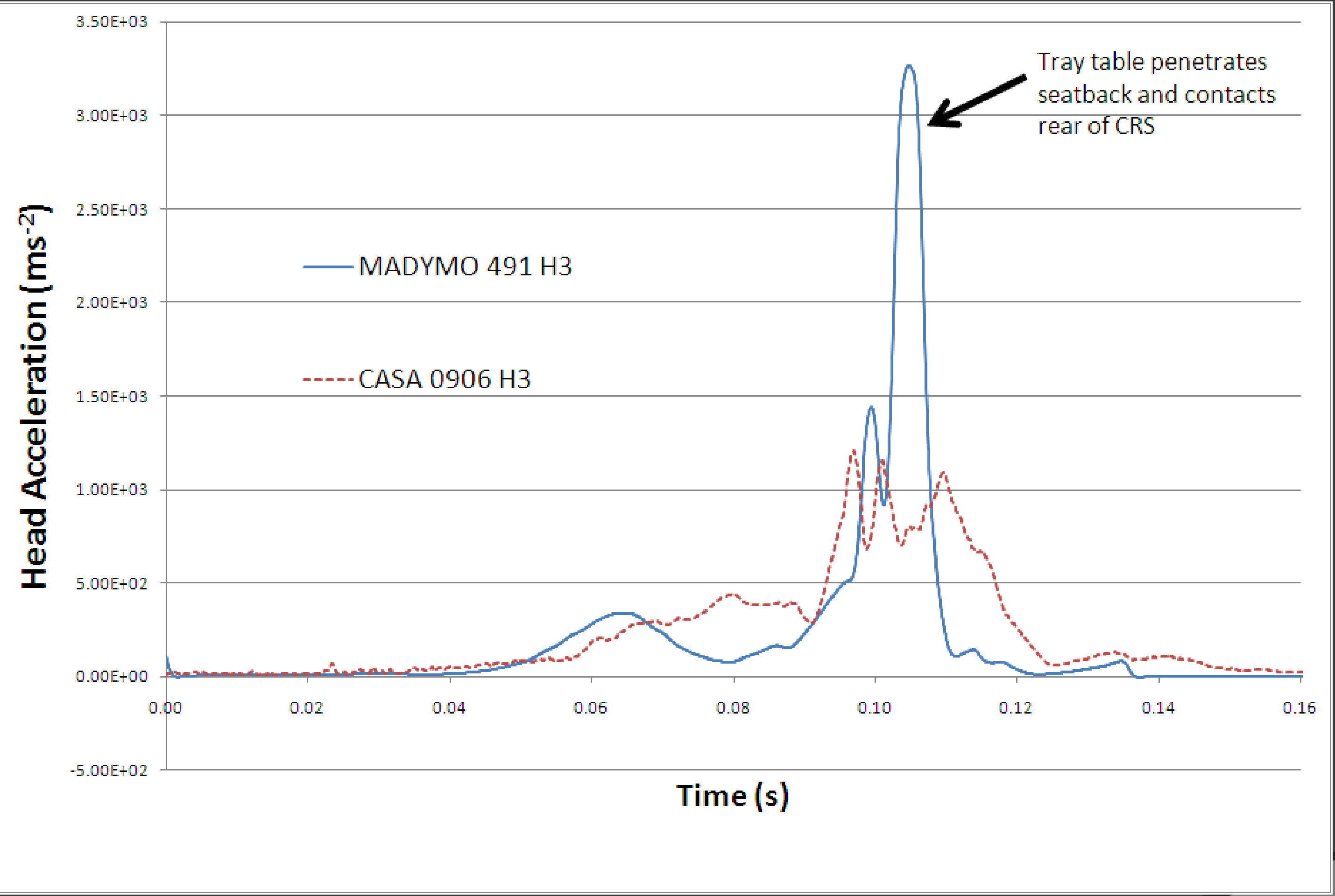
CRS installed with ISOFIX, P3 and H3 50th occupants

Results - ISOFIX



CRS installed with ISOFIX, P3 and H3 50th occupants

Results - ISOFIX

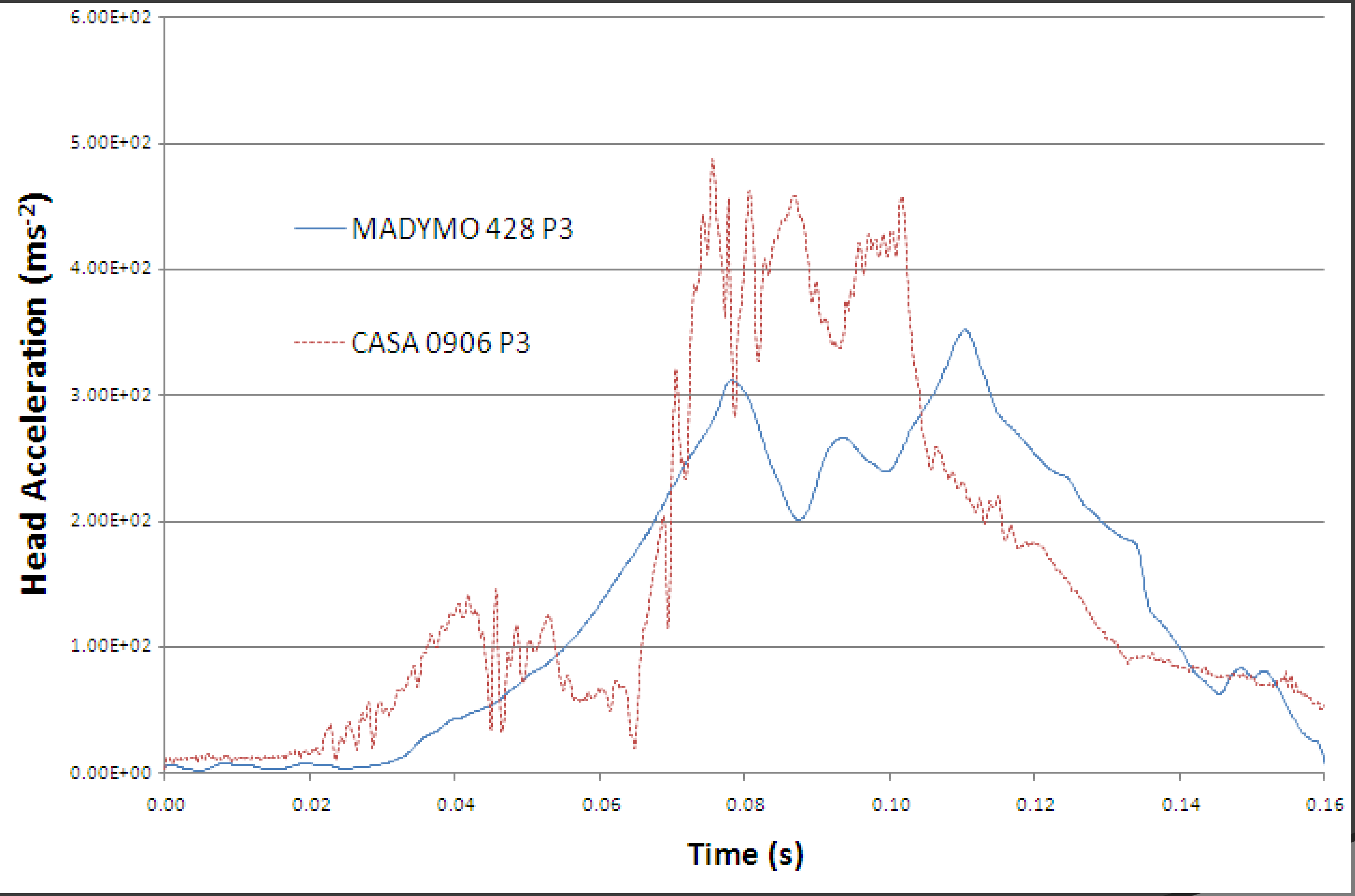


Values of proposed SAE ARP5765 Error Metric:

Delta Error-Max	**-2062**
Mag. Error-Max	**171%**
Delta Error-Min	**7.42**
Mag. Error-Min	**167%**
Shape Error	**56.52%**

H3 head acceleration comparison w/ test data
CRS installed with ISOFIX, P3 and H3 50th occupants

Results - ISOFIX

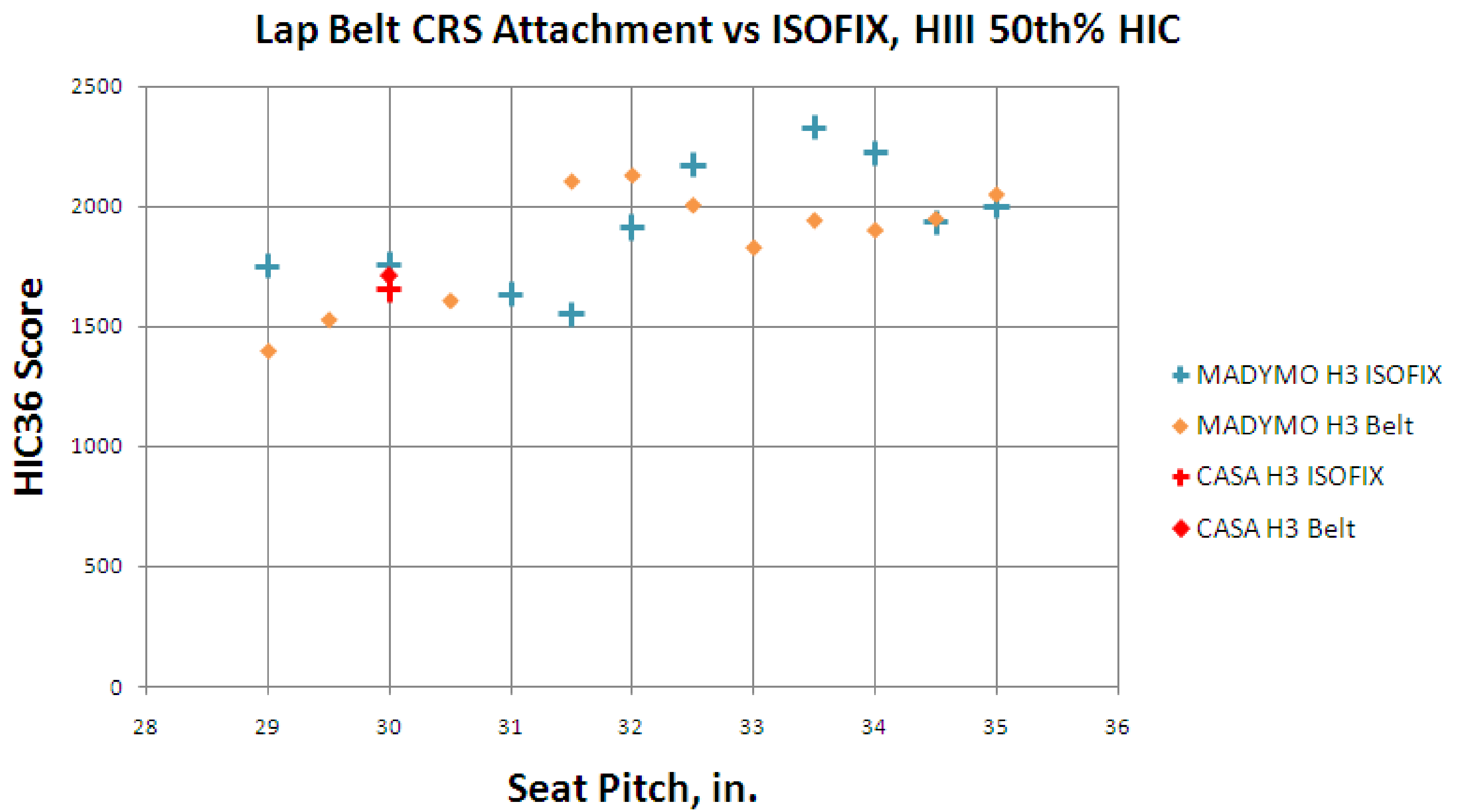


Values of proposed SAE ARP5765 Error Metric:

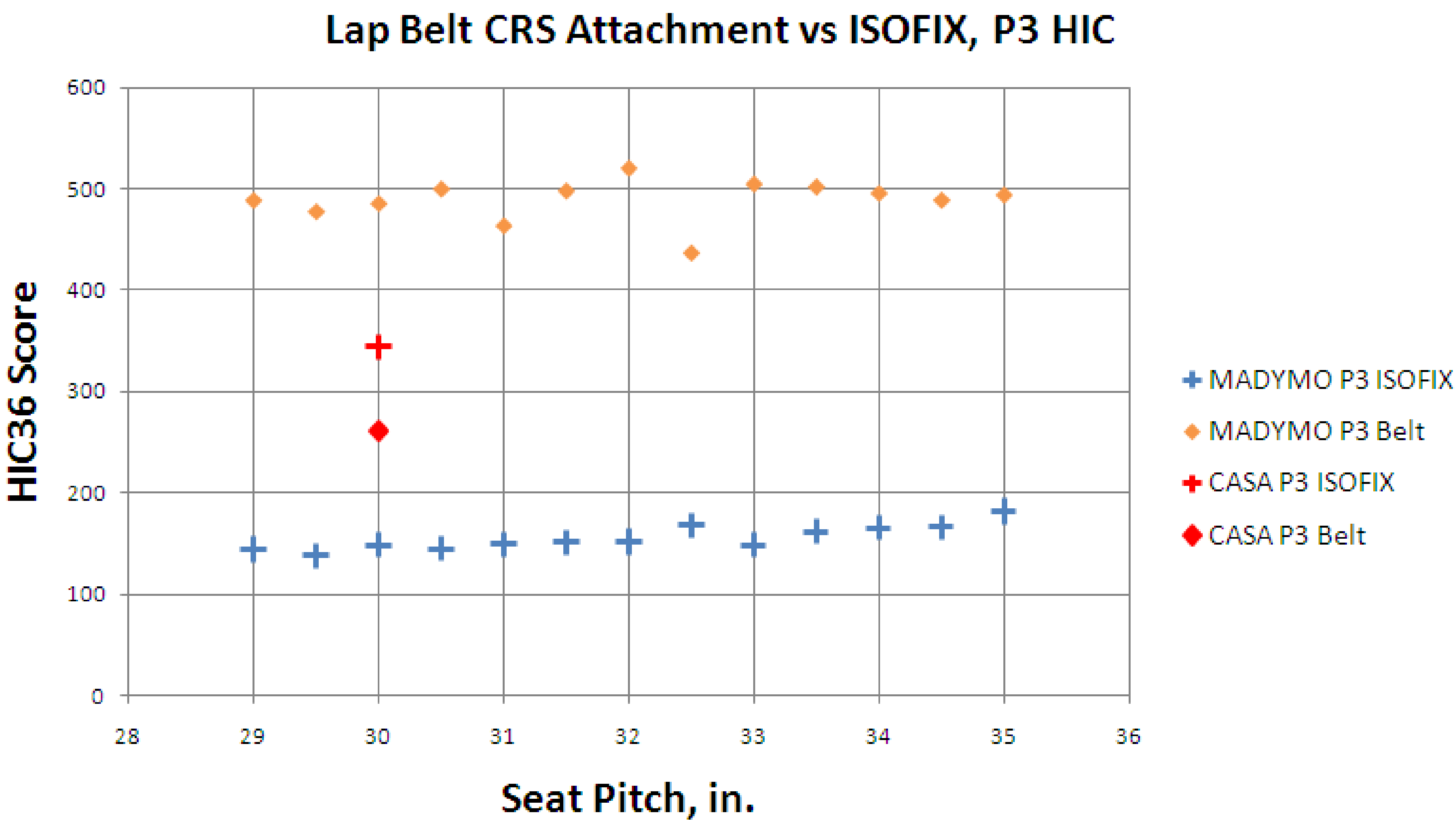
Delta Error-Max	**135.97**
Mag. Error-Max	**27.87%**
Delta Error-Min	**1.042**
Mag. Error-Min	**41.26%**
Shape Error	**19.60%**

P3 head acceleration comparison w/ test data
CRS installed with ISOFIX, P3 and H3 50th occupants

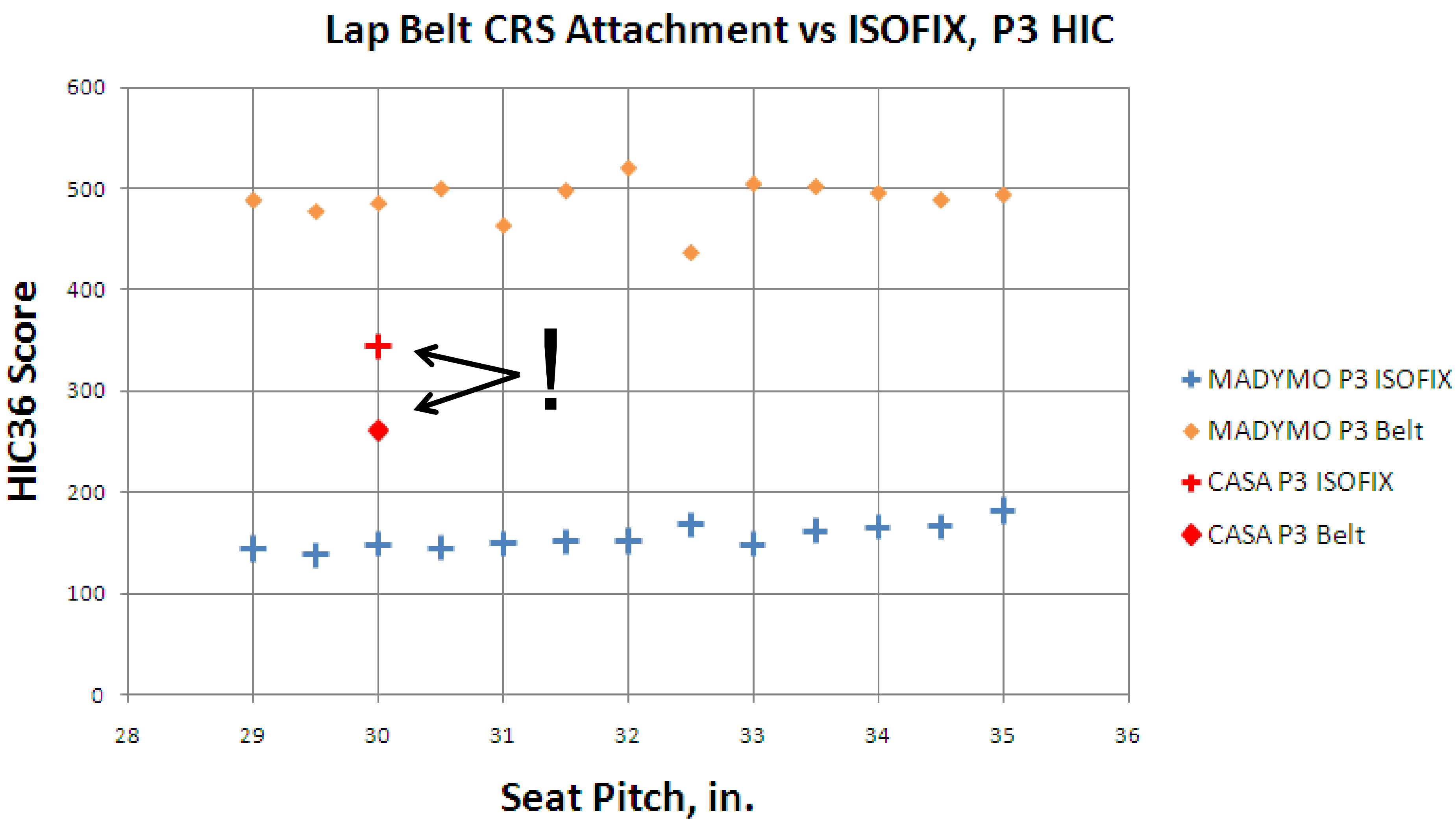
Results – Seat Pitch



Results – Seat Pitch



Results – Seat Pitch



Discussion

- Presently there is not a good match between physical and simulation data during tray table impact.
- Possible causes:
  - Better tray table component testing required
  - In simulation, ATD head acceleration prior to impact differs from test
  - Tray table can penetrate seatback and contact CRS shell

Questions Raised

- What is a reasonable level of validation for a model of this complexity?
- Is ‘error’ really error? What is the level of variability in physical tests of this nature?
- How should parameters that can’t easily be measured be dealt with? (eg. head/tray friction, foam damping)

Conclusion

- It is expected that a better result will be achieved with further model refinement and updated tray table material data
- A validated dynamic model of a complex system such as an aircraft seat/child restraint configuration is feasible
- Such a model will facilitate fast and economical research into the crashworthiness of ISOFIX/LATCH child restraints in aircraft

References

- Bathie, M. (2007). *An investigation of automotive child restraint installation methods in transport category aircraft*, Civil Aviation Safety Authority.
- Moorcroft, D. (2007). *Selection of validation metrics for aviation seat models,* The Fifth Triennial International Aviation Fire and Cabin Safety Research Conference.
- Olivares, G. and P. Amesar (2007). *Implementation of ISOFIX and LATCH equipped automotive child restraint systems in an aircraft environment*, National Institute for Aviation Research.
- Sprague, M. A. and T. L. Geers (2003). *Spectral elements and field separation for an acoustic fluid subject to cavitation*. Journal of Computational Physics **184: 149-162.**

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