Comparison of the Compressive Response of the PMHS and 50th% Hybrid III ATD Thorax Utilizing Nonparametric System Identification Techniques

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INTRODUCTION

- Restraint systems found in motor vehicles are designed to increase the safety of occupants involved in motor vehicle accidents.
- In frontal motor vehicle accidents the interaction of the thorax with the vehicle's restraint system and components help dictate the kinematic behavior of the head, neck, and spine.
- Effectiveness of restraint systems is evaluated using anthropomorphic test devices (ATD).
- The response of the ATD thorax to an applied anterior compressive force is imperative to its ability to accurately represent a vehicle's occupant.
- The more biofidelic an ATD's thoracic force-deflection characteristics, the better the restraint systems can be designed.

OBJECTIVE

To compare the frontal compressive response of the adult hybrid III 50th% male ATD thorax with an adult post mortem human surrogate (PMHS) thorax in an effort to improve the biofidelity of the ATD thorax.

METHODS

Nonparametric System Identification

- Characterize nonlinear biological systems through linear operating points [1,2,3].
- Make no assumptions about system's structure.
- Perturbation analysis.
  - Using small perturbations, the thorax is operating within a linear region and experiment is un-injurious.

Figure 1: PMHS Pre-Test Photo.

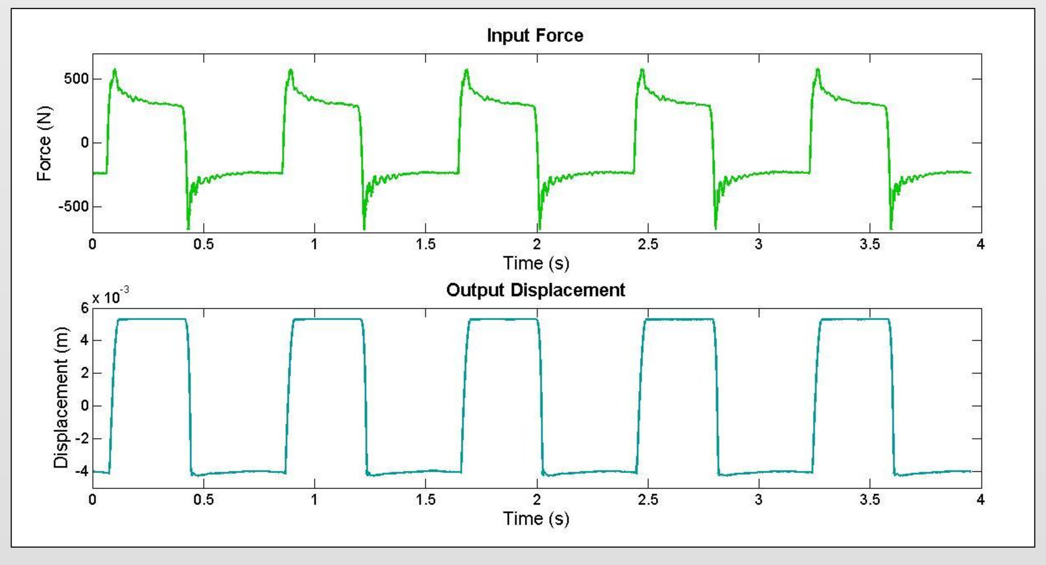

Figure 2: Input Force and Output Displacement Sequences for a 0.5 m/s 10% Initial Compression Hybrid III Test.

Test Device (TAPPER)

- Thoracic Apparatus for Producing PERturbations
- Cam actuated 9.5 mm perturbations anteriorly.
- Six-axis load cell on seat back.
- Using the compliance model for parameter estimation, input/output are reversed, Figure 2.

1. Hunter, I. W. and R. E. Kearney (1982). "Dynamics of human ankle stiffness: variation with mean ankle torque." Journal of Biomechanics 15(10): 747.
2. Kearney, R. E. and I. W. Hunter (1990). "System identification of human joint dynamics." CRC Critical Reviews in Biomedical Engineering 18(1): 55.
3. Moorhouse, K. M. and K. P. Granata (2005). "Trunk stiffness and dynamics during active extension exertions." Journal of Biomechanics 38(10): 2000-2007.

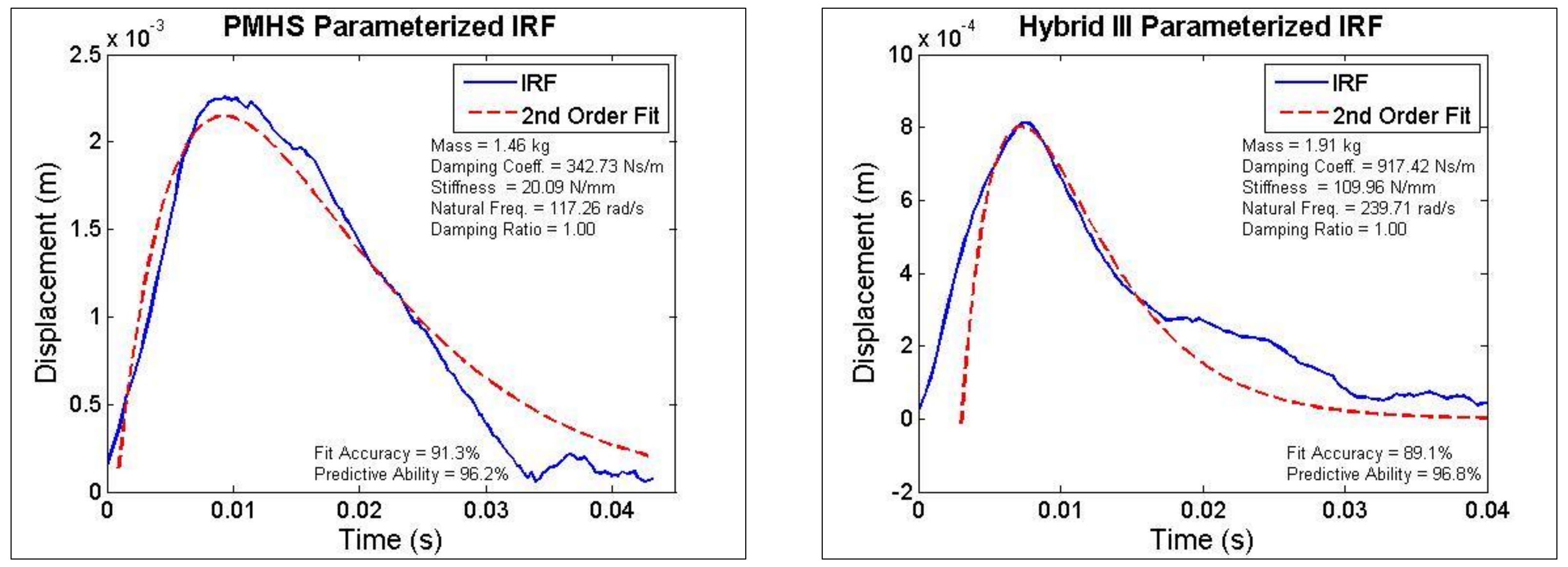

Figure 3: 0.5 m/s 10% Initial Compression Parameterized IRFs.

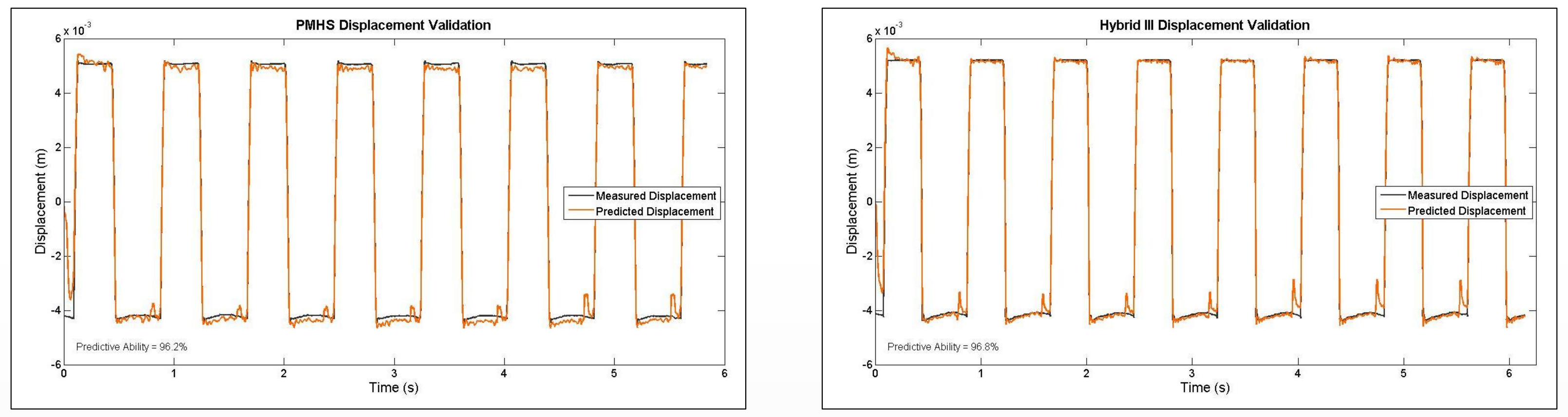

Figure 4: Validation of Predicted Displacements, 0.5 m/s 10% Initial Compression.

System Identification

Impulse Response Function (IRF)

- System's transfer function in the form of a curve, Figure 3.
  - Obtained through time-domain deconvolution.
- System response to an input of unit force.
- Fit with linear second-order curve.
  - System characteristics mass, damping, and stiffness calculated from fitted curve.
  - Fit Accuracy
    - Calculated using NRMSD (normalized root mean squared deviation) normalized to IRF amplitude.

Table I: Test Matrix.

Perturbation Amplitude: 9.5mm		Perturbation Velocity (m/s)		
Initial Chest Deflection (%)	5	0.5	1.5	2.5
	10	0.5	1.5	2.5
	15	0.5	1.5	2.5

IRF Validation

- IRF convolved with a validation input dataset to calculate displacement predicted by IRF, Figure 4.
  - Compared against recorded validation displacement dataset.
- Predictive Ability
  - IRF's ability to accurately predict an output.
  - Calculated using NRMSD normalized to range of displacement.

Table I lists the operating points in a test series, the points are tested in a random order.

RESULTS & DISCUSSION

Table II: Rate Averaged PMHS and HIII System Characteristics.

Rate Effects

	PMHS				Hybrid III			
	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)
0.5 m/s	1.37	0.92	340.18	26.92	2.63	1.00	978.51	101.27
1.5 m/s	0.91	0.94	268.89	21.77	1.45	0.91	737.11	121.89
2.5 m/s	0.83	0.82	268.40	29.04	0.93	0.96	612.06	108.86

Table III: Compression Level Averaged PMHS and HIII System Characteristics.

Compression Level Effects

	PMHS				Hybrid III			
	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)
5%	0.69	0.76	189.34	21.51	2.43	0.88	791.07	94.56
10%	1.10	1.00	309.64	22.64	1.40	0.99	757.69	105.94
15%	1.33	0.92	378.50	33.58	1.18	1.00	778.92	131.53

Rate Effects

- Decreasing effective mass for both PMHS and ATD with increasing rate.
- Damping coefficient:
  - No clear pattern for PMHS.
  - Effective damping appears to decrease with increasing rate.
- Effective stiffness does not seem to be correlated with perturbation rate.

Compression Level Effects

- Mass:
  - PMHS effective mass increases with compression level.
  - ATD effective mass seems to decrease even if the 0.5 m/s, 5% test is excluded.
- Damping coefficient:
  - Effective damping appears to increase for PMHS with increasing compression.
  - Effective damping for ATD has no clear pattern.
- Both PMHS and ATD show increasing stiffness with increasing compression.

Table IV: PMHS and HIII Second Order System Characteristics.

	PMHS				Hybrid III			
	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)	Mass (kg)	Damping Ratio	Damping Coeff (Ns/m)	Stiffness (N/mm)
0.5 m/s 5%	0.92	1.00	308.37	25.86	4.38	1.00	1150.59	75.61
0.5 m/s 10%	1.46	1.00	342.73	20.09	1.91	1.00	917.42	109.96
0.5 m/s 15%	1.72	0.75	369.44	34.82	1.59	1.00	867.51	118.23
1.5 m/s 5%	0.49	0.82	150.85	17.49	2.01	0.72	690.68	114.39
1.5 m/s 10%	0.98	1.00	270.68	18.64	1.33	1.00	754.45	107.01
1.5 m/s 15%	1.27	1.00	385.14	29.17	1.02	1.00	766.19	144.28
2.5 m/s 5%	0.65	0.46	108.80	21.18	0.90	0.92	531.94	93.67
2.5 m/s 10%	0.85	1.00	315.50	29.19	0.96	0.97	601.19	100.85
2.5 m/s 15%	0.99	1.00	380.91	36.76	0.94	1.00	703.05	132.07
Mean	**1.04**	**0.89**	**292.49**	**25.91**	**1.67**	**0.96**	**775.89**	**110.67**

CONCLUSIONS

- Effective stiffness of 50th% male hybrid III ATD thorax is over four times greater than the PMHS effective stiffness.
- Effective stiffness increases with compression level for both PMHS and hybrid III.
- Hybrid III effective mass slightly higher than PMHS.
- Effective damping relationship not straightforward.

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