Evaluation of Mid-Size Male Hybrid III Models for use in Spaceflight Occupant Protection Analysis

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Overview

• Background of the Hybrid III & FE Model
• NASA Occupant Protection Environment & Challenges
• Approach to meet those challenges (current study)
• Results & Interpretation
• What to do with these results
Hybrid III Anthropomorphic Test Device (ATD)

- Mid-size male developed in the 1970s for automotive testing
- Designed for frontal, automotive, severe crashes
- Steel and rubber architecture
- Limitations
  - Not intended for lateral use
  - Neck response limited outside design
  - Automotive Seating Posture
Implementation of Hybrid III

- **Injury Assessment Reference Values (IARV)**
  - Transfer function between mechanical response & human injury
  - Used to establish vehicle standards

- **Vehicle Testing**
  - Standard Evaluation
  - Design Optimization

- **Limitations**
  - Cost
  - Time
Finite Element (FE) Modeling

- **Intent**
  - Optimize vehicle design prior to testing
  - Evaluate vehicle safety outside testing scope

- **LSTC Hybrid III FE Models**
  - Developed 1990’s
  - Use in Automotive Simulation
  - Approximated Mat. Properties
  - Calibrated to for intended use
  - *Extensibility?*

- **Detailed HIII Model**
  - 451,768 Elements
  - Detailed joint definitions
  - Accurate Geometry
  - ~1.5 hour run time *(300ms pulse)*

- **Fast HIII Model**
  - 4,310 Elements
  - Simplistic joint definitions
  - Simplified geometry
  - ~26 hour run time *(300ms pulse)*
Hybrid III Extended Uses

Aerospace

Spaceflight

Military

Hybrid III ATD
Spaceflight’s Need for Occupant Protection

• New multipurpose crew vehicle (MPCV) Orion to be face of the National Space program

• Development of commercial space enterprises will see a dramatic increase in human space travel.
  • ISS Transport
  • Recreation
  • Asteroid mining
  • Colonization
Challenge of Spaceflight Occupant Protection

- Unique aspects of spaceflight
  - “Crash” every time – need low probability of injury
  - Spacesuits – blunt trauma, load path
  - Deconditioning – understand how it changes impact tolerance

- Variable Landing conditions

  **Nominal**
  - Planned
  - Low g impact
  - Directional control (+X)

  **Off - Nominal**
  - Weather, Chute failure, abort, etc.
  - Variable g impact
  - Multi-directional
    - (±X, ±Y, +Z)
Current approach to Spaceflight Occupant Protection

- **Physical Testing**
  - Vehicle Qualification
  - Defined Hybrid III IARV limits
  - Extremely Costly

- **FE-Modeling**
  - Efficient (Time and Money)
  - Versatility
  - Used early in design
  - Accuracy?

*How accurate are current Hybrid III FE models in predicting the physical ATD under spaceflight loading conditions?*
Testing Overview

- ATD sled test series
- Performed at WPAFB on HIA
- Auto & FAA Hybrid III
- Exercise ATD response
  - Directional
  - Rate Dependence
Testing Overview: Impacts

Frontal Impact

Spinal Impact

Rearward Impact
Testing Overview: Impacts

Lateral Impact: No Side Restraints

Shoulder & Leg Restraints

Full Lateral Restraint
Modeling Setup

- Rigid generic seat (mitigate model uncertainty)
- 5 point belt: as spaceflight design
- Limitations
  - Initial position
  - Unknown Arm restraints
    - Sensitivity showed minor effect
Modeling Overview: Initialization Checks

- Defined $F(t)$
- Belt Pretension
- 1G Preload

Pre-Load : 150 ms

- Belt Load
- Seat Contact
- Total Energy
- Kinetic Energy

Belt Tension: 20 lb

Ratio = 0.04

1g
ISO Curve Comparisons

**Corridor**

**Magnitude**

**Phase**

**Slope**

\[
\frac{(.4xS_c) + (.2xS_m) + (.2xS_p) + (.2xS_p)}{1}
\]

**ISO Score (1/1)**
Results: Test Repeatability

- Min. 1 Tests repeat per direction
- >.75 ISO threshold for analysis
- Limited kinematic responses removed

**Rearward:** .80

**Frontal**
- SPFZ: .69

**Spinal**
- SPFZ: .32

**Lateral**
- SPFZ: .73
Frontal Impact: Predicted Responses

- Accurately Predicted Frontal kinematics
  - Forward flexion

- Test --FE Detailed --FE FAST
Frontal Impact: Areas Concern

- FAST FE lumbar spine response
Frontal Impact: Rate Dependence

- Acceleration Rate (Peak / Rise Time) dependence
- Detailed FE: Head/Neck rotation response

-Test --FE Detailed --FE FAST

**ISO score vs Acceleration Rate**

\[ R^2 = 0.9932 \]

\[ R^2 = 0.6287 \]

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10g - 110 ms

10g – 30 ms
Spinal Impact: Predicted Responses

- Accurately Predicts Off-axis kinematics
  - Forward flexion

-Test1--FE Detailed --FE FAST
-Test2
Spinal Impact: Areas of Concern

• On Axis Response
• Detailed FE
Spinal: Rate dependency

- Acceleration Rate (Peak / Rise Time) dependence
- Both FE: Pelvis Acceleration

Pelvis Response ISO score vs Acceleration Rate

- Test --FE Detailed --FE FAST
Rearward: Predicted Responses

- Test  --FE Detailed  --FE FAST

• Head & Pelvis

[Graphs showing acceleration over time for Head & Pelvis]
Rearward: Areas of Concern

- Chest & Neck
- Lateral: No Side Restraints
- Overall well correlated
- Head Y acceleration not picked up
Lateral: Shoulder & Leg Restraints

- Shape and Size prediction
- Head Y acceleration not picked up
- Head Y acceleration not picked up
- Pelvis: Detailed rate dependence
- Shape and Size prediction
Overall Conclusions

- **Directional dependence**
  - Consistent to field of design

- **Detailed vs. Fast**
  - Detailed though marginal

- **Belt driven motion**
  - Both models demonstrate accuracy

- **Seat driven motion**
  - Detailed model demonstrates incorrect rate effects

- **Questions?**
  - Simplified shape = improved rate dependence?
    - Shape + Material compensation?
Future Work

• Tease out model Inconsistencies
• Component evaluation
  • Rate Dependence
  • Geometry Effects
• Sensitivity Analysis
  • Identify positioning effects
  • Rate thresholds
• Expand use
  • Flexible Seat environment
  • Combined Loading
  • Full crew loads analysis
Thank You!