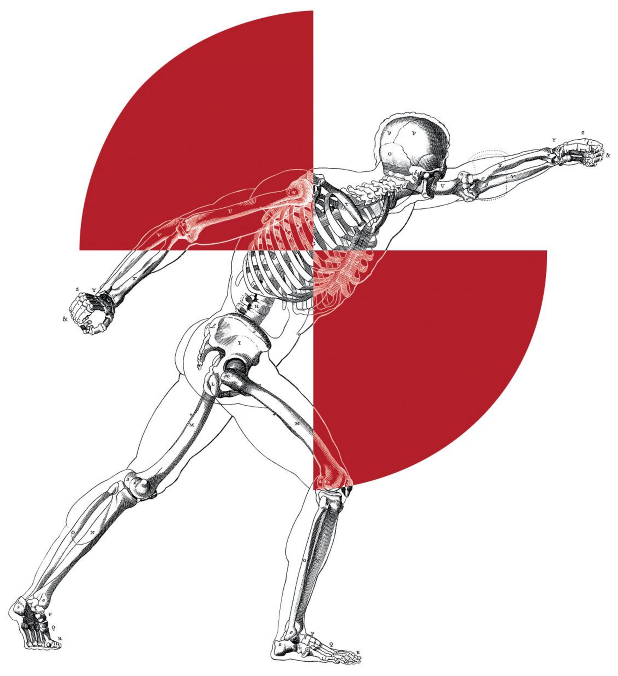

Development of Innovative 6aω Head Instrumentation Fixture for the Hybrid III 50th Percentile Male

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INTRODUCTION

- Motor vehicle collision (MVC) was the second leading cause of traumatic brain injury (TBI) with an estimated 292,202 people (17.3%) sustaining a TBI from MVC annually.[1] MVC resulted in the largest percentage of TBI related deaths with 16,402 occurring annually (31.8%).[1]
- Six degrees of freedom (6 DOF) rigid body kinematics are often measured using six linear accelerometers, nine linear accelerometers in a 3-2-2-2 configuration (NAAP), or three linear accelerometers with three angular rate sensors (3aω). However, each of these methods have mathematical limitations that affect the accuracy of the 6 DOF kinematics in severe impact conditions.[2, 3]
- Measuring 6 DOF kinematics using six linear accelerometers and three angular rate sensors (6aω) has been shown to minimize these limitations and provide the most accurate 6DOF kinematics by offering the following advantages[3, 4, 5]:
  - **Algebraic equations** for angular acceleration
  - **Direct measurement** of angular velocity
  - **Single numerical integration** for transformation matrix (Euler Angles)
- Additional advantages are offered by implementing the 6aω approach in a coplanar configuration (C6aω) at the head center of gravity (CG) of an anthropomorphic test device (ATD):
  - **Reduced cost**, a specialized headform (e.g., NAAP head) is not required
  - **Skull deformation errors do not occur** since sensors are mounted at the head CG rather than on the periphery of the ATD skull
- This study sought to develop and validate a universal, light weight C6aω fixture for an ATD head CG that reduces vibrational noise and improves data accuracy and ease of use.

MATERIALS & METHODS

Fixture Design

- A frequency response analysis of the Hybrid III 50th percentile male (HIII 50M) standard and NAAP heads was completed using data from hammer, pneumatic ram, and New Car Assessment Program (NCAP) impact scenarios. The heads did not have natural frequency content in the 4000 Hz range in any of those test conditions, so this was chosen as the fixture design target to avoid data analysis errors resulting from frequency resonance.
- Design Objectives:
  - First natural frequency in 4000 Hz range
  - Able to be installed at the CG of the HIII 50M head
    - No issues due to skull deformation
  - Securement utilizing the HIII 50M head base plate bolt pattern
    - Enables installation in other ATDs (HIII 5F, HIII 10YO, ES-2, SID-IIs)
  - Allow for installation of 6aω instrumentation
  - Total mass less than 102.36 grams
  - Modular design utilizing standard instrumentation blocks
    - Reduced cost and improved ease of use
  - Easy access to securement locations
  - Mass CG alignment between fixture and head assembly
- Figure 1 shows the final C6aω fixture design meeting the design objectives

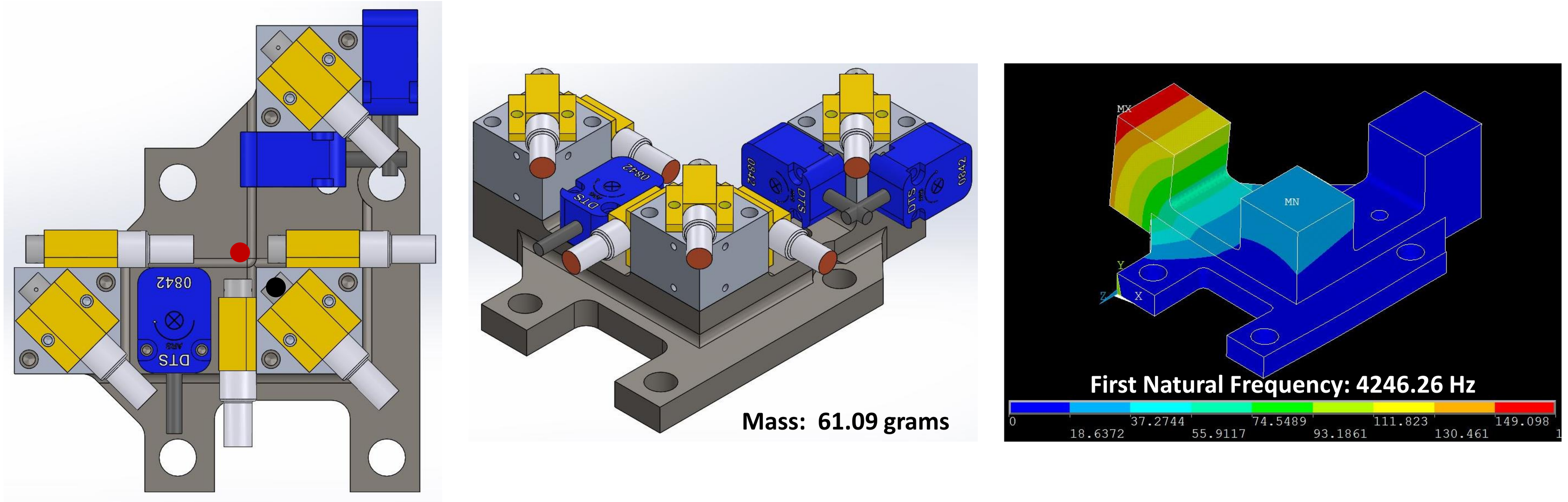

Figure 1: Final design of C6aω fixture

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MATERIALS & METHODS

Fixture Validation

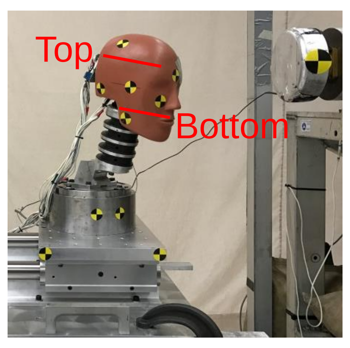

Figure 2: Test setup for a top left-oblique, 45° impact of the HIII 50M headform

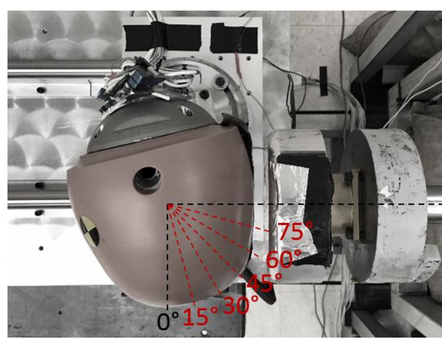

Figure 3: Impact directions for left-oblique locations

- A pneumatic ram weighing 23 kg impacted a HIII 50M headform at four speeds (1, 2, 3, 4 m/s), four locations (top right-oblique, bottom right-oblique, top left-oblique, bottom left-oblique), and five impact directions (15°, 30°, 45°, 60°, 75°), Figure 2 and Figure 3.
- A HIII 50M ATD was instrumented with six accelerometers and three angular rate sensors (ARS) in a C6aω head CG fixture, Figure 4. The C6aω fixture was validated against nine accelerometers (tNAAP) and six accelerometers with three ARS (t6aω) on a tetrahedron fixture mounted to the ATD skull cap, Figure 5.[6] The ATD headform was attached to the standard HIII 50M neck.

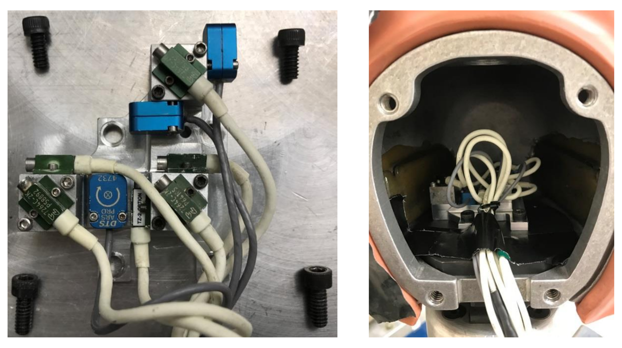

Figure 4: Instrumented C6aω fixture

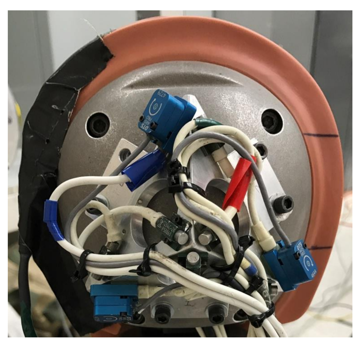

Figure 5: Instrumented tetrahedron fixture[6]

- From each test, linear acceleration and angular velocity were measured directly within the headform utilizing the C6aω fixture and externally on the tetrahedron fixture. This data was used to validate the C6aω fixture compared to tNAAP by calculating angular acceleration, transformed kinematic data, HIC-15 and BrIC values.

RESULTS & DISCUSSION

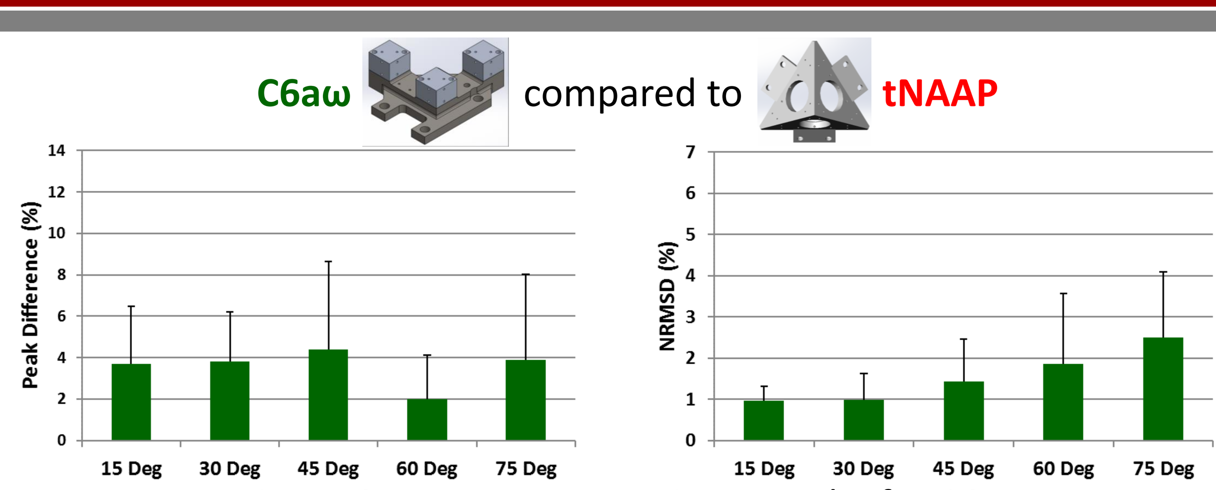

Figure 6: Average comparison results for C6aω compared to tNAAP resultant angular accelerations

- Figure 6 shows C6aω validated against tNAAP with less than 5% average peak differences and 3% average NRMSD for resultant angular acceleration with impacts ranging from HIC-15 values of 1.0 to 3126.6 and BrIC values of 0.14 to 2.0.

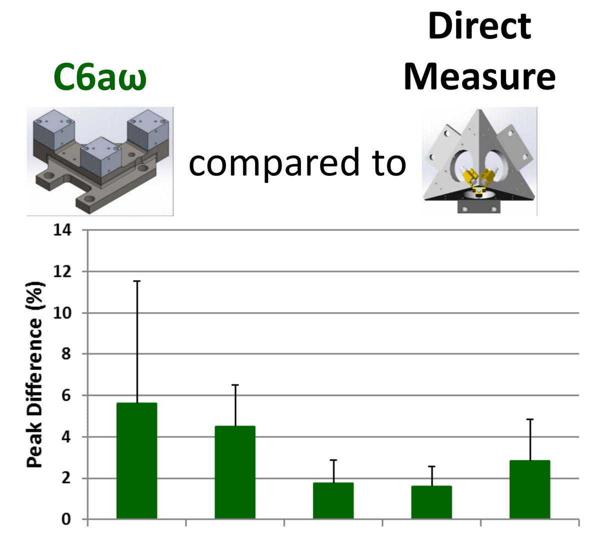

Figure 7: Average comparison results for C6aω compared to direct measure resultant linear accelerations

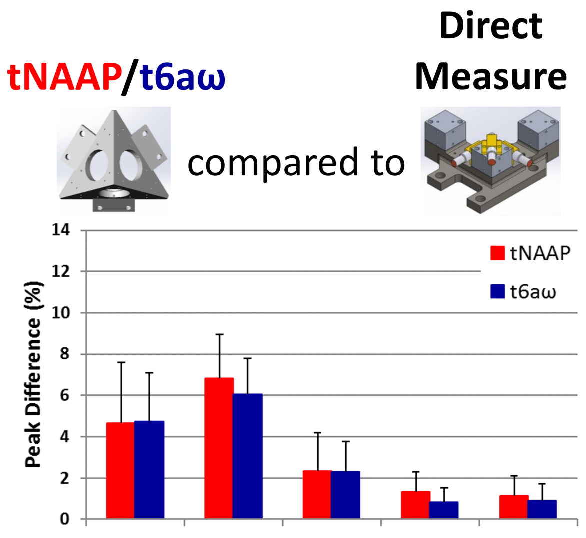

Figure 8: Average comparison results for tNAAP and t6aω compared to direct measure resultant linear accelerations

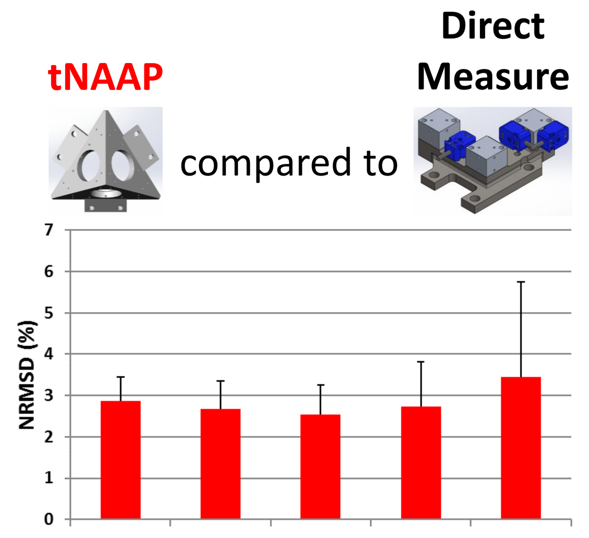

Figure 9: Average comparison results for tNAAP compared to direct measure resultant angular velocities

- Figure 7 shows C6aω validated against directly measured resultant linear acceleration with < 6% average peak percent difference.
- Figure 8 shows tNAAP and t6aω compared to directly measured resultant linear acceleration with average peak percent differences > 6%.
- Figure 9 shows average angular velocity NRMSD > 3% for tNAAP compared to directly measured resultant angular velocity, demonstrating the mathematical error associated with the numerical integration required to obtain angular velocity using tNAAP.
- The repeatability and reproducibility of the C6aω fixture was confirmed with the maximum peak percent differences between Fixture 1 and Fixture 2 < 1% and the peak percent differences within each fixture to be < 4% for resultant angular acceleration, linear acceleration and angular velocity for all repeatability tests.

CONCLUSIONS

- The C6aω fixture met all proposed design requirements.
- The C6aω fixture was validated against the tNAAP scheme with < 5% average peak differences and < 3% average NRMSD for resultant angular acceleration in all test conditions with impacts ranging from 1.0 to 3126.6 HIC-15 values and 0.14 to 2.0 BrIC values.
- The C6aω fixture had lower peak percent difference errors compared to tNAAP and t6aω for directly measured resultant linear acceleration and t6aω had overall lower peak percent differences compared to tNAAP.