Analysis of a Frontal Impact of a Formula SAE Vehicle

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Overview

- Introduction
  - Formula SAE
  - Impact Attenuator Rules
  - Methodology
- Evaluation Criteria
  - HIC, Neck Loads and Moments, Nij, Femur Loads
- Testing Procedures
  - Baseline Testing, Pulse Shape Comparison, Critical Speed Test
- Results
  - Comparison of evaluation criteria
  - Kinematic Analysis using high speed video
- Conclusions
Introduction - Formula SAE

- Worldwide collegiate competition
- Students conceive, design, and fabricate small formula style cars
- Driver risks have never been tested in a crash environment
3.3.6.4 Impact Attenuator Data Requirement

- The team must submit calculations and/or test data to show that their Impact Attenuator, when mounted on the front of the vehicle with a total mass of 300 kgs (661 lbs) and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 m/s (23 ft/s), would give an average deceleration of the vehicle not to exceed 20 g.

- Does not specify deceleration time-history pulse shape.
Introduction – Methodology

- Evaluate the Impact Attenuator rule based on ATD Injury Criteria
- Explore the “Safety Envelope” by increasing impact speeds
- Evaluate Pulse Shape
- Kinematic Analysis Using High Speed Video
- Evaluate HANS Device Effectiveness
Typical Test

Test Conditions
• 7.0 m/s
• 16.5 g avg
• 35 ms
Evaluation Criteria - HIC

- Head Injury Criteria (HIC) is used to evaluate the severity of head trauma based on accelerations.
- HIC consists of two criterion, $HIC_{36}$ and $HIC_{15}$.
- $HIC_{36}$ and $HIC_{15}$ calculate the highest average acceleration over a 36 ms and 15 ms period respectively.
- Values for $HIC_{36}$ that exceed 1000 and values of $HIC_{15}$ that exceed 700 represent a 31% chance of skull fracture.
Evaluation Criteria - Nij

- $N_{ij}$ criteria is based on the resultant neck loads and moments experienced by the ATD.
- $N_{ij}$ represents the four major combinations of neck loading in a frontal crash:
  - $N_{ce}$: Compression load and Extension moment
  - $N_{cf}$: Compression load and Flexion moment
  - $N_{te}$: Tension load and Extension moment
  - $N_{tf}$: Tensions load and Flexion moment
- $N_{ij}$ values that exceed 1.0 and individual load and moment values that exceed their IARV represent a 22% chance of AIS 3 neck injury.
Evaluation Criteria - Femur

- Axial load cell in femur measures compression and tension loads

- Axial loads that exceed 10,000 N represent a 35% chance of a moderate injury to the femur
Procedure

- **Baseline Test**
  - Replicate as close as possible the deceleration due to the impact attenuator: 7.0 m/s, 20 g average, 35 ms pulse

- **Pulse Shape Comparison**
  - Increased speed to 12.5 m/s, average of 16 g, 80 ms pulse
  - Three pulse shapes compared: early high-g peak, constant g, and late high-g peak
  - Each pulse shape compared both with and without the use of a HANS device

- **Critical Speed Test**
  - Increased impact speed until Injury Assessment Reference Values were exceeded
  - Test specifications: 15.6 m/s, 80 ms pulse, 20 g average deceleration
  - Utilized late high-g pulse shape and was tested with and without HANS
Early High-g Pulse
Constant-g Pulse
Late High-g Pulse
Results – Baseline

- Showed no condition where IARV were exceeded
- Test one, two, and three values were negligible when compared to the IARV
- Many values in test four were much closer to the IARV
  - May be due to much higher initial velocity (11.2 m/s) and average deceleration (27.6) than tests one, two, and three
- Femur load cell was not utilized
Results - Baseline

<table>
<thead>
<tr>
<th>Test</th>
<th>Average Acceleration (g's)</th>
<th>V (m/s)</th>
<th>Tension Neck Load (N)</th>
<th>Compression Neck Load (N)</th>
<th>Flexion Neck Moment (N-m)</th>
<th>Extension Neck Moment (N-m)</th>
<th>N&lt;sub&gt;ce&lt;/sub&gt;</th>
<th>N&lt;sub&gt;le&lt;/sub&gt;</th>
<th>N&lt;sub&gt;cf&lt;/sub&gt;</th>
<th>N&lt;sub&gt;lf&lt;/sub&gt;</th>
<th>Peak Resultant Head Accel (g's)</th>
<th>HIC&lt;sub&gt;se&lt;/sub&gt;</th>
<th>HIC&lt;sub&gt;ts&lt;/sub&gt;</th>
<th>Axial Femur Load (N)</th>
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Results - Baseline

- ATD did not experience maximum acceleration until after 35 milliseconds

Test Conditions:
- Baseline Test #4
Results - Pulse Shape

- No condition where IARVs were exceeded
  - On average the constant-g measured values exceeded that of the early-g and late-g pulses
  - The average initial velocity of the constant-g pulse was also 1 m/s higher than the early-g pulse and 2.5 m/s higher than the late-g pulse
  - The addition of the HANS device reduced the tension neck load in every test
## Results – Pulse Shape

<table>
<thead>
<tr>
<th>Test</th>
<th>Average Acceleration (g's)</th>
<th>ΔV (m/s)</th>
<th>Tension Neck Load (N)</th>
<th>Compression Neck Load (N)</th>
<th>Flexion Neck Moment (N-m)</th>
<th>Extension Neck Moment (N-m)</th>
<th>N_ex</th>
<th>N_xx</th>
<th>N_d</th>
<th>N_y</th>
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<th>HIC&lt;sub&gt;g&lt;/sub&gt;</th>
<th>HIC&lt;sub&gt;c&lt;/sub&gt;</th>
<th>Axial Femur Load (N)</th>
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## Results – Pulse Shape

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<th>Test</th>
<th>V (m/s)</th>
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<th>N_e</th>
<th>N_c</th>
<th>N_f</th>
<th>N_e</th>
<th>Peak Resultant Head Accel (g's)</th>
<th>HIC_e</th>
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### Average Values w/o HANS

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<th>V (m/s)</th>
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### Average Values w/ HANS

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### Comparison with and w/o HANS

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Results – Critical Speed

- During the critical late high-g test the tension neck load, HIC$_{15}$, HIC$_{36}$, and femur load IARV were exceeded.
- The use of the HANS device reduced the tension neck load below the IARV.
- The use of the HANS did not affect the HIC$_{15}$, HIC$_{36}$, and femur load values.

<table>
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<tr>
<th>Test</th>
<th>Axial Femur Load (N)</th>
<th>Peak Resultant Head Accel (g's)</th>
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Results – Critical Speed Kite Graph (no HANS)

Test Conditions
• 15.6 m/s
• 20 g avg
• 80 ms
Results – Critical Speed Kite Graph (w/ HANS)

Test Conditions
- 15.6 m/s
- 20 g avg
- 80 ms
Conclusions

- The baseline tests that approximated the Formula SAE rules (7.0 m/s, 20-g average deceleration) resulted in measured injury values that were negligible compared to the IARV.
- The tests comparing pulse shape all resulted in values which were less than the IARV.
- The statistically highest values comparing pulse shape were seen during the constant-g test however, the average acceleration was slightly higher for these tests.
Conclusions Cont.

- The addition of a HANS device reduced the tension neck load in every test and brought the test value below the IARV for the critical speed test.
- An impact from 15.6 m/s with a 20-g average deceleration rate was found to pose a serious risk of injury to the driver, with and without the HANS device.

To reduce the risk of injury to the driver, horizontally mounted tubes should be placed a...
Acknowledgements

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References

Thank You For Your Time

Any Questions?