



Development and Calibration of the LSTC Hybrid III 95th Finite Element Model Head-Neck Complex

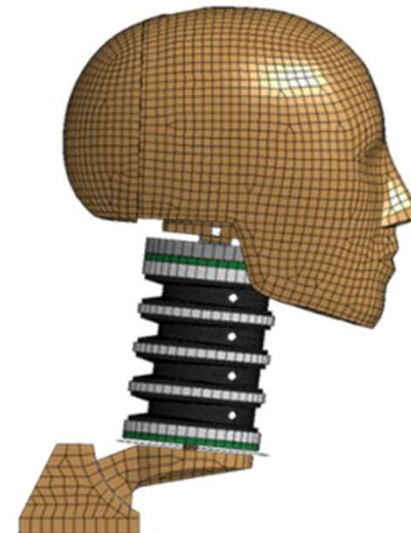
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Hybrid III 95th



- **History**
 - Developed in the 1980's through scaling of the Hybrid III 50th
 - Upgraded in early 2000's to improve measurement capabilities
- **Use in Automotive**
 - Primary use as ballast for belt integrity evaluation
- **Used in Aerospace Industry**
 - Necessity in certification with helmeted occupants
 - Used in certification of the NASA Orion Spacecraft

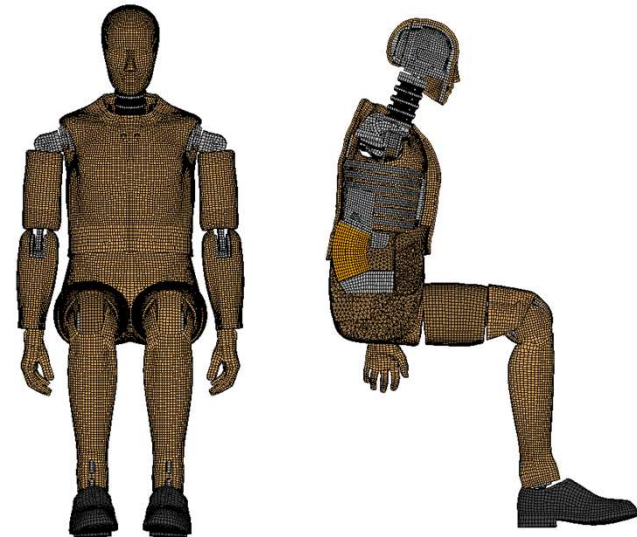


Hybrid III 95th Finite Element Model (FEM)



- **LSTC Hybrid III 95th FEM**
 - Geometrically scaled from the Hybrid III 50th FEM
 - Primary use as representative mass for automotive simulation
 - Material properties not updated to match different materials used in 50th and 95th ATD's
 - Neck and materials stiffened in physical ATD to represent increased musculature

Need to quantify the effects of improper scaling and material definitions of the 95th FEM on it's predictive capabilities

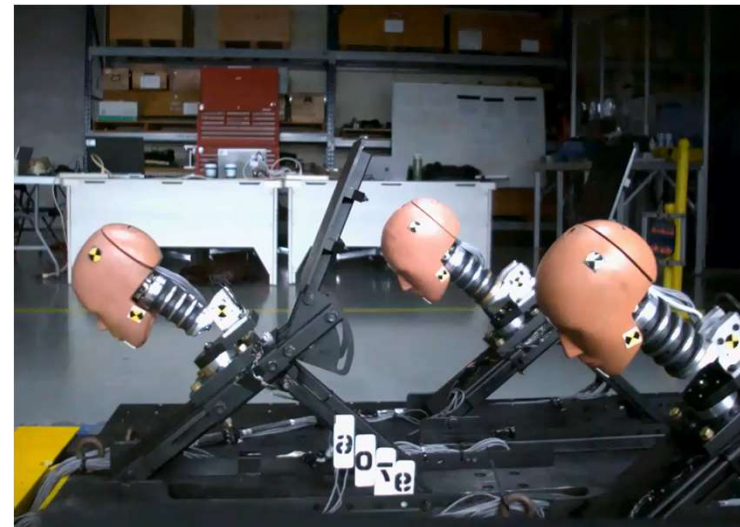


- **LSTC 95th HIII V3**
 - 451,779 Elements
 - ~26 hour run time (300ms pulse)

Testing Overview



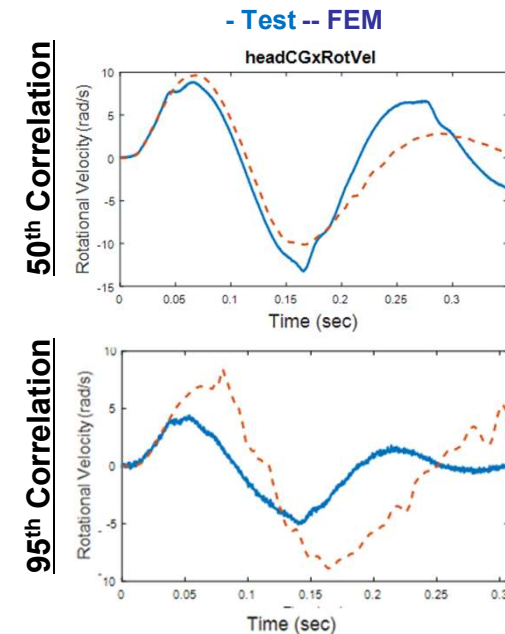
- Test series to evaluate the LS-DYNA FEMs of the Hybrid III 5th, 50th, and 95th percentile head-neck complex
- Sled test series performed at Wright Patterson Air force Base (WPAFB) on Horizontal Impact Accelerator (HIA)
- Combined vertical-horizontal loading and multi-directional ATD response
 - Head-Neck at 40° to sled
 - Varied impact directions (frontal, rearward, lateral)
 - Varied accelerative conditions (6-16g, 50-100ms rise times)



Test Findings



- **5th and 50th percentile FEM predictions were reasonable**
 - Closely predicted shape, phasing, and peak response of test data
- **95th percentile male FEM predictions were not reasonable**
 - Model does not accurately predict natural frequency or magnitude of head motion under inertial loading



How do we improve the correlation of the 95th head-neck FEM to develop confidence in it's predictive capability?

Path to Improvement



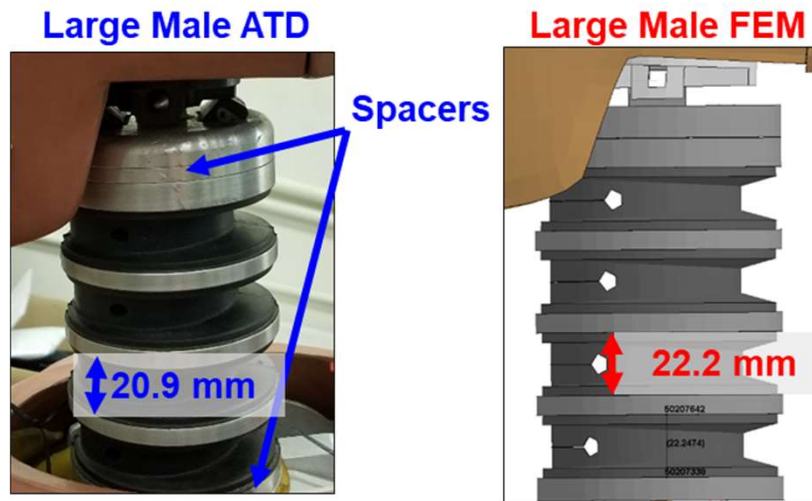
1. Investigate differences in head and neck geometry, mass properties and material properties
2. Update geometry and mass properties to match physical ATD
 - For difference in neck, use medium male FEM neck as starting point
 - Add FEM spacers to match physical ATD configuration
3. Conduct optimization study to determine material properties
4. Assess correlation of updated FEM against existing head-neck test data, using existing head-neck sled test data for correlation comparison

1. Investigate Differences in Head-Neck Geometric Properties



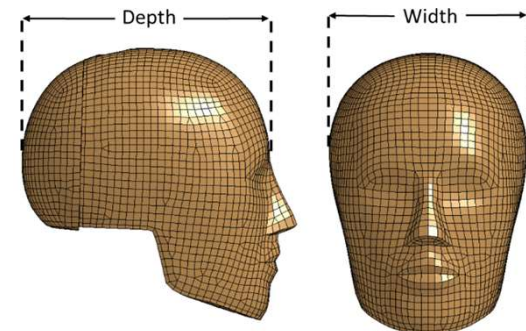
Neck Geometry

- FEM is missing two spacer plates in the neck
- FEM neck puck components were longer than in the physical ATD



Head Geometry

- FEM head-form dimensions were verified against physical ATD specifications
- FEM head-form mass below design specifications



Head Property	Physical ATD	Baseline FEM
Head Depth (in)	7.87	7.95
Head Width (in)	6.10	6.14
Head Weight (lb.)	10.89 ± 0.11	10.27



2. Update Geometry and Mass Properties

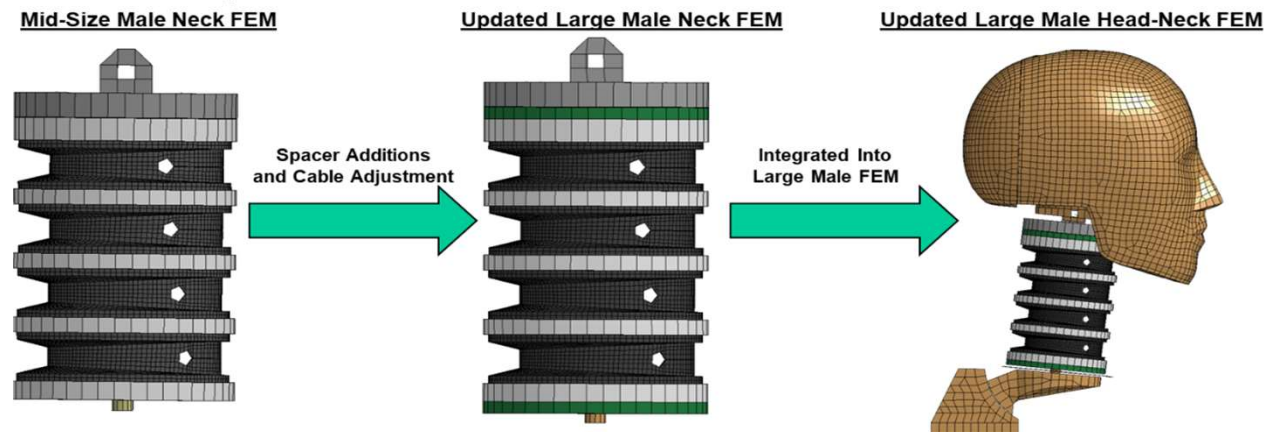
Head Mass

- 0.5 lb point mass added to CG of FEM head-form

Head Property	Physical ATD	Baseline FEM	Updated FEM
Head Weight (lb.)	10.89 ± 0.11	10.27	10.80

Neck Geometry

- Mid-Size Male FEM neck as starting geometry
- Add spacers to match physical ATD configuration
- Lengthen Neck Cable
- Replace Neck in Large Male FEM

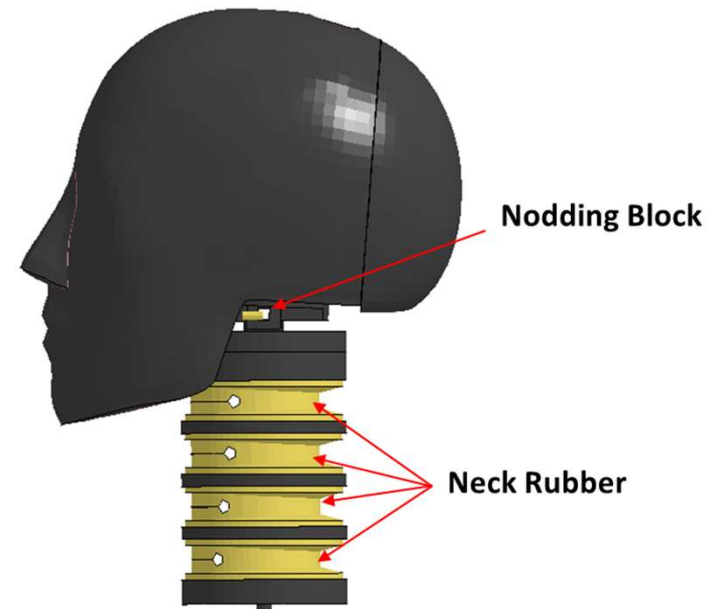




3.1 Selection of Material Parameters for Optimization

Sensitivity Analysis Methodology

- Neck rubber and nodding block parts evaluated
- Material stiffness parameters varied between baseline and 10X baseline to determine sensitivity
 - Parts known to be stiffer in ATD than FEM
- Head rotational velocity evaluated under frontal impact simulation





3.1 Selection of Material Parameters for Optimization

Sensitivity Analysis Results

- Changes to shear modulus of neck rubber found to drive response changes
- Three parameters defining shear modulus selected for optimization: G_0, G_i, β

Shear Modulus Definition

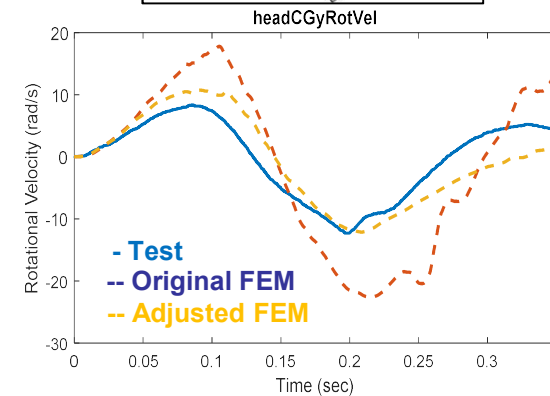
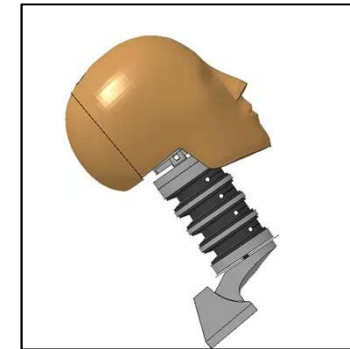
$$G(t) = G_i + (G_0 - G_i)e^{-\beta t}$$

G_i : Long term shear modulus

G_0 : Short term shear modulus

β : Decay Constant

Frontal Impact





3.2 Optimization Procedure

Multi-Step Optimization

- 1: LS-Opt- Lateral impact to better characterize G_0 and G_i
- 2: LS-Opt- Rearward impact including all 3 shear parameters of neck pucks
- 3: Manual optimization – Manually tuned model using information gained from the LS-Opt optimization runs

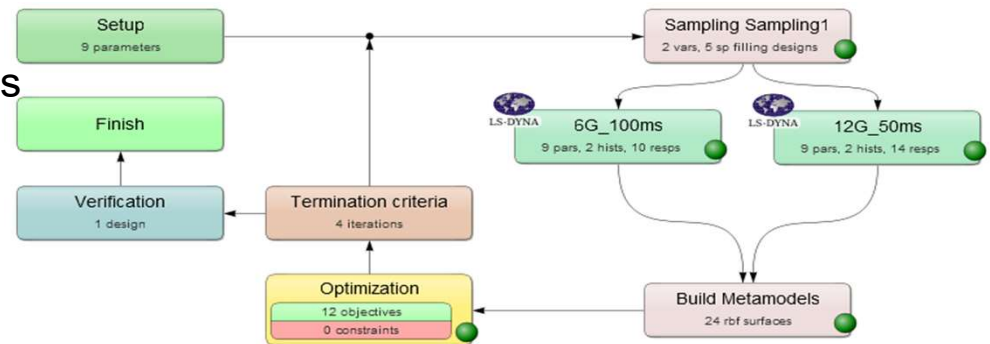
Variable	Original
G_0 , [psi]	6.67E2
G_i , [psi]	1.45E2
β	0.11



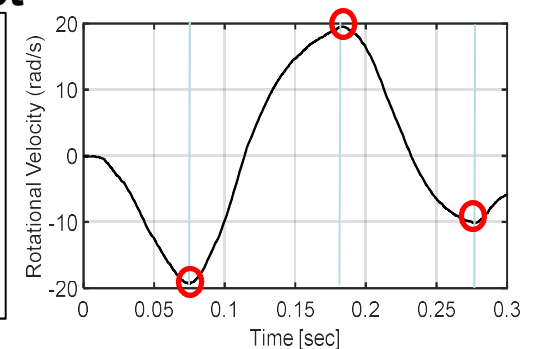
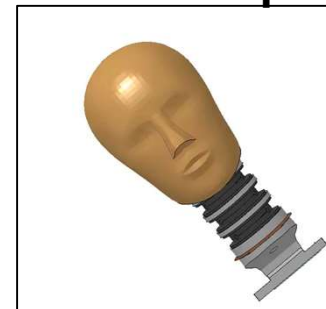
3.3 Lateral Optimization: Setup

Optimization Procedure

- Simulated 6G_100ms and 12G_50ms lateral impact cases
- Independent variables: G_0 and G_i
- Objectives: head rotational velocity and neck compression - peak and time of peaks
- 40 Simulations: 4 Iterations x 5 variable designs x 2 simulation cases



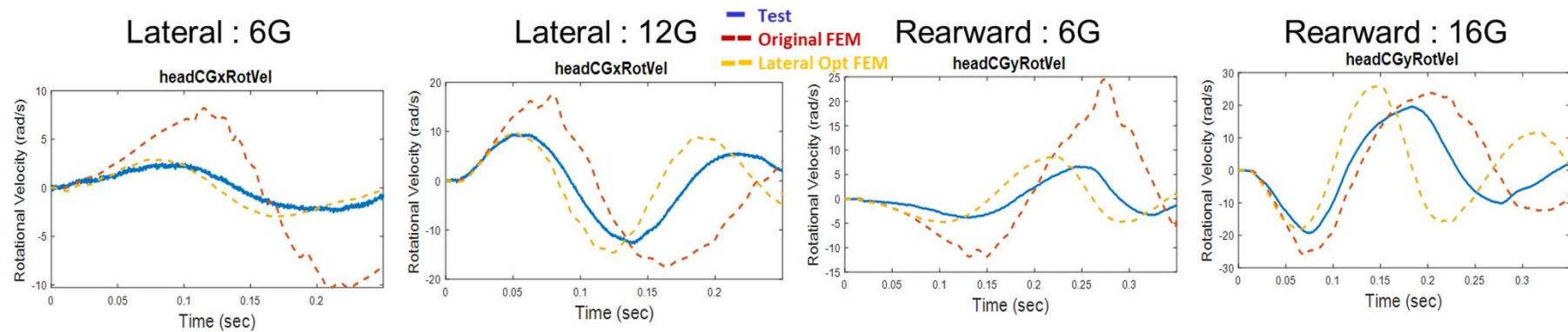
Lateral Impact





3.3 Lateral Optimization: Results

Improved peak values, but had timing issues, particularly when evaluated under the rear impact conditions



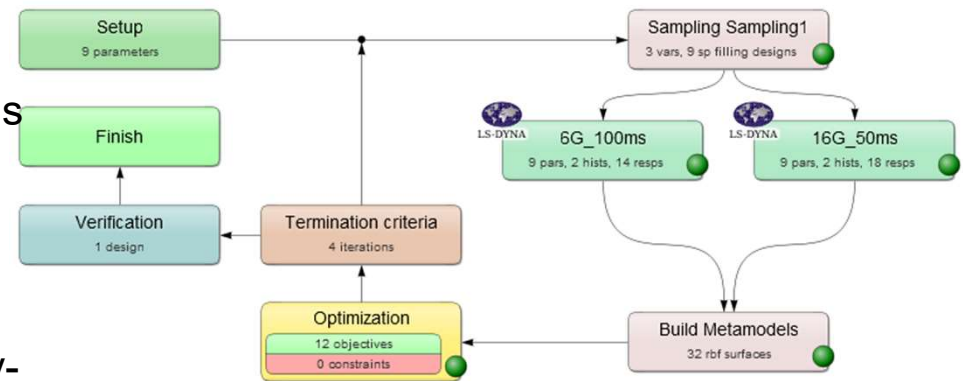
Variable	Original	Lateral Opt
G_0 ,[psi]	6.67E2	1.16E3
G_i ,[psi]	1.45E2	5.80E2



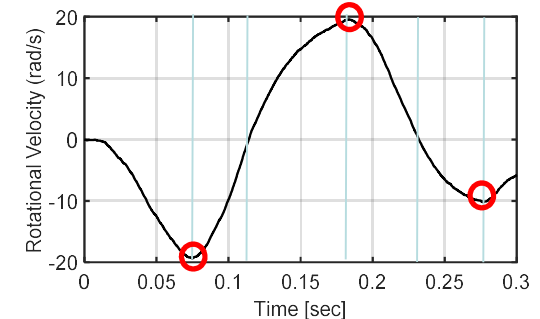
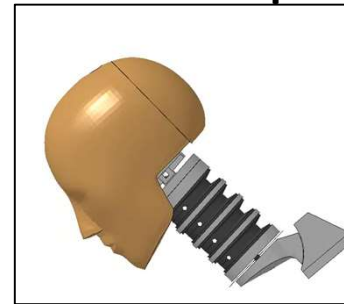
3.4 Rearward Optimization: Setup

Optimization Procedure

- Simulated 6G_100ms and 16G_50ms rearward impact cases
- Independent variables: G_0, G_i, β
- Objectives: head rotational velocity peak, time of peak, and crossing of y-axis
- 72 Simulations: 4 Iterations x 9 variable designs x 2 simulation cases



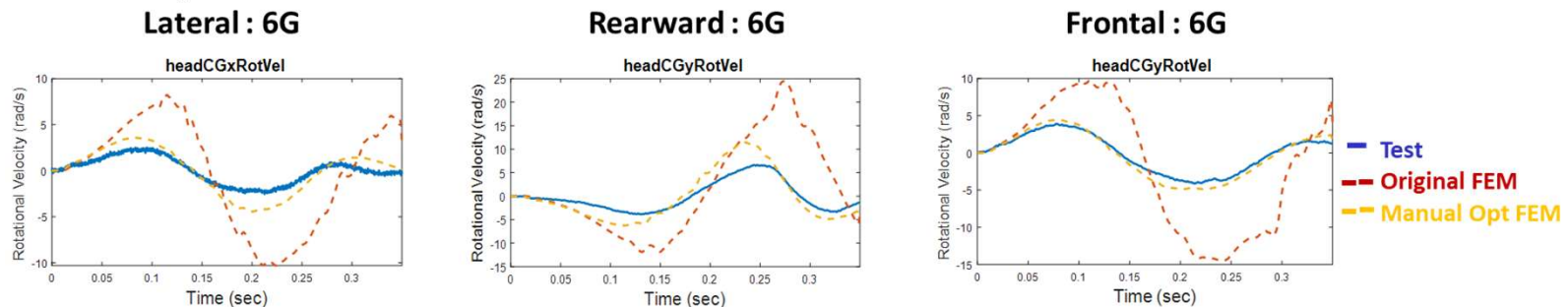
Rearward Impact





3.5 Manual Optimization: Results

- A compromise between peak values at lower impact energy and phasing was made
- Final solution resulted in significant improvement to model response verified in frontal impact simulations

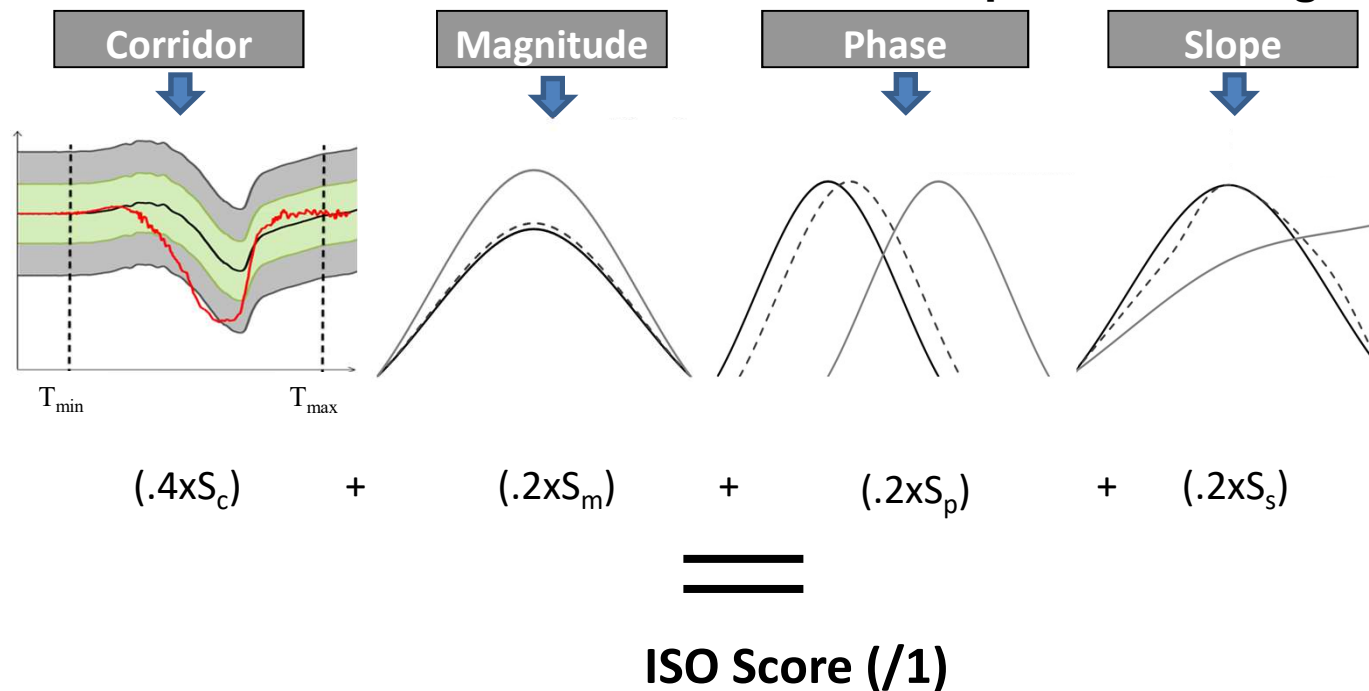


Variable	Original	Lateral Opt	Rearward Opt	Manual Opt
G_0 ,[psi]	6.67E2	1.16E3	1.31E3	1.15E3
G_1 ,[psi]	1.45E2	5.80E2	1.45E2	3.63E2
β	0.11	N/A (0.11)	0.07	0.116



4. Optimization Verification: Approach

- All isolated head-neck tests conditions were simulated and evaluated
- Qualitative evaluation : ISO-TR 16250 Curve Comparison Rating Methodology



4. Optimization Verification: ISO Scores



Original FEM ISO Scores

Green : ISO > 0.5

Red : ISO < 0.5

	Head Gx	Head Gy	Head Gz	Head Gx Rot Vel	Head Gy Rot Vel	Neck Upper Fx	Neck Upper Fy	Neck Upper Fz	Neck Upper Mx	Neck Upper My	Nij
Frontal 6g 100ms	0.50		0.34		0.25	0.50		0.25		0.37	0.31
Frontal 8g 50ms	0.54		0.42		0.29	0.54		0.53		0.44	0.35
Frontal 10g 100ms	0.71		0.35		0.31	0.68		0.33		0.56	0.41
Frontal 12g 100ms	0.79		0.38		0.35	0.75		0.33		0.62	0.51
Frontal 12g 50ms	0.65		0.42		0.38	0.65		0.59		0.56	0.49
Frontal 16g 50ms	0.63		0.56		0.50	0.64		0.63		0.60	0.52
Lateral 6g 100ms		0.58	0.40	0.24			0.55	0.41	0.47		0.54
Lateral 8g 50ms		0.46	0.61	0.26			0.43	0.70	0.38		0.58
Lateral 10g 100ms		0.62	0.28	0.27			0.58	0.30	0.52		0.600
Lateral 10g 50ms		0.48	0.56	0.28			0.46	0.67	0.41		0.64
Lateral 12g 100ms		0.52	0.59	0.26			0.49	0.62	0.47		0.610
Lateral 12g 50ms		0.47	0.58	0.29			0.43	0.65	0.42		0.53
Rearward 6g 100ms	0.50		0.32		0.29	0.42		0.34		0.31	0.34
Rearward 8g 100ms	0.70		0.38		0.35	0.59		0.41		0.36	0.43
Rearward 8g 50ms	0.49		0.57		0.27	0.43		0.65		0.31	0.47
Rearward 10g 100ms	0.72		0.39		0.36	0.63		0.41		0.47	0.61
Rearward 12g 100ms	0.56		0.62		0.33	0.53		0.69		0.47	0.68
Rearward 12g 50ms	0.72		0.42		0.44	0.67		0.41		0.57	0.74
Rearward 16g 50ms	0.55		0.71		0.46	0.53		0.72		0.53	0.79
Rear-Lat 8g 50ms	0.40	0.50	0.67	0.22	0.27	0.38	0.48	0.71	0.41	0.32	0.57
Rear-Lat 12g 50ms	0.43	0.57	0.64	0.31	0.30	0.41	0.54	0.66	0.46	0.40	0.68
Rear-Lat 16g 50ms	0.49	0.60	0.70	0.33	0.37	0.46	0.56	0.69	0.51	0.46	0.77
Front-Lat 8g 50ms	0.57	0.53	0.47	0.26	0.30	0.56	0.48	0.63	0.43	0.50	0.49
Front-Lat 12g 50ms	0.69	0.48	0.46	0.28	0.48	0.67	0.45	0.56	0.38	0.54	0.48
Front-Lat 16g 50ms	0.70	0.50	0.59	0.31	0.56	0.70	0.47	0.66	0.45	0.60	0.59

4. Optimization Verification: ISO Scores



Optimized FEM ISO Scores

Green : ISO > 0.5

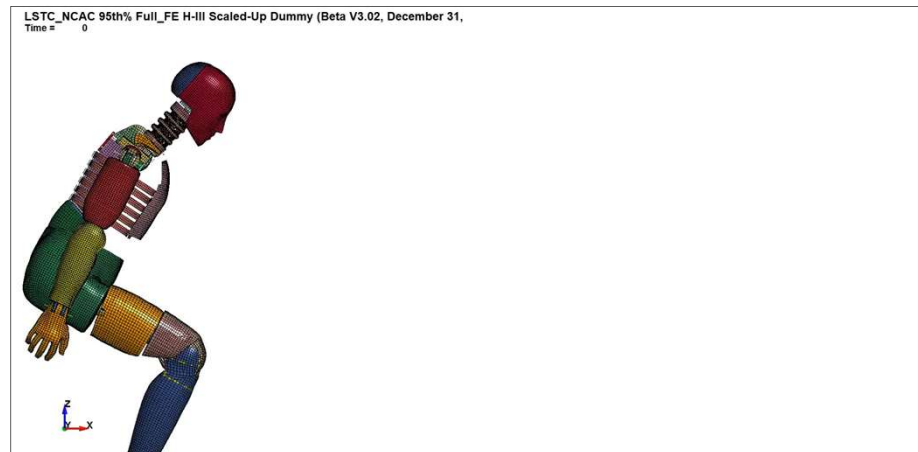
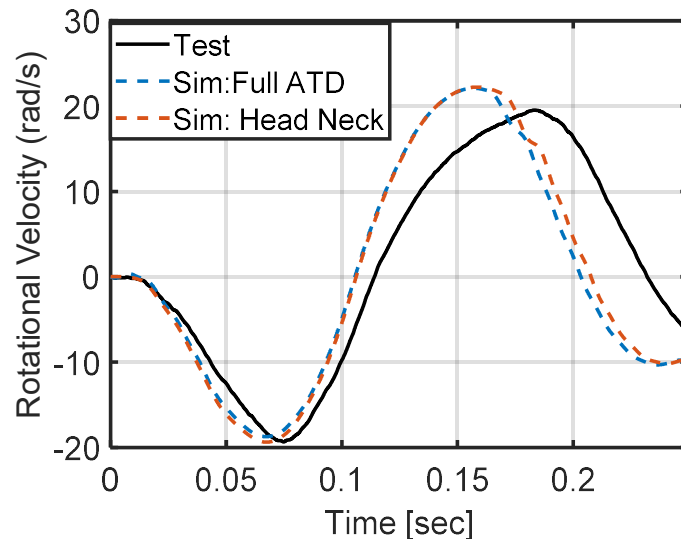
Red : ISO < 0.5

	Head Gx	Head Gy	Head Gz	Head Gx Rot Vel	Head Gy Rot Vel	Neck Upper Fx	Neck Upper Fy	Neck Upper Fz	Neck Upper Mx	Neck Upper My	Nij
Frontal 6g 100ms	0.98		0.84		0.78	0.96		0.89		0.93	0.94
Frontal 8g 50ms	0.93		0.78		0.88	0.95		0.80		0.89	0.90
Frontal 10g 100ms	0.94		0.72		0.84	0.95		0.73		0.86	0.86
Frontal 12g 100ms	0.87		0.63		0.72	0.85		0.73		0.75	0.82
Frontal 12g 50ms	0.78		0.65		0.60	0.60		0.67		0.69	0.80
Frontal 16g 50ms	0.72		0.68		0.56	0.71		0.73		0.64	0.75
Lateral 6g 100ms		0.94	0.91	0.45			0.88	0.89	0.95		0.95
Lateral 8g 50ms		0.90	0.94	0.69			0.83	0.87	0.83		0.90
Lateral 10g 100ms		0.96	0.88	0.80			0.92	0.83	0.93		0.960
Lateral 10g 50ms		0.96	0.91	0.92			0.93	0.85	0.91		0.93
Lateral 12g 100ms		0.93	0.86	0.81			0.90	0.81	0.89		0.93
Lateral 12g 50ms		0.96	0.91	0.91			0.92	0.86	0.92		0.89
Rearward 6g 100ms	0.77		0.55		0.47	0.71		0.69		0.56	0.61
Rearward 8g 100ms	0.58		0.55		0.56	0.50		0.68		0.47	0.61
Rearward 8g 50ms	0.80		0.77		0.63	0.68		0.84		0.62	0.72
Rearward 10g 100ms	0.56		0.56		0.56	0.48		0.66		0.49	0.65
Rearward 12g 100ms	0.63		0.72		0.58	0.50		0.78		0.53	0.71
Rearward 12g 50ms	0.64		0.62		0.61	0.56		0.66		0.58	0.75
Rearward 16g 50ms	0.66		0.78		0.65	0.56		0.81		0.64	0.81
Rear-Lat 8g 50ms	0.86	0.88	0.88	0.65	0.75	0.86	0.84	0.89	0.81	0.78	0.90
Rear-Lat 12g 50ms	0.72	0.87	0.83	0.76	0.69	0.72	0.86	0.88	0.82	0.68	0.87
Rear-Lat 16g 50ms	0.71	0.89	0.84	0.77	0.65	0.67	0.86	0.88	0.86	0.68	0.91
Front-Lat 8g 50ms	0.96	0.93	0.89	0.74	0.94	0.98	0.81	0.89	0.84	0.94	0.93
Front-Lat 12g 50ms	0.81	0.96	0.77	0.84	0.68	0.84	0.82	0.76	0.90	0.78	0.90
Front-Lat 16g 50ms	0.89	0.74	0.73	0.61	0.74	0.89	0.78	0.72	0.71	0.88	0.82



4. Optimization Verification: Full FEM Integration

- **Verification of head-neck integration into complete FEM**
 - 16g-Rear impact driven from the spine-box (rigidly connected to all parts up to the lower neck attachment point) to ensure properly integrated
 - Results verify model stability and accuracy equal to the isolated head-neck



Optimized 95th FEM Use



- Full-Scale Aircraft crash analysis being performed using updated LSTC-95th FEM
 - Complex loading environment: Inertial and contact driven response



Fokker F28 Crash Test
(NASA Langley 2019)





Conclusions

- **The original LSTC Hybrid III FEM did not accurately predict the head-neck response of the physical ATD under inertial loading**
- **Changes were made to the LSTC Hybrid III FEM to better capture head-neck geometry of the physical ATD**
 - Neck FEM rebuilt to include neck spacer components
 - Mass added to Head-CG to match physical specifications
- **Material properties of the neck puck part were calibrated to improve response**
 - Shear modulus parameters calibrated using multi-step material optimization
- **Updates were found to significantly improve predictive capability of the head-neck complex**



Questions?

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