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Temperature Sensitivity of the Hybrid III 5th Percentile Female Dummy

Time Constants and Component Responses

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Temperature Sensitivity of the Hybrid III 5th Percentile Female Dummy

Time Constants and Component Responses

Final Draft
NHTSA Technical Report

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Executive Summary

The current temperature requirement for the Hybrid III 50th percentile male dummy when used in a FMVSS 208 test is between 69 and 72 F. This narrow test window is difficult to maintain prior to and during the test. This study examines the need for this temperature requirement by investigating the temperature sensitivity of the Hybrid III 5th percentile female dummy. This study examined 1) the temperature vs. time relationship of various dummy components when the dummy is subject to a temperature gradient, and 2) the effect of temperature changes on the dynamic response characteristics of the dummy's components.

The major conclusions of this study were:

1. Soak duration of sixteen hours, as currently stated in the FMVSS 208 test procedure, is sufficient to insure a stabilized temperature for all components of a Hybrid III 5th percentile female dummy.
2. The temperature sensitivity to thorax impacts observed in the current study is similar to the results observed in the previous study conducted by Saul, which served as the basis for the current temperature requirement in the FMVSS 208 test.

Based on the findings of the current study, it is recommended that the current requirements for a stabilized test temperature between 69 and 72 F be maintained for FMVSS 208 tests.

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1. Introduction

Test dummies are composed of several materials that have very different thermal properties. This has prompted the specification of temperature ranges for Part 572 dummy component tests. Various studies have evaluated the temperature sensitivity of different types of dummies in both component and total system tests. Haffner et al. [1] conducted tests on the Hybrid II dummy to evaluate thermal response of components to step changes in temperature. They monitored seven dummy locations and found that the forehead location responded most rapidly to ambient temperature change, and the lumbar spine responded most slowly. They also determined through curve-fitting that certain components' thermal behavior could be modeled with a single function for both heating and cooling responses, while others warranted different functions for each. Seiffert et al. [2] looked at the effect of temperature change on the response of the head, neck, thorax, lumbar spine, and abdominal insert in the Hybrid II dummy. These component tests were followed by total system sled tests, in which more exaggerated kinematic motion of heated dummies was observed. Saul [3] performed similar component tests to evaluate the Hybrid II, APROD'81, and Hybrid III dummies in terms of biofidelity, durability, and temperature sensitivity. Different thermal response trends were found for each dummy, indicating that the temperature sensitivity of a particular dummy is directly related to its structure.

The Saul study served as the basis for the current temperature requirements for the Hybrid III dummy when used in a FMVSS 208 test. This study showed that the Hybrid III dummy is considerably more sensitive to temperature changes as compared to the Hybrid II, especially in the thorax region. For example, over a temperature change of 66 to 78 F, the peak sternal deflection for the same impact varied 10% for the Hybrid II as compared to 42% for the same impact to the Hybrid III. To combat this sensitivity, the allowable temperature range for testing was reduced from 12 degrees F (66 to 78 F) to 3 degrees (69 to 72 F). The problem with this narrow range is that it has been, and is still, difficult to maintain and results in test delays and additional costs.

Since the Saul study was conducted in 1984, the Hybrid III dummy has evolved with a number of changes occurring, including the introduction of new materials, as some materials became obsolete or unavailable. Furthermore, the agency has recently introduced into regulation a Hybrid III dummy family including 5th percentile female, three-year-old, six-year-old, and 12-month-old dummies. Therefore, it is appropriate to revisit the issue of the Hybrid III dummy's sensitivity to temperature.

This study examined 1) the temperature vs. time relationship of various dummy components when the dummy is subject to a temperature gradient, and 2) the effect of temperature changes on the dynamic response characteristics of the dummy's components. The initial task of this effort was to determine the transient temperature response, characterized by the time constant, of the various segments of the test dummy. This was achieved by soaking the dummy in a temperature controlled test chamber and monitoring the temperature versus time response of the dummy's components using thermocouples. The second task was to determine how changes in temperature affected the response characteristics of the dummy's various segments. This was accomplished by conducting component tests with the head, neck, and thorax of the Hybrid III 5th percentile female dummy over a range of test temperatures.

2. Methods

2.1. Time Constant Determination

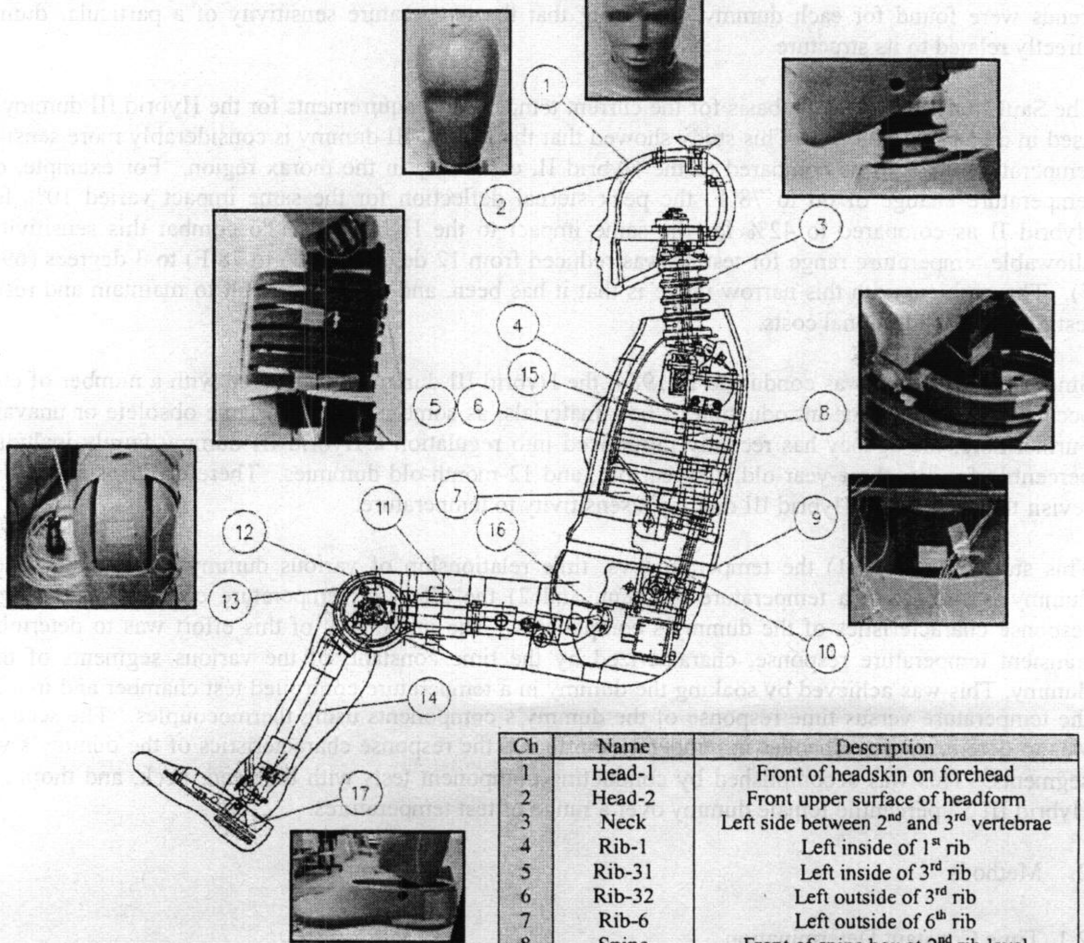
2.1.1. Temperature Measurement

Thermocouples were attached at seventeen locations with masking tape on the Hybrid III 5th percentile female (HIII-5F) test dummy (Fig. 1). Temperature was acquired in real-time (ChartView, IOtech, Inc.) and transferred automatically into a spreadsheet, where it could be easily analyzed and viewed during the tests.

2.1.2. Time Constant Test Procedure

The dummy was placed in a padded car seat (Fig. 2) inside a thermally controlled chamber (Fig. 3). Aluminum ducts were added to distribute the air more evenly throughout the chamber. Three thermocouples (ambient, upbox, and downbox) were combined to provide the reference temperature inside the box for the other channels. Two sets of tests were performed (heat to 95 F and cool to 60 F). Each test provided both heating and cooling gradient data.

The chamber was conditioned at temperature overnight, while the dummy was at ambient temperature. Data acquisition was started, and the dummy was placed inside the chamber in the car seat. The dummy was left inside the chamber for 8 hours to get heating or cooling gradients for each location, then taken out and placed in ambient temperature once again. Data acquisition continued for another 8 hours to get gradients for the various dummy locations as they returned to ambient temperature. Three tests were completed at both soak temperatures of 60 F and 95 F.



Ch	Name	Description
1	Head-1	Front of headskin on forehead
2	Head-2	Front upper surface of headform
3	Neck	Left side between 2nd and 3rd vertebrae
4	Rib-1	Left inside of 1st rib
5	Rib-31	Left inside of 3rd rib
6	Rib-32	Left outside of 3rd rib
7	Rib-6	Left outside of 6th rib
8	Spine	Front of spine box at 2nd rib level
9	Lumbar-1	Back of lumbar flex joint
10	Lumbar-2	Front of lumbar flex joint
11	Femur	Anterior side of femur component
12	Knee-1	Outside surface of left kneeskin
13	Knee-2	Directly attached to left knee joint
14	Tibia	Rear left tibia surface
15	Sternum	Center of sternal shield at 1st rib level
16	Pelvis	Left hip joint (acetabular cup)
17	Foot	Left side of left footskin

Fig. 1. Thermocouple Locations

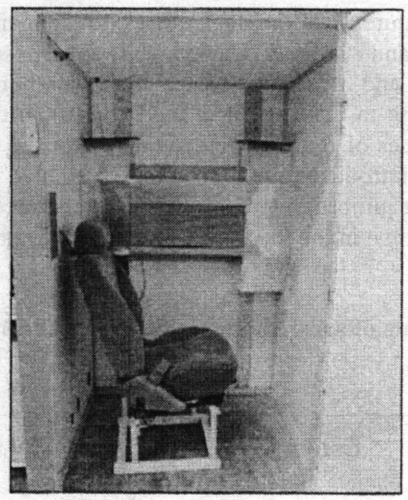


Fig. 2. Padded Car Seat Inside Thermally Controlled Chamber

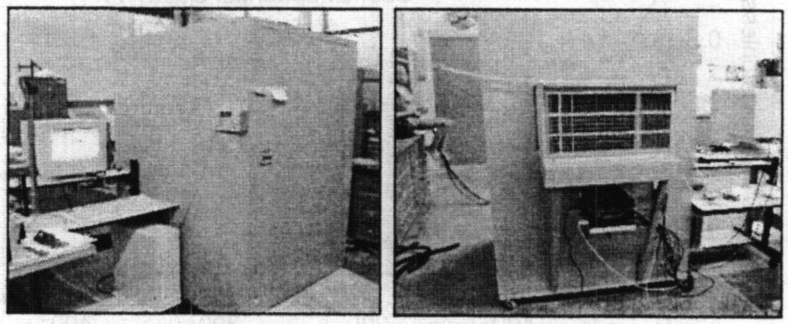


Fig. 3. Thermally Controlled Chamber

2.1.3. Time Constant Calculation

The experimental temperatures were converted to non-dimensional values to facilitate least squares curve-fitting [1]:

$$T_i = 1 - \frac{t_i - t_o}{t_\infty - t_o} \quad \text{(cooling)} \qquad \text{(Eq. 1)}$$

$$T_i = \frac{t_i \;\; t_o}{t_\infty - t_o} \quad \text{(heating)} \qquad \text{(Eq. 2)}$$

where T_i is the non-dimensional temperature, t_i is the current temperature of the channel, t_o is the initial temperature of the channel, and t_∞ is the maximum (heating) or minimum (cooling) temperature of the channel. The fit of the experimental data was assumed to be an exponential decay function, where τ is the time constant. We see from equations 3 and 4 that when $t = \tau$, the function Z is 36.8% (e^{-1}) of the initial value B in the cooling case, and equal to 1 – 0.368B (1- Be^{-1}) in the heating case, where B is the final value.

$$Z_i = Be^{-t/\tau} \quad \text{(cooling)} \qquad \text{(Eq. 3)}$$

$$Z_i = 1 - Be^{-t/\tau} \quad \text{(heating)} \qquad \text{(Eq. 4)}$$

where Z_i the theoretical temperature, B is the coefficient corresponding to the initial or final value of the function, τ is the time constant, and t is time. Using a least squares solver routine, the sum of the squared errors between the experimental and theoretical values of all data points (Eq. 5) were minimized based on optimization of B and τ, resulting in the best fit of the exponential decay function with the experimental data (Fig. 4). The resulting values of B and τ were averaged for the three tests for each channel. For the purposes of this study, we have introduced the terminology "required soak time" and defined it as the time required to get to within 5% of equilibrium temperature. The required soak times have been computed for each location by solving for the time in the theoretical equations developed for Z.

$$\sum_{i=1}^{n}(T_i - Z_i)^2 \quad \text{(Sum of squared error minimized by changing } B \text{ and } \tau\text{)} \qquad \text{(Eq. 5)}$$

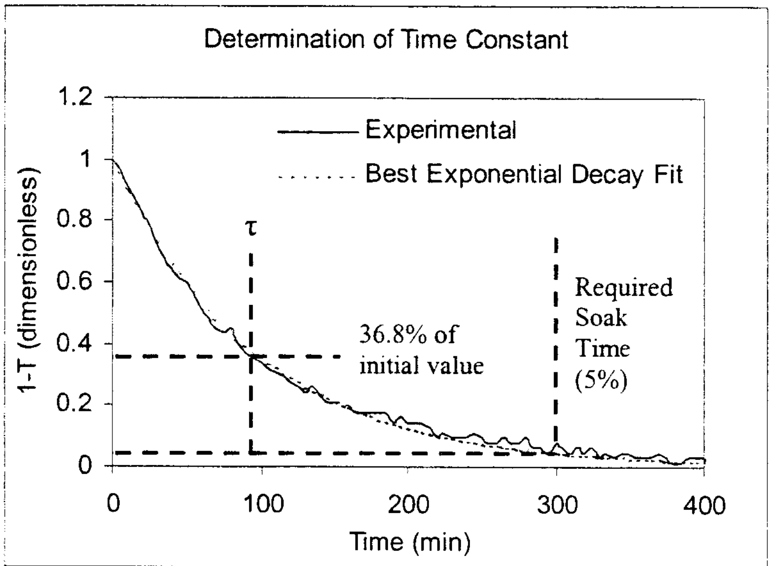


Fig. 4. An exponential decay function was fit to the experimental data

2.2. Component Tests

2.2.1. Head Drops

The head of a HIII-5F dummy was instrumented and tested in accordance with S572.132(c). Eight tests were completed at various temperatures between 60 and 90 F. The head assembly was placed in the thermal chamber to equilibrate for at least four hours at a temperature setting of 55 F for tests at 62, 66, and 70 F. The same was done for tests at 88, 78, and 74 F with a chamber setting of 95 F. Two additional tests were conducted at 65 and 73 F. The temperature of the head was monitored, and a drop test was conducted when the head reached various temperatures between soak and ambient.

2.2.2. Neck Flexions

The head and neck assembly of that same HIII-5F dummy was instrumented and tested in accordance with S572.133(c). Eighteen total tests were completed with three at each 60, 66, 80, and 87 F, and six at 72 F. The temperature of the neck segment was monitored, and a flexion test was conducted when the neck reached the prescribed temperature (Fig. 5). The assembly was placed in the thermal chamber to equilibrate for at least four hours at a temperature setting of 55 F for the 60, 66, and half of the room temperature tests. The same was done for tests at 87, 80, and half of the room temperature tests with a chamber setting of 95 F.

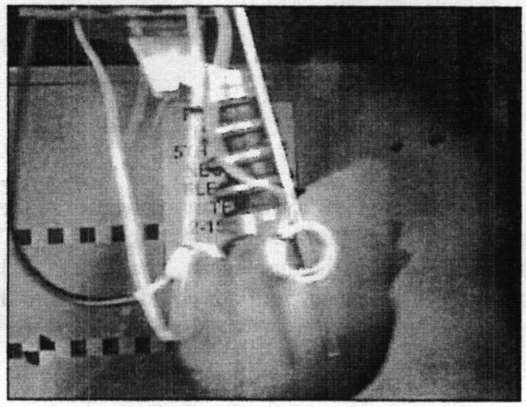


Fig. 5. Neck Flexion

2.2.3. Neck Extensions

The head and neck assembly of that same HIII-5F dummy was instrumented and tested in accordance with S572.133(c). Thirty-six total tests were completed with six at each 60, 66, 80, and 87 F, and twelve at 72 F. The temperature of the neck segment was monitored, and an extension test was conducted when the neck reached the prescribed temperature (Fig. 6). The assembly was placed in the thermal chamber to equilibrate for at least four hours at a temperature setting of 55 F for the 60, 66, and half of the room temperature tests. The same was done for tests at 87, 80, and half of the room temperature tests with a chamber setting of 95 F.

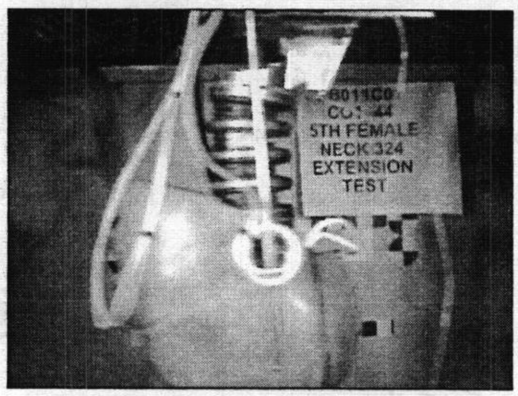


Fig. 6. Neck Extension

2.2.4. Thorax Impacts

The HIII-5F dummy was instrumented and tested in accordance with S572.134(c). Twenty-two tests were completed at various temperatures between 60 and 90 F. The temperature of the interior side of rib #3 was monitored, and impact tests were conducted when this location reached various temperatures between soak and ambient. The dummy was placed in the thermal chamber to equilibrate for at least four hours at a temperature setting of 55 F for tests below ambient and 95 F for tests above ambient.

3. Results

3.1. Time Constants

3.1.1. Heating Tests

Table 1 summarizes the results of the heating tests for all dummy locations (see Fig. 1), and Fig. 7-9 show the measured temperature changes for the head, thorax, and leg region channels. The symbols σ_B and σ_τ are the standard deviations of B and τ calculated for the three tests. The initial t_o values varied for each channel because the relative locations of the thermocouples were not equidistant from the air source in the thermal chamber. The temperatures were normalized for the curve-fitting operation, so this variation did not affect the results.

	B	σ_B	τ (hrs)	σ_τ
Head-1	0.984	0.023	1.501	0.274
Head-2	1.009	0.046	1.441	0.178
Neck	1.002	0.013	1.424	0.367
Rib-1	1.011	0.004	1.899	0.153
Rib-31	1.025	0.031	1.859	0.163
Rib-32	1.022	0.023	1.872	0.153
Rib-6	1.032	0.016	1.870	0.235
Spine	0.989	0.080	2.482	0.562
Lumbar-1	0.962	0.089	2.723	0.126
Lumbar-2	1.077	0.030	2.484	0.228
Femur	1.061	0.068	2.435	0.212
Knee-1	1.007	0.049	2.164	0.137
Knee-2	1.049	0.021	2.117	0.184
Tibia	1.068	0.049	1.646	0.221
Sternum	1.059	0.024	1.900	0.108
Pelvis	1.142	0.025	3.370	0.102
Foot	1.102	0.064	0.960	0.328

Table 1. Time constants and coefficients for heating to 95 F

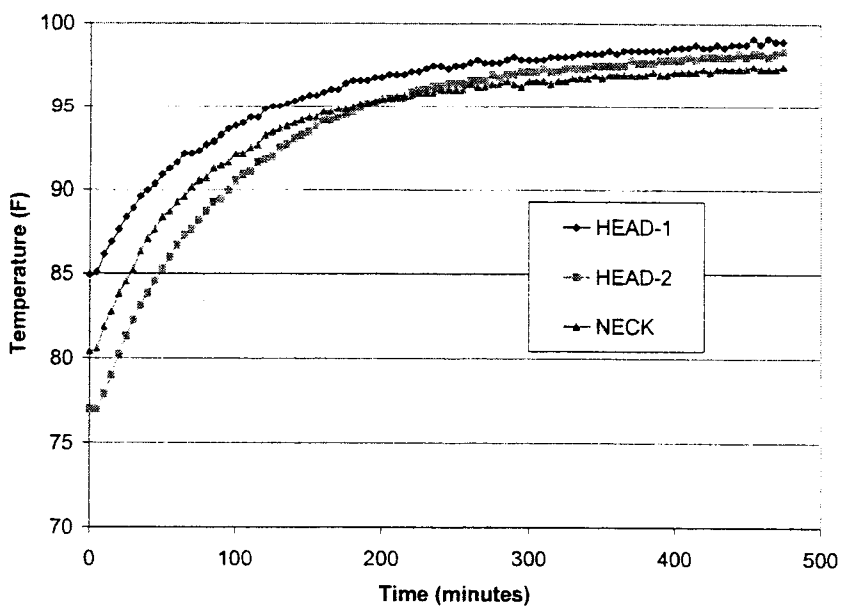


Fig. 7. Head Region Temperatures

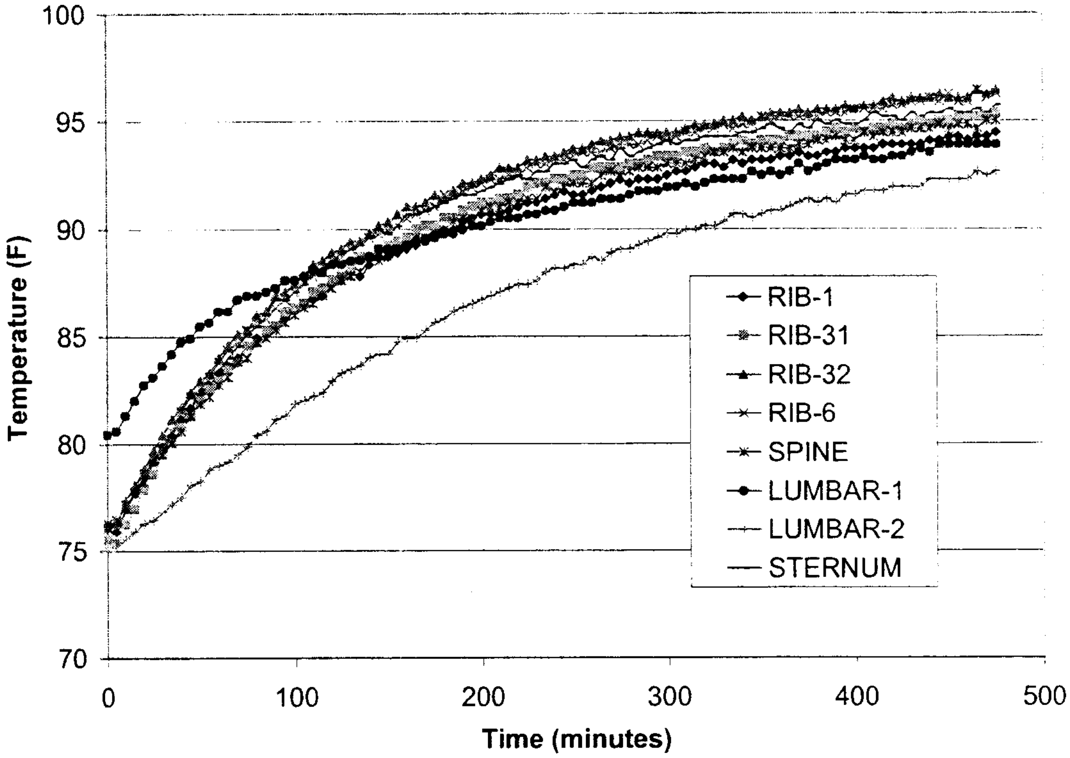


Fig. 8. Thorax Region Temperatures

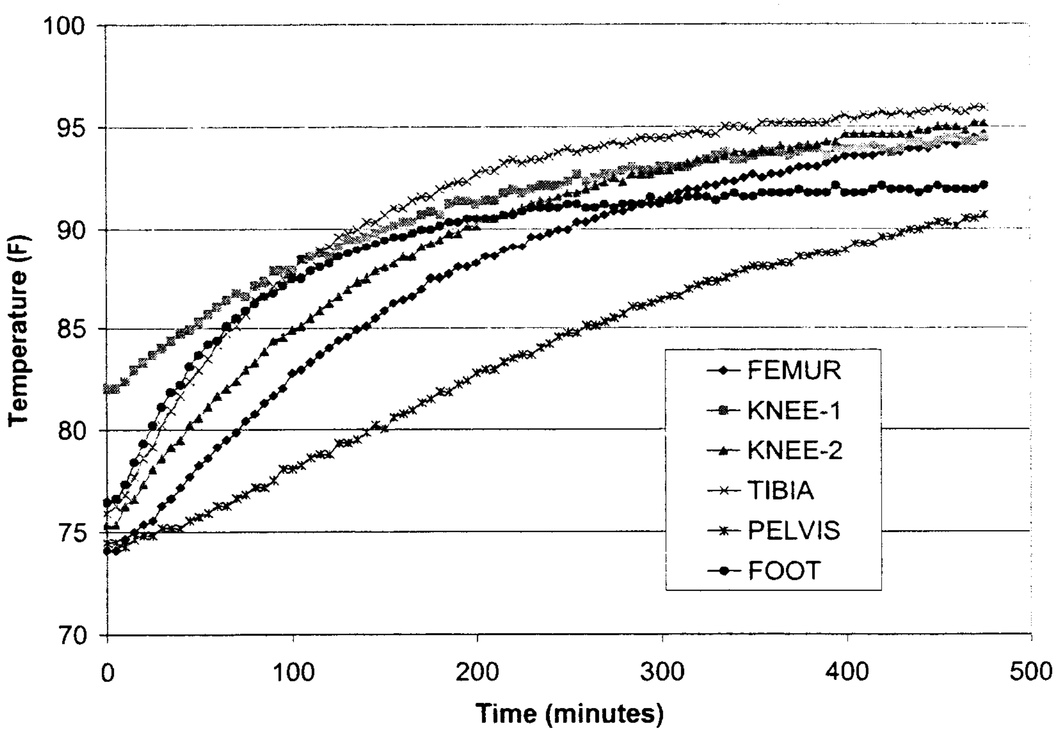


Fig. 9. Leg Region Temperatures

From Table 1, we see, for instance, that the Head-1 location's temperature response can be modeled by the equation $Z(t) = 1 - 0.984\, e^{-t/1.501}$, where t is in hours. Using the non-dimensional Z value as the non-dimensional T value in equations 1 and 2 in section 2.1.3, we get the estimated temperature in degrees F at a certain time. Table 2 summarizes the results of the channels for all dummy locations returning to ambient temperature after being heated to 95 F, and Fig. 10-12 show the temperature changes for the head, thorax, and leg region channels.

	B	σ_B	τ (hrs)	σ_τ
Head-1	0.918	0.071	1.701	0.025
Head-2	0.947	0.047	1.725	0.034
Neck	0.942	0.007	1.826	0.052
Rib-1	0.953	0.021	1.874	0.123
Rib-31	0.974	0.014	1.735	0.088
Rib-32	0.938	0.028	1.723	0.085
Rib-6	0.906	0.038	1.825	0.113
Spine	0.993	0.031	1.407	0.868
Lumbar-1	0.963	0.067	0.992	1.112
Lumbar-2	1.006	0.092	2.639	0.138
Femur	0.996	0.154	2.474	0.235
Knee-1	0.954	0.072	2.469	0.128
Knee-2	1.047	0.015	2.229	0.273
Tibia	1.039	0.012	1.939	0.180
Sternum	1.069	0.053	2.324	0.623
Pelvis	1.086	0.068	2.634	0.812
Foot	0.985	0.007	1.609	0.036

Table 2. Time constants and coefficients for cooling from 95 F

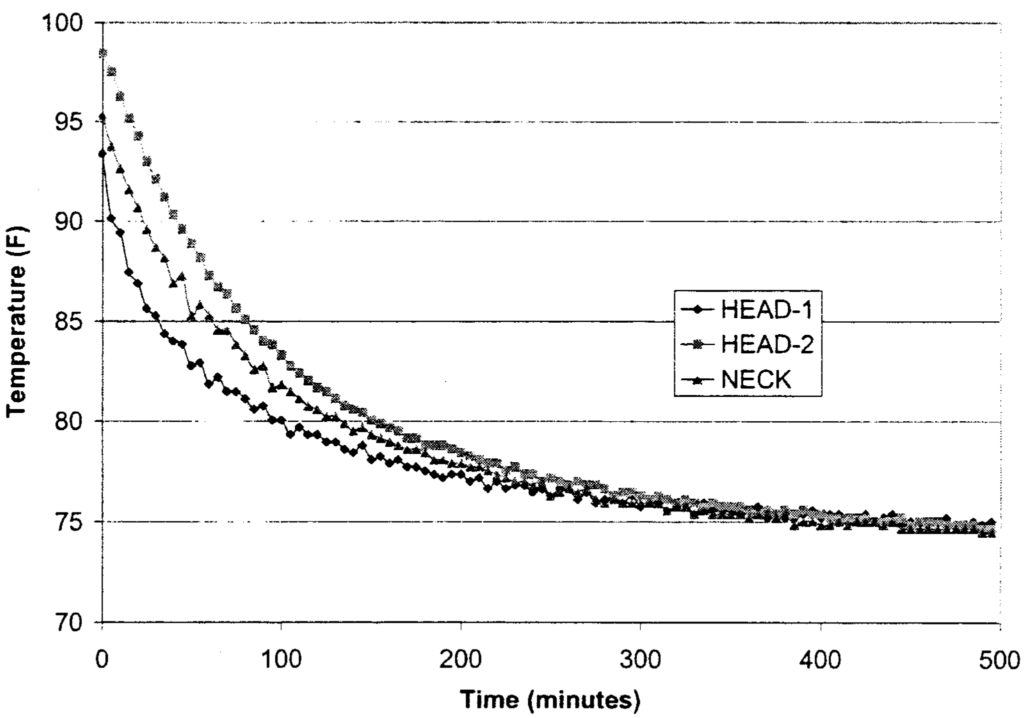


Fig. 10. Head Region Temperatures

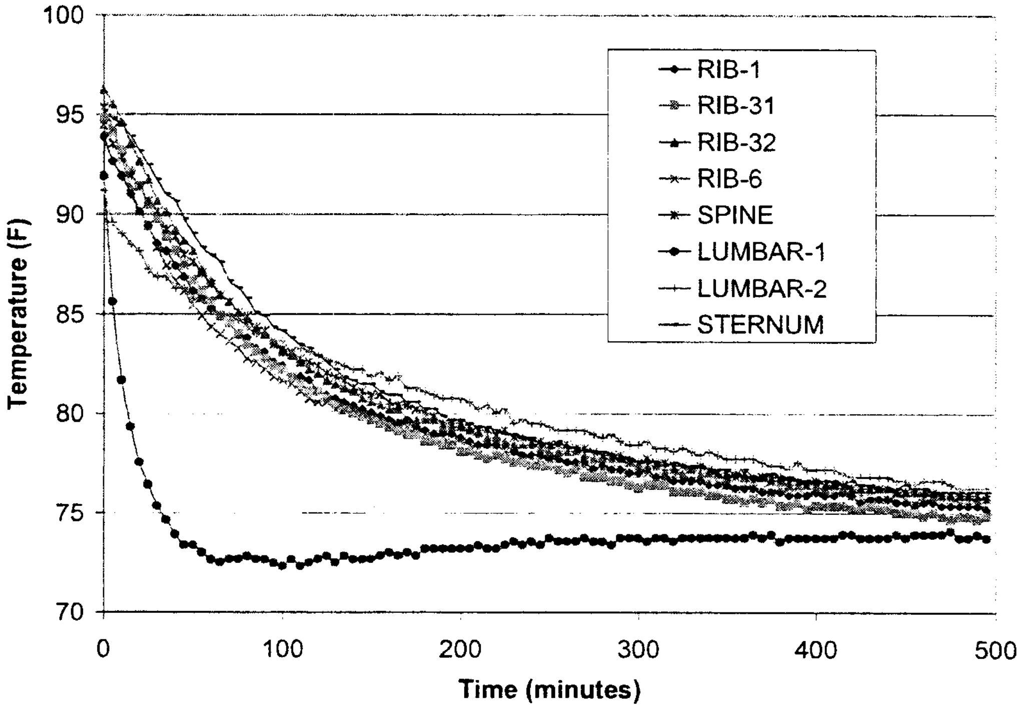


Fig. 11. Thorax Region Temperatures

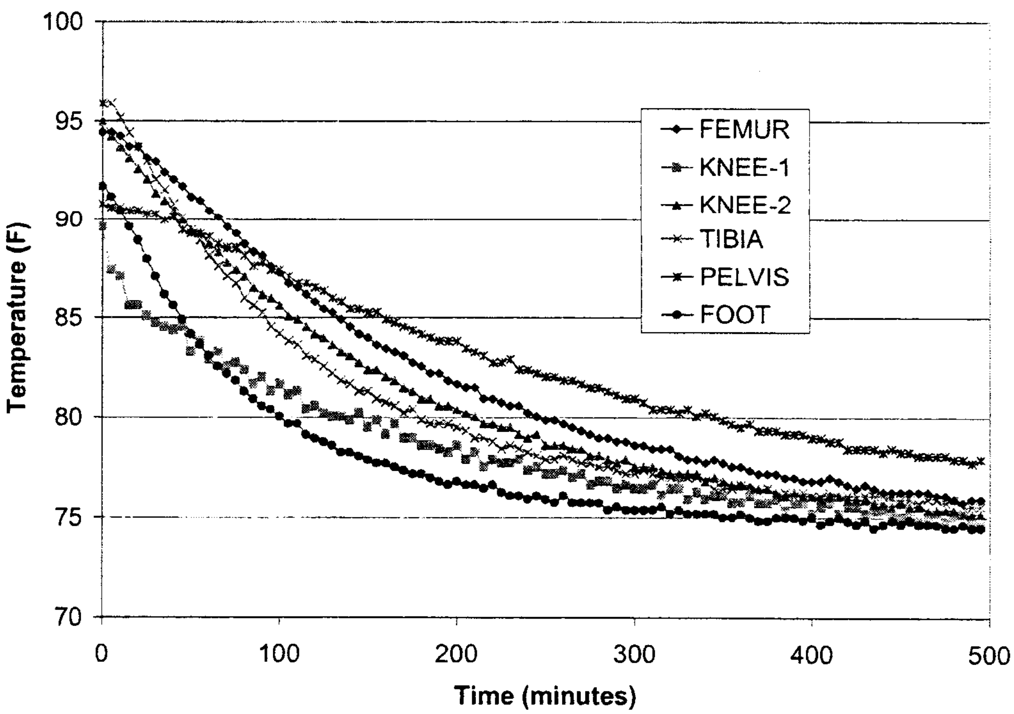


Fig. 12. Leg Region Temperatures

For the head region, all the channels follow roughly the same trend. For the thorax region, there is more variability, most likely because of the complexity of the rib and spine components. The Lumbar-1 and Lumbar-2 channels are especially variable, with Lumbar-2 taking longest to reach its maximum temperature and Lumbar-1 decreasing very rapidly early into the test (Fig. 11). These differences most likely stem from the relative positions of these channels, with the Lumbar-2 channel being more internal than the Lumbar-1 channel. For the lower body, the Pelvis channel is slowest to respond to temperature gradients, which comes as no surprise because the pelvis thermocouple is located far internally from the exterior surface.

3.1.2. Cooling Tests

Table 3 summarizes the results of the cooling tests for all dummy locations, and Fig. 13-15 show the temperature changes for the head, thorax, and leg region channels.

	B	σ_B	τ (hrs)	σ_τ
Head-1	0.870	0.080	1.694	0.183
Head-2	1.035	0.016	1.560	0.065
Neck	0.992	0.040	1.689	0.008
Rib-1	0.973	0.006	2.168	0.081
Rib-31	0.985	0.025	2.018	0.139
Rib-32	0.997	0.036	1.962	0.131
Rib-6	0.893	0.037	1.943	0.101
Spine	0.995	0.014	2.226	0.089
Lumbar-1	0.952	0.078	1.255	0.606
Lumbar-2	0.984	0.043	2.842	0.061
Femur	1.110	0.025	2.753	0.122
Knee-1	0.930	0.154	2.686	0.180
Knee-2	1.051	0.021	2.491	0.091
Tibia	1.038	0.036	1.709	0.065
Sternum	1.060	0.017	1.993	0.049
Pelvis	1.127	0.023	3.190	0.124
Foot	1.002	0.040	1.089	0.086

Table 3. Time constants and coefficients for cooling to 60 F

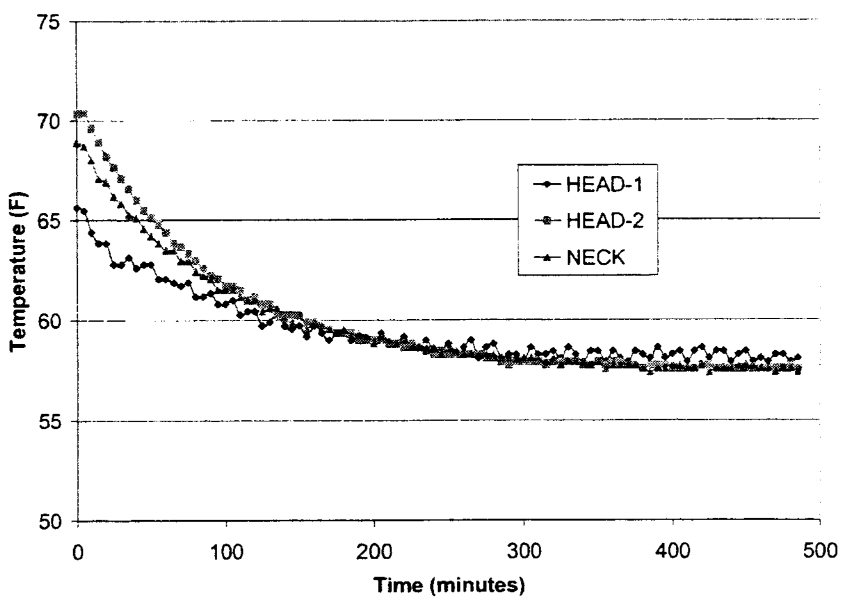


Fig. 13. Head Region Temperatures

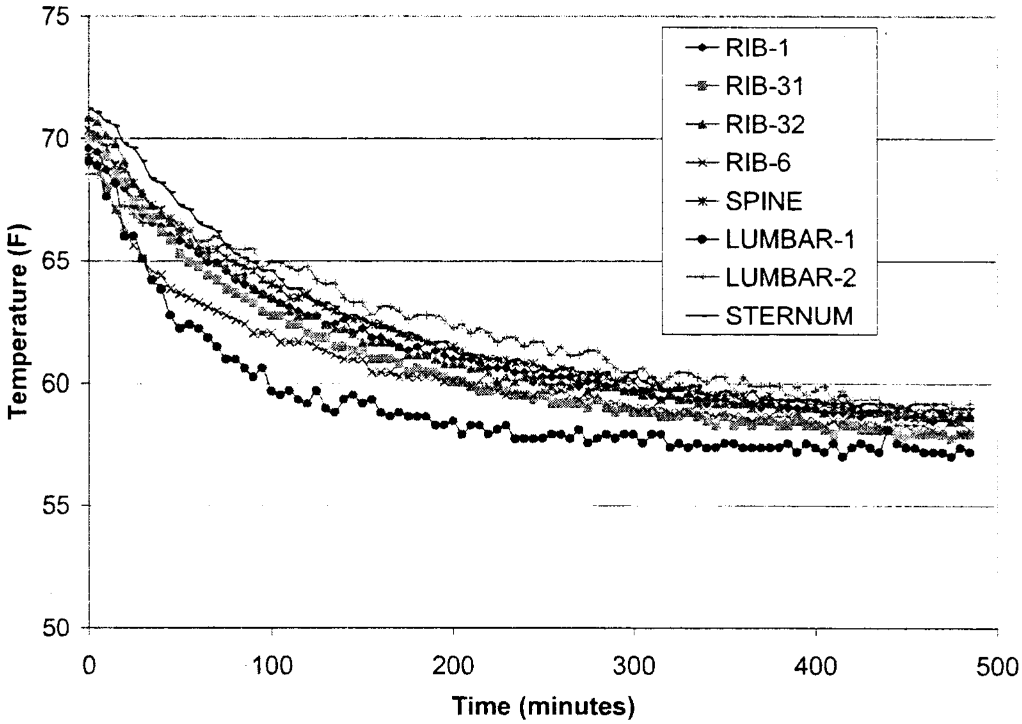


Fig. 14. Thorax Region Temperatures

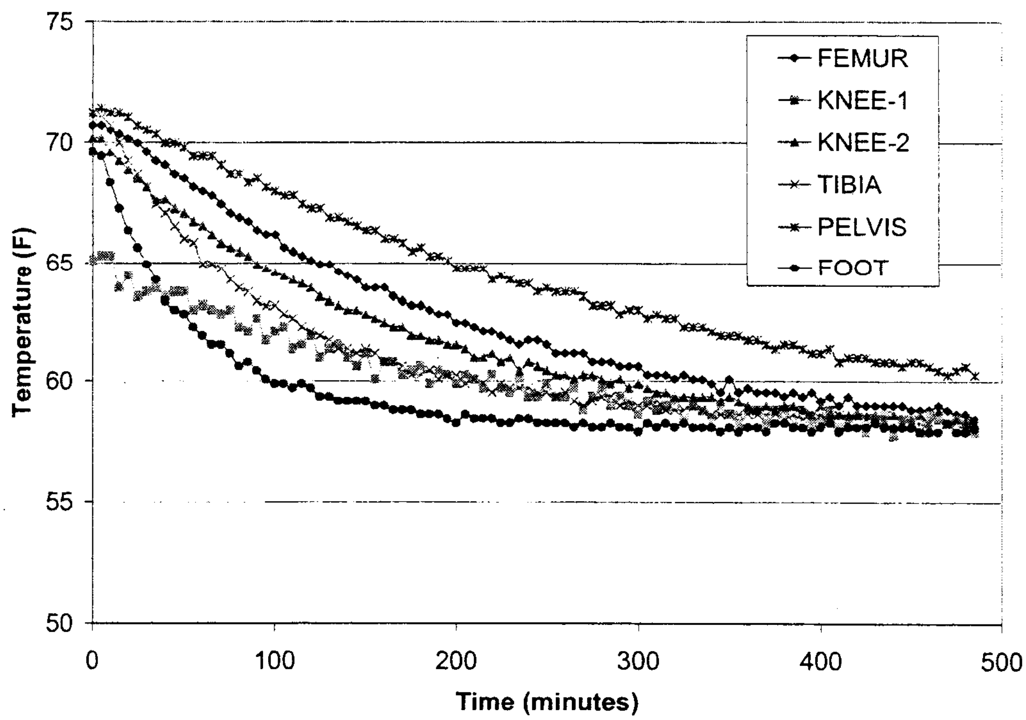


Fig. 15. Leg Region Temperatures

Table 4 summarizes the results of the channels for all dummy locations returning to ambient temperature after being cooled to 60 F, and Fig. 16-18 show the temperature changes for head, thorax, and leg region channels.

	B	σ_B	τ (hrs)	σ_τ
Head-1	0.856	0.046	1.209	0.074
Head-2	1.038	0.022	1.337	0.066
Neck	0.914	0.021	1.059	0.059
Rib-1	0.995	0.022	1.757	0.167
Rib-31	1.047	0.010	1.759	0.132
Rib-32	1.044	0.029	1.731	0.153
Rib-6	1.009	0.017	1.790	0.086
Spine	1.024	0.006	1.895	0.122
Lumbar-1	0.985	0.034	0.392	0.023
Lumbar-2	1.100	0.022	2.630	0.041
Femur	1.126	0.014	2.621	0.085
Knee-1	0.781	0.079	2.216	0.224
Knee-2	1.031	0.014	2.354	0.122
Tibia	1.075	0.034	1.841	0.070
Sternum	1.059	0.017	1.925	0.178
Pelvis	1.171	0.011	3.379	0.032
Foot	1.045	0.021	1.352	0.037

Table 4. Time constants and coefficients for heating from 60 F

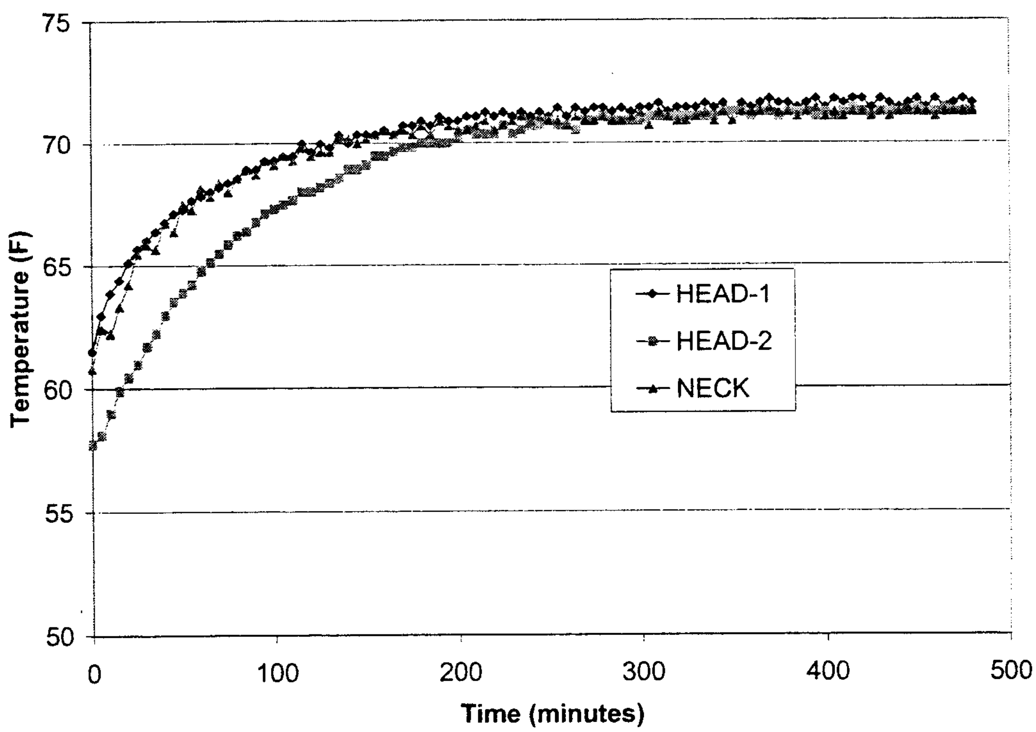


Fig. 16. Head Region Temperatures

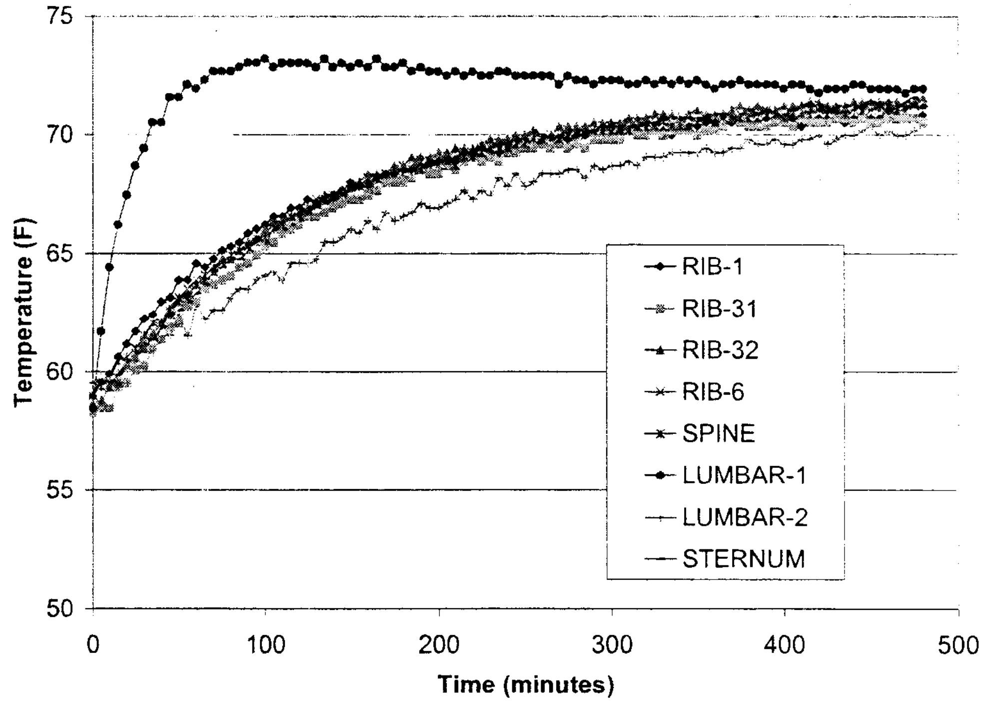


Fig. 17. Thorax Region Temperatures

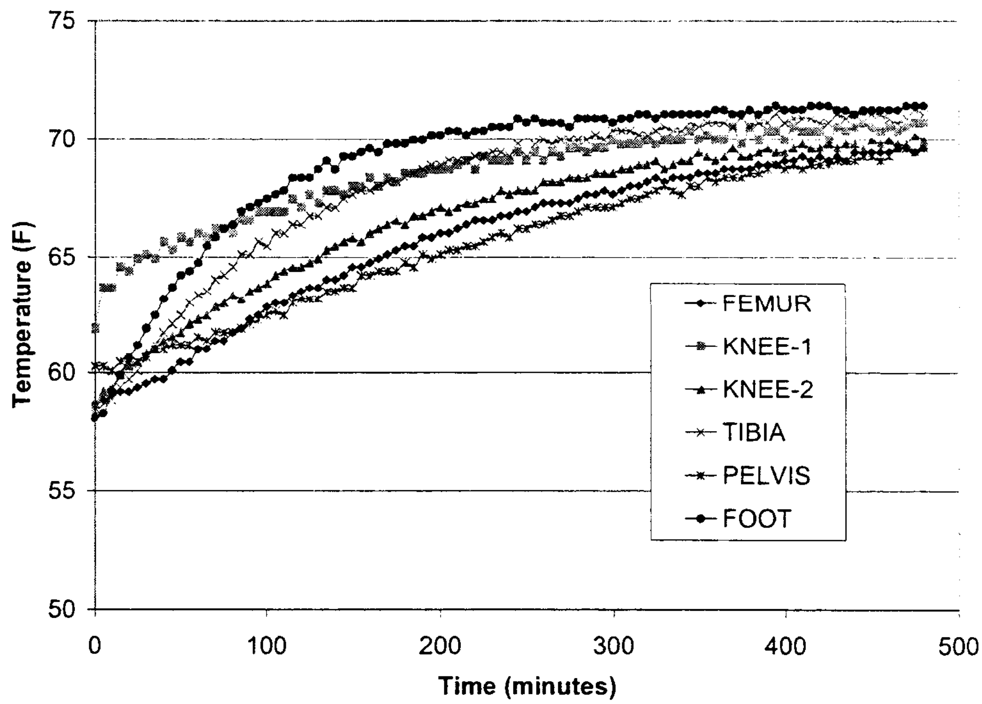


Fig. 18. Leg Region Temperatures

Using the time constants and initial value coefficients, the required soak time for each location to get to within 5% of their stabilized temperature can be calculated. For example, the soak time required for Head-1 to cool from 95 F to within 5% of its equilibrium ambient temperature is

$$0.05 = 0.856e^{-t/1.209}$$
$$t = 4.950 \text{ hrs}$$

Similarly, the soak time required for the Head-1 location to heat from 60 F to 95% of its equilibrium ambient temperature is

$$0.95 = 1 - 0.918\, e^{-t/1.701}$$
$$t = 3.434 \text{ hrs}$$

The following table summarizes the minimum soak times necessary to reach the FMVSS 208 test 69 – 72 F temperature requirement for each location in both cooling and heating:

	Heating from 60 F (hrs)	Cooling from 95 F (hrs)
Head-1	3.434	4.950
Head-2	4.055	5.074
Neck	3.077	5.362
Rib-1	5.255	5.524
Rib-31	5.350	5.151
Rib-32	5.261	5.050
Rib-6	5.379	5.287
Spine	5.721	4.204
Lumbar-1	1.168	2.934
Lumbar-2	8.131	7.921
Femur	8.161	7.402
Knee-1	6.092	7.282
Knee-2	7.123	6.780
Tibia	5.648	5.882
Sternum	5.877	7.117
Pelvis	10.656	8.107
Foot	4.111	4.795

Table 5. Required soak times based on measured time constants and initial value coefficients

3.2. Component Tests

3.2.1. Head Drops

Head resultant accelerations for all tests fell within the specification of 250 to 300 g (S572.132(b)), including those performed at temperatures outside of the 66 to 78 F range (Fig. 19). There was evidence of increasing acceleration with increasing temperature, but there was no significant correlation between temperature and acceleration, as shown by the low r-squared value (0.3691).

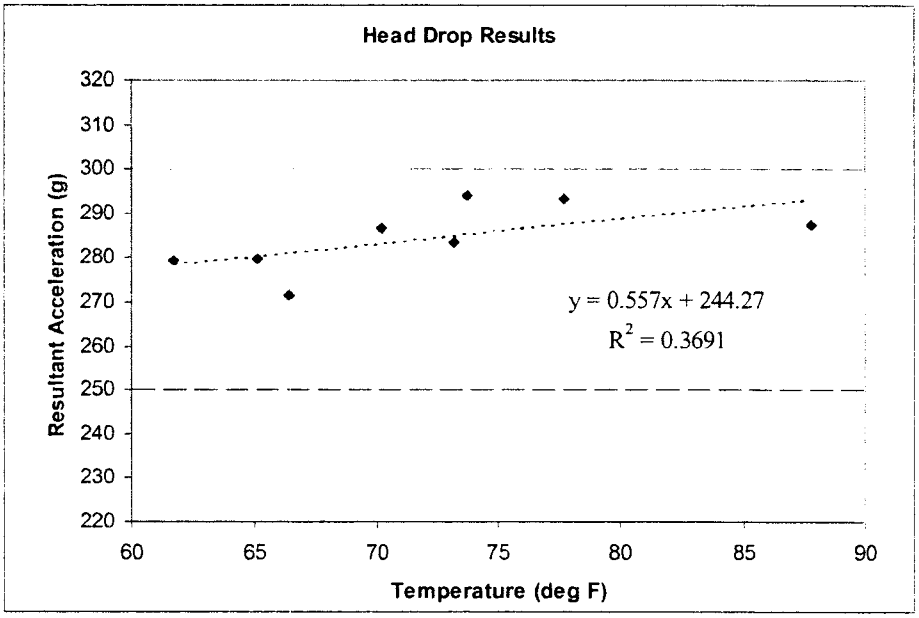


Fig. 19. Head resultant acceleration

3.2.2. Neck Flexions

All neck flexion moments about the occipital condyle were within the 69 to 83 N-m specification (S572.133(b)(1)), and there was no significant dependence on temperature (Fig. 20). The head D-plane rotation increased with temperature (Fig. 21).

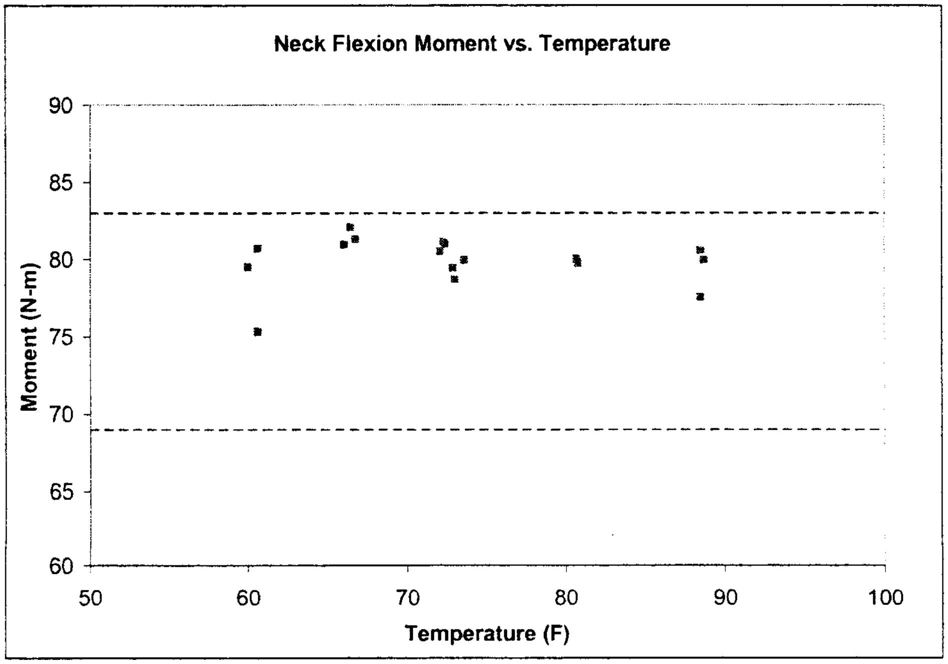


Fig. 20. Neck flexion moment about the occipital condyle

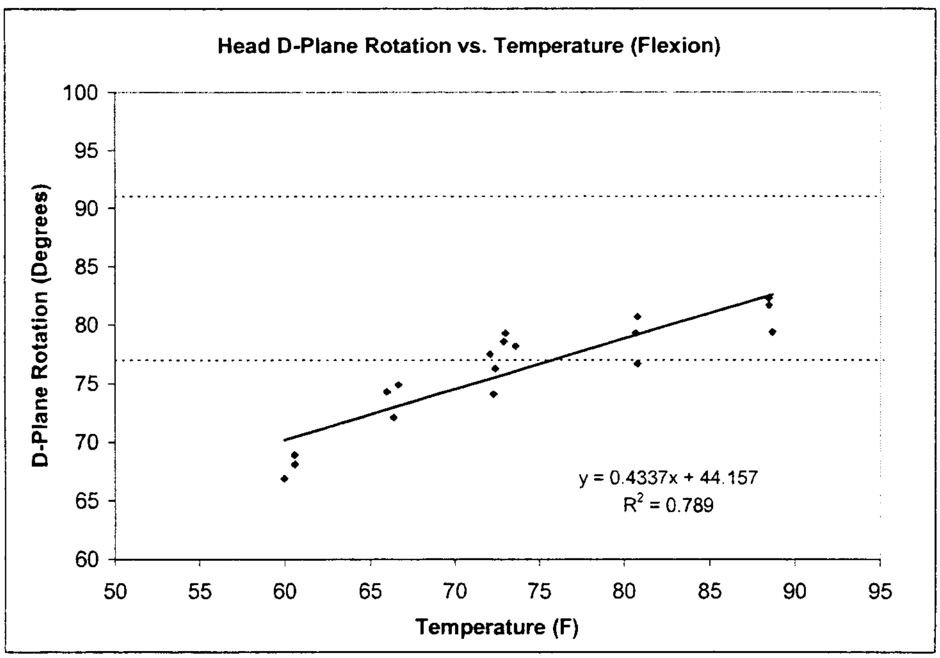


Figure 21. Head D-Plane rotation in flexion

3.2.3. Neck Extensions

Neck extension moments were within the –53 to –65 N-m corridor (S572.133(b)(2)) for temperatures between 65 and 81 F. Two out of six tests above 81 F were outside of the corridor, and five out of the six below 65 F were not within the specified range. Again, there was no significant dependence of the moment on temperature (Fig. 22). Like in flexion, the head D-plane rotation increased with temperature (Fig. 23).

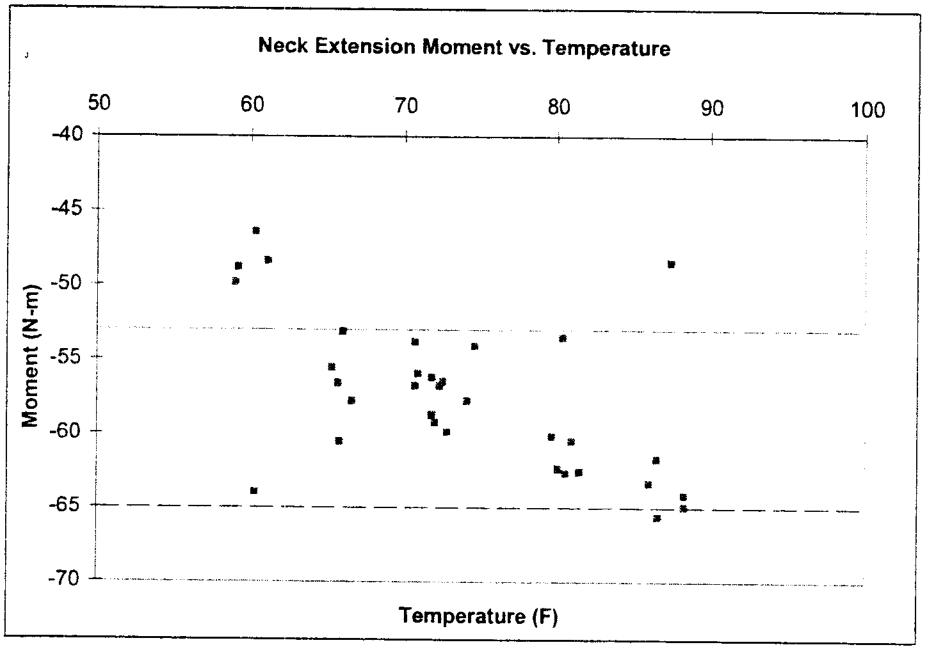


Fig. 22. Neck extension moment about the occipital condyle

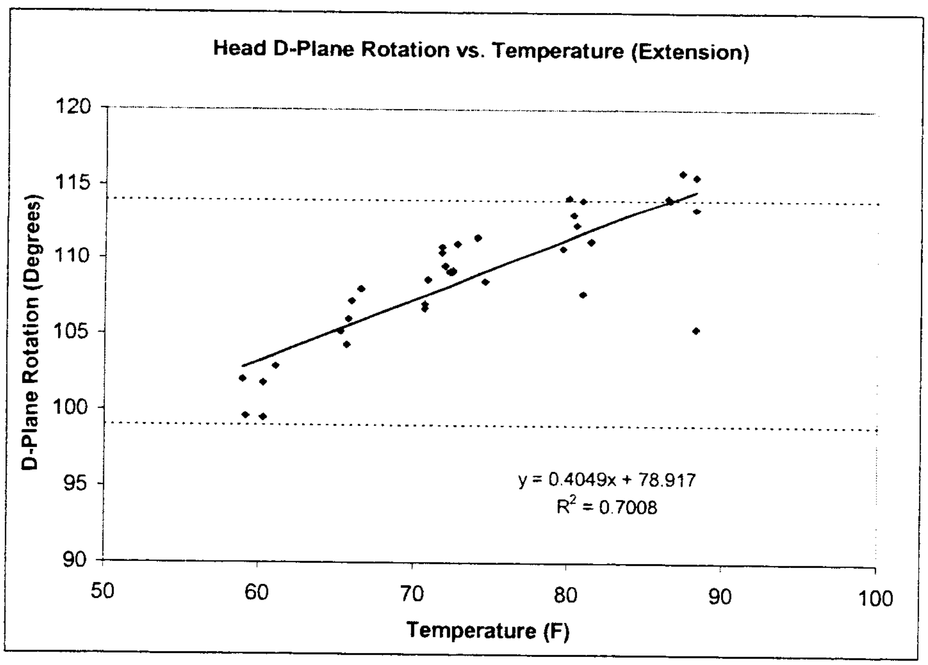
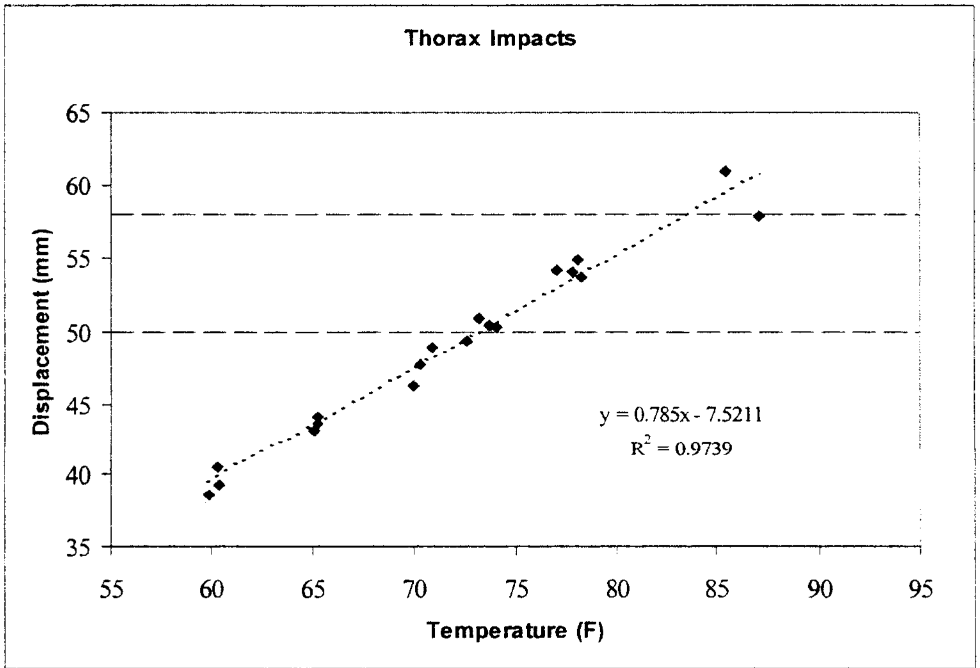


Figure 23. Head D-plane rotation in extension

3.2.4. Thorax Impacts

The thorax response was temperature-dependent, with displacement increasing and force decreasing with temperature (Fig. 24). The R-squared value for the displacement response was 0.9739, which indicates a very good correlation of displacement to temperature. The force response also exhibited good correlation to temperature with an R-squared value of 0.8989. Note that several of the thorax impacts tests conducted within the 69 - 72 degree range did not meet all of the specified force-deflection requirements (see Discussion for explanation).



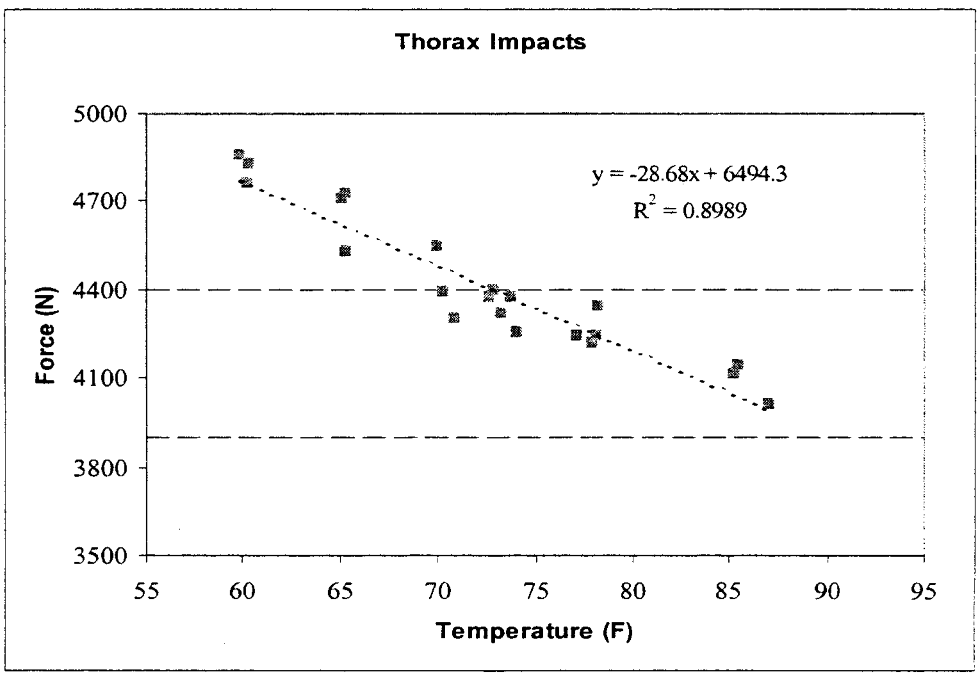


Fig. 24. Thorax displacement (top) and force (bottom)

4. Discussion

4.1. Time Constants

As expected, the dummy locations showed different temperature-time relationships in terms of how fast they respond to changes in ambient temperature. Internal locations responded more slowly to changes in temperature than locations on the exterior surface, as was the case in a previous study [1]. In addition, most locations took longer to cool down than to heat up (higher τ values), with the exception of the Spine, Lumbar-1, and Pelvis locations (Tables 2 and 4). All of the time constants were consistently below four hours, and the soak times required to get the locations to 95% of the equilibrium temperature were all considerably less than sixteen hours (Table 5), which is stated as the necessary duration in the FMVSS 208 laboratory test procedure. The highest soak time required was for the pelvis location (10.6 hrs). Component performance tests at different temperatures further evaluated how the response characteristics change for each location.

4.2. Component Tests

A temperature range is specified for Part 572 tests because of the thermal sensitivity of dummy components. The sensitivity of the HIII-5F dummy was investigated by performing tests on the head, neck, and thorax at various temperatures. Definitive trends were seen in the head drop tests and thorax impacts, but the neck responses in both flexion and extension did not show any conclusive relationships with temperature. The head resultant acceleration increased only about 5% from 60 F to 87 F, but all responses were within the required 250-300 g range (Fig. 19). This small increase in acceleration with temperature is consistent with previous results observed by Saul for a Hybrid III dummy [3], where peak acceleration increased 3% from 65 F to 80 F. The temperature range specified in Part 572 is 66 F to 78 F for these tests, which is easily large enough based on our tests. The increase in acceleration makes sense because as the head skin temperature increases, it becomes less rigid, and therefore more energy is transferred directly to the internal metal components.

The neck test results are not as easy to interpret. The neck is not symmetric in the fore-aft direction about the longitudinal centerline (Fig. 25). There is more rubber material present anterior to the plane than there is posterior to the plane, which makes the neck weaker in extension than in flexion. The dependence of the equivalent neck moment about the occipital condyle on temperature is not clear. In flexion, temperature did not seem to affect the moment, with values consistently around 80 N-m from 60 F to 87 F (Fig. 20). There was a steady increase in head D-plane rotation with an increase in temperature, however, with rotations of 68 degrees at 60 F increasing to 80 degrees at 87 F (Fig. 21). This increase in rotation shows that the neck did become more yielding at higher temperatures, but the moments for higher and lower temperatures were similar because the nonsymmetrical shape of the neck in that direction negated this increase in flexibility.

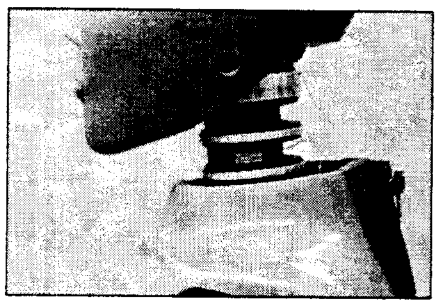


Fig. 25. Hybrid III 5th Female Neck

The behavior of the neck in extension is a more complex situation. The first eighteen tests indicated an *increase* in moment with an increase in temperature (-49 N-m at 60 F to -65 N-m at 87 F). This occurred even as D-plane rotation increased with temperature, as it did in flexion. The rotation increased from about

102 degrees at 60 F to 114 degrees at 87 F (Fig. 23). Initially, it was thought that the metal segments were topping out, which would leave no more room for rotation and an increase in moment about the occipital condyle. High-speed video for some additional tests in both flexion and extension indicated that this was not the case. This finding was further verified by the absence of signal anomalies at the peaks of the moment and force plots, which would almost certainly occur with a change in resistance from rubber to aluminum. The test procedure was also double-checked. It was decided that an additional set of tests would be conducted to see if this behavior was consistent. The first six tests showed the *opposite* trend, with a *decrease* in moment with increase in temperature (-64 N-m at 60 F decreasing to –48 N-m at 87 F). However, the remaining twelve tests returned to the initial trend. After looking at several possible reasons for this behavior, including fatigue of the neck, it was concluded that the moment of the neck in extension, while consistently in the –53 to –65 N-m corridor for tests between 65 and 80 F (Fig. 22), did not display a predictable relationship with temperature.

For thorax impacts, an increase in temperature from 65 to 80 F increased the peak deflection of the chest by 27% and decreased the peak pendulum force necessary to deform it by 9% (Fig. 24). The correlation between both deformation and force with temperature was high, as evidenced by the high r-squared values (Fig. 24). Several of the thorax impacts tests conducted within the 69 - 72 degree range did not meet all of the specified force-deflection requirements. There are two possible explanations for this result: 1) the dummy's ribs used in this testing were slightly bent prior to this testing; or 2) the chest potentiometer sensitivity was incorrect. Since the force responses were above the specified corridor and the deflection responses were below, the most plausible explanation is that the ribs were slightly deformed prior to this test series. Most importantly, neither of these scenarios would be expected to have any influence on the temperature sensitivity characteristics of the thoracic responses.

This behavior was not as magnified as in the Hybrid III 50^{th} Percentile Male results observed by Saul, in which the peak pendulum force response decreased 30% and the sternal deflection increased 42% from 65 F to 80 F [3]. The sensitivity of the thorax deflection in the Saul study was thought to be related to the damping material/steel thickness ratio of the rib designs. Even with the differences in allowable deflection and input energy specified in the 50^{th} Male and 5^{th} Female Part 572 tests, there is nonetheless a consistent trend of decreasing pendulum force and increasing deflection with increasing temperature.

5. Conclusions

The main results of this study are

1. Temperature sensitivity was seen in the thorax impacts and head D-plane rotations, but the neck moments in both flexion and extension did not show any conclusive relationships with temperature.
2. The head resultant acceleration increased roughly 5% from 60 F to 87 F, but all responses remained within the required 250-300 g range, and the correlation between temperature and acceleration was weak ($r^2 = 0.3691$).
3. In flexion, temperature did not seem to affect the moment, with values consistently around 80 N-m from 60 F to 87 F. The head D-plane rotation increased from 68 degrees at 60 F to 80 degrees at 87 F.
4. The response of the neck in extension, while consistently in the –53 to –65 N-m corridor for tests between 65 and 80 F, did not display a predictable relationship with temperature. The head D-plane rotation increased from 102 degrees at 60 F to 114 degrees at 87 F.
5. For thorax impacts, an increase in temperature from 65 F to 80 F increased the deflection of the chest by 27% and decreased the force necessary to deform it by 9%.

The major conclusions of this study based on these results are

1. Soak duration of sixteen hours, as currently stated in the FMVSS 208 test procedure, is sufficient to insure a stabilized temperature for all components of a Hybrid III 5th percentile female dummy.
2. The temperature sensitivity to thorax impacts observed in the current study is similar to the results observed in the previous study conducted by Saul, which served as the basis for the current temperature requirement in the FMVSS 208 test.

Even though system-level crash or sled tests were not conducted as part of this study, it is expected that the conclusions of such an effort would result in similar findings. For instance, it is expected that the thoracic response of the dummy would exhibit a strong correlation to temperature change in system-level tests.

Therefore, based on the results of this study, it is concluded that the dummy temperature range of 69 to 72 F be maintained as the requirement for FMVSS 208 tests.

6. References

1. Haffner M.P., Cook E.C. "Thermal Response of the Part 572 Dummy to Step Change in Ambient Temperature," NHTSA Technical Report DOT HS-801 960 (1976).
2. Seiffert, U.W., Leyer, H.E., "Dynamic Dummy Behavior Under Different Temperature Influence," Twentieth Stapp Car Crash Conference, SAE Paper No. 760804 (1976).
3. Saul R.A., "State-of-the-Art Dummy Selection – Volume I," NHTSA Technical Report No. DOT HS-806 722 (1984).