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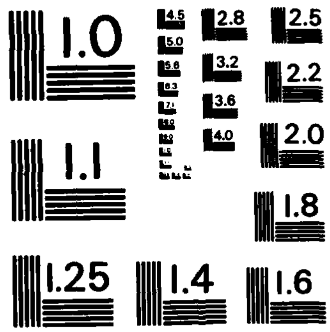


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# ANALYSIS OF PERSONAL THERMAL CONTROL SYSTEM (PTCS) ON HEAD-SPINE STRUCTURE EJECTION DYNAMICS

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**FOR THE COMMANDER**

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Head-Spine Model (HSM) ejection simulations have been conducted for the purpose of determining what effects a Personal Thermal Control System (PTCS) Headliner/Vest will have on occupant dynamic response during ejection. Only the inertial effects of the headliner and vest were considered. Three simulations were run: 1) without any inertial loading of the headliner and vest; 2) and 3) with inertial effects included for two possible vest locations. The prescribed acceleration profile used in the simulations approximated the first 250 msec of a

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20. severe H7 seat (used in some F-4 aircraft) acceleration profile. Results demonstrated that the PTCS had negligible effects on the dynamic response and injury potential of the head-spine system.

## PREFACE

This work was performed by the Modeling and Analysis Branch, Biodynamics and Bioengineering Division, Air Force Aerospace Medical Research Laboratory, for Headquarters, Aerospace Medical Division, Research and Development Systems, Chemical Defense (AMD/RDSX).

## INTRODUCTION

The Personal Thermal Control System (PTCS) Headliner and Vest is a proposed system to help regulate an aircrewmember's body temperature. The PTCS Headliner and Vest is worn underneath the crewmember's flight gear. A cooling fluid circulates through the headliner and vest, controlling body temperature. The cooling fluid is supplied by means of flexible coupling tubes that connect the vest to an external device.

Since the PTCS Headliner and Vest is worn directly on the aircrewmember, it can be expected to have some influence on the crewmember's dynamic response during ejection. A computer analysis was performed by the Modeling and Analysis Branch (BBM) of the Air Force Aerospace Medical Research Laboratory to determine the effects of the PTCS Headliner and Vest on the dynamic response and injury likelihood of the crewmember's head-spine system during a severe ejection acceleration event. The computer analysis used BBM's Head-Spine Model (HSM) [1,2,3] to compare ejection simulations in which the PTCS Headliner and Vest were incorporated into the model to an identical ejection simulation without the PTCS. In addition to the analytic evaluation, the potential mechanical hazards of the PTCS coupling system during emergency escape were considered.

## ANALYSIS

### QUANTIFICATION OF REQUIRED PARAMETERS

PTCS effects on head-spine structure dynamics during ejection were analyzed using the Air Force Aerospace Medical Research Laboratory's (AFAMRL) Head-Spine Model (HSM). The HSM is a dynamic, detailed, three-dimensional mathematical model of the human head and torso in a seated upright configuration. The HSM is fully discretized, i.e., the inertial distribution of the torso is discretized by assigning to each vertebral level the inertial properties of the corresponding torso cross section. The vertebral levels interact through deformable elements representing the various connective tissues; e.g., spinal ligaments, articular facets, intervertebral discs. The HSM can interact externally with an ejection seat (defined by a system of viscoelastic planes) and a restraint system (defined by deformable elements). The equations of motion for the HSM with specified initial conditions, i.e., the prescribed force or acceleration environment, are solved using a three-dimensional, large-displacement, small-deformation dynamic matrix structural analysis program.

It was assumed that the only significant effects the PTCS would have on the ejection dynamics of the head-spine structure would result from its added mass. It was therefore necessary to determine the in-use geometry of the PTCS and geometric variations due to the possible range of fit adjustments on the vest. The necessary dimensions were obtained through measurements taken of 1) the PTCS worn by an individual of average size and build and 2) the PTCS laid out flat on a level surface. Based on these measurements, the following parameters were determined:

$c$ = mean vest circumference
= 89.54 cm (35.25 in)

$h$ = mean vest height
= 30.48 cm (12 in)

$t_v$ = mean wet vest thickness
= .76 cm (.30 in)

and

$r$ = cap equivalent radius
= 13.14 cm (5.17 in)

The mean wet vest thickness was assumed to be the same as the mean "not compressed" thickness.

Using these dimensions, the vest was approximated as a hollow circular cylinder with outer circumference, height and thickness of 89.54, 30.48 and .76 cm, respectively. The total wet mass of the vest, M, was given as 771.8 gm. The mass, $m_i$, of a section of the vest normal to the longitudinal axis and having a height, $h_i$, is then given by

$$m_i = h_i/h\ M\ .$$

Similarly, the moment of inertia of such a section about its principal axis perpendicular to the midsagittal plane (e.g., the y-axis as commonly used in DoD human biodynamics studies) is given by

$$I_{yy_i} = \frac{m_i}{12}\,[3(a^2 + b^2) + h_i{}^2]$$

where $b$ = outer radius

$= c/2 = 14.25$ cm (5.61 in)

and $a$ = inner radius

$= b - t_v = 13.49$ cm (5.31 in) .

To determine the effects of the cooling vest, $m_i$ and $I_{yy_i}$ were simply added to the mass and y moment of inertia of the corresponding vertebral level in the HSM (i.e., it was assumed that the vest and torso move together). The moments of inertia about the x and z axes were not required because mid-sagittal plane symmetry was assumed. The HSM and cooling vest inertial distribution data are summarized in Tables 1 and 2. Two possible vest locations were considered corresponding to two different adjustments of the vest shoulder straps. The first location corresponds to the vest covering roughly vertebral levels T4 through L2 and the second, T7 through L4.

TABLE 1

HSM AND PTCS TRANSLATIONAL MASS DISTRIBUTION

| Vertebral Level (i)* | $h_i$ (cm) | Mass (gm x $10^3$) HSM | PTCS** | Combined |
| --- | --- | --- | --- | --- |
| T4 | 2.12 | 2.189 | .098 | 2.287 |
| T5 | 2.17 | 2.154 | .099 | 2.253 |
| T6 | 2.26 | 2.014 | .095 | 2.109 |
| T7 | 2.37 | 1.961 | .089 | 2.050 |
| T8 | 2.49 | 1.677 | .081 | 1.758 |
| T9 | 2.61 | 1.604 | .074 | 1.678 |
| T10 | 2.73 | 1.354 | .069 | 1.423 |
| T11 | 2.91 | 1.418 | .066 | 1.484 |
| T12 | 3.20 | 1.327 | .063 | 1.390 |
| L1 | 3.50 | 1.310 | .060 | 1.370 |
| L2 | 3.76 | 1.194 | .057 | 1.251 |
| L3 | 3.90 | 1.177 | .055 | 1.232 |
| L4 | 3.88 | 1.065 | .054 | 1.119 |
| Head | -- | 5.612 | .098 | 5.710 |

* Only modified levels are listed.

** $m_i \text{ (vest)} = (h_i/h)\, M$

where $h$ = mean vest height = 30.48 cm
$M$ = wet vest mass = 771.8 gm

TABLE 2

HSM AND PTCS SAGITTAL PLANE MOMENT OF INERTIA ($I_y$) DISTRIBUTION

| Vertebral Level* | $I_y$ (gm - cm$^2$ x 10$^4$) HSM | PTCS** | Combined |
|---|---|---|---|
| T4 | 3.138 | .519 | 3.657 |
| T5 | 3.838 | .531 | 4.369 |
| T6 | 4.425 | .553 | 4.978 |
| T7 | 5.347 | .581 | 5.928 |
| T8 | 5.543 | .610 | 6.153 |
| T9 | 6.164 | .640 | 6.804 |
| T10 | 6.028 | .670 | 6.698 |
| T11 | 7.056 | .715 | 7.771 |
| T12 | 7.022 | .787 | 7.809 |
| L1 | 8.061 | .862 | 8.923 |
| L2 | 8.354 | .928 | 9.282 |
| L3 | 8.264 | .963 | 9.227 |
| L4 | 8.083 | .958 | 9.041 |
| Head | 44.790 | 1.127 | 45.917 |

* Only modified levels are listed.

** $I_{y_i} = \frac{m_i}{12}\left[3(a^2 + b^2) + h_i^2\right]$

where $m_i$ and $h_i$ are listed in Table 1
b = outer radius = 14.25 cm
a = inner radius = 13.49 cm

The cap was approximated as a very thin hemispherical shell having a radius of 13.14 cm. The wet mass of the cap was given as 97.9 gm. The moment of inertia of a very thin hemispherical shell about any principal axis in the plane containing the largest circumference is 2/3 $mr^2$ [= 2/3 (97.9) $(13.14)^2$ = $1.13 \times 10^4$ gm-$cm^2$ for the cap]. The cap mass and y principal moment of inertia were simply added to the corresponding values for the HSM head/helmet body since it was assumed that the head + helmet + cap move together. The assumption of sagittal plane symmetry again meant that the cap x and z principal moments of inertia need not be included in the HSM.

## SIMULATION RESULTS

Three HSM ejection simulations were run to determine the effects of the PTCS on head-spine structure ejection dynamics. The first simulation, designated by I, did not include the inertial effects of the PTCS. Simulations II and III included the PTCS for different vest locations; T4 through L2 for II and T7 through L4 for III. A vertical (z) acceleration profile, shown in Figure 1, was prescribed for the seatback and the pelvis. This profile approximates a severe H-7 seat (used in some F-4 models) catapult phase acceleration.

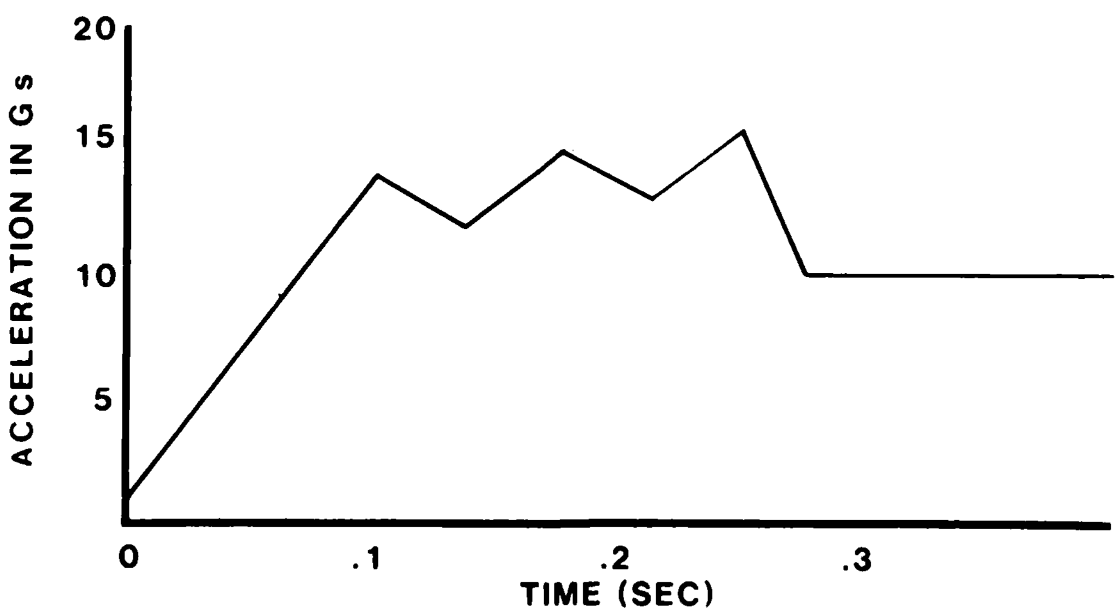


Figure 1. H-7 Seat Catapult Acceleration Profile

Table 3 compares the peak accelerations at each vertebral level while Figure 2 compares the HSM injury functions for the three simulations. Neither Table 3 nor Figure 2 shows any significant variations among the three simulations. Figure 3 depicts HSM sagittal plane configurations at times 0, 100, 200 and 250 msec. These configurations were essentially identical for all three simulations. These results demonstrate that the inertial effects of the PTCS on head-spine system ejection dynamics are negligible.

TABLE 3

PEAK ACCELERATIONS

| Level | I | II | II/I | III | III/I |
|---|---|---|---|---|---|
| T1 | 16.52* | 16.49* | 1.00 | 16.50* | 1.00 |
| T2 | 16.44 | 16.41 | 1.00 | 16.42 | 1.00 |
| T3 | 16.46 | 16.44 | 1.00 | 16.40 | 1.00 |
| T4 | 16.44 | 16.40 | 1.00 | 16.40 | 1.00 |
| T5 | 16.41 | 16.43 | 1.00 | 16.44 | 1.00 |
| T6 | 16.30 | 16.40 | 1.01 | 16.45 | 1.01 |
| T7 | 16.34 | 16.30 | 1.00 | 16.31 | 1.00 |
| T8 | 16.46 | 16.43 | 1.00 | 16.45 | 1.00 |
| T9 | 16.35 | 16.34 | 1.00 | 16.35 | 1.00 |
| T10 | 16.17 | 16.10 | 1.00 | 16.14 | 1.00 |
| T11 | 16.14 | 16.03 | 0.99 | 16.07 | 1.00 |
| T12 | 16.21 | 16.20 | 1.00 | 16.17 | 1.00 |
| L1 | 16.23 | 16.17 | 1.00 | 16.20 | 1.00 |
| L2 | 16.24 | 16.19 | 1.00 | 16.22 | 1.00 |
| L3 | 16.21 | 16.19 | 1.00 | 16.21 | 1.00 |
| L4 | 16.12 | 16.13 | 1.00 | 16.13 | 1.00 |
| L5 | 15.86 | 15.85 | 1.00 | 15.86 | 1.00 |
| Head (z) | 14.83 | 14.82 | 1.00 | 14.84 | 1.00 |
| Head (x) | 7.884 | 8.073 | 1.02 | 8.107 | 1.03 |
| Head ($\theta_x$) | 0.4201** | 0.4237** | 1.01 | 0.4244** | 1.01 |

* $cm/sec^2 \times 10^3$ (= 1.02 g)

** $rad/sec^2 \times 10^3$

The HSM Injury Function, which represents the ratio, at each vertebral level, of the peak computed cortical shell compressive stress (due to combined axial compression and bending) tc :he compressive yield stress, is currently in the process of being validated. Until this validation is completed, the significance of HSM injury results, such as shown in Figure 2, should be placed on relative values (i.e., degree of variation among the three simulations) rather than on absolute values.

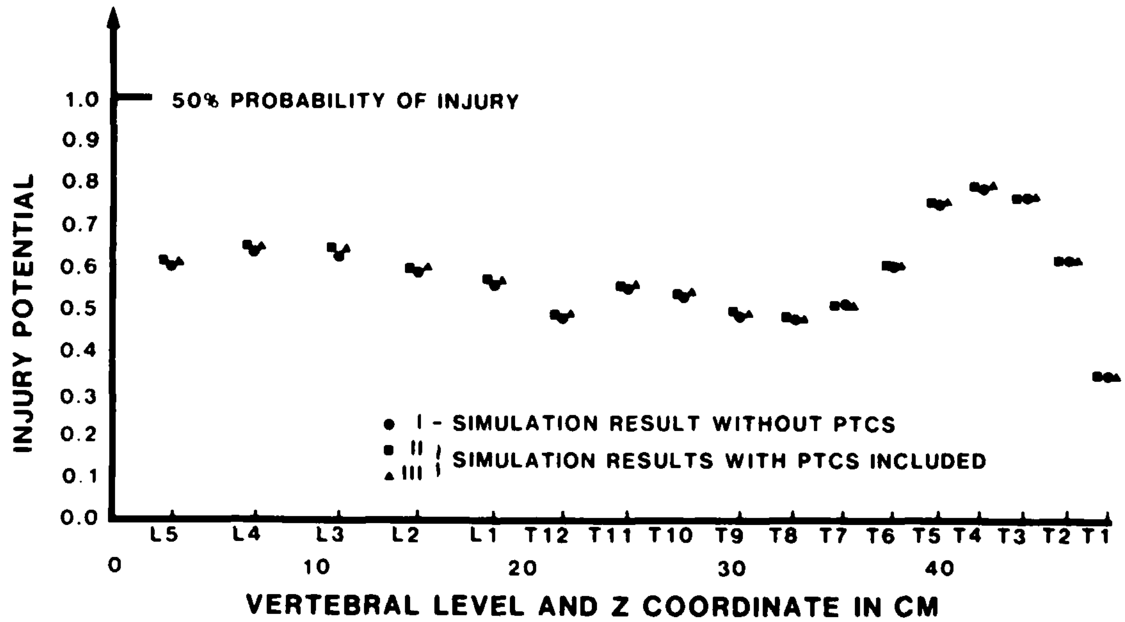


Figure 2. PTCS Effects on HSM Injury Predictions

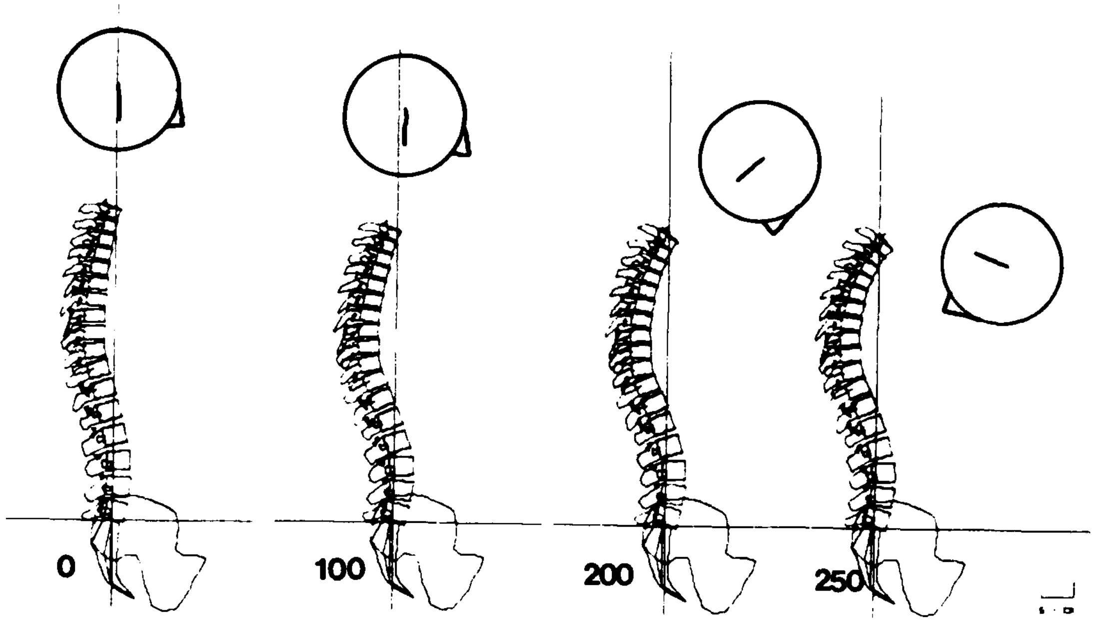


Figure 3. HSM Sagittal Plane Configurations for H-7 Seat Catapult Acceleration

## CONCLUSIONS

We found that the PTCS Headliner and Vest do not significantly alter the dynamic response of an aircrewmember experiencing typical ejection loading. The three HSM simulations showed that the inertial force of the PTCS Headliner and Vest have a negligible effect on the dynamic response and probability of injury. This was not an unexpected result because of the relatively low masses of the PTCS Headliner and Vest. The HSM analysis assumed that the only significant effect of the PTCS on the head-spine structure would result from its added mass. Other injury modes due to the PTCS were considered, and it was concluded that a much greater hazard was posed by the mechanical tube coupler than by the inertial loading of the PTCS Headliner and Vest.

The vest/seat (aircraft) connecting tubes are fastened by a plastic/metal coupler that has a dry weight of 155 grams. There are approximately 12 inches of flexible tubing between the vest coupler and the seat (aircraft) coupler. If the seat coupler is allowed to break away from the seat while the vest connector is still attached, there is a good possibility that this coupler will "thrash about" and injure the crewmember. Allowing the connecting tube to be fixed at only one end, large inertial forces can be created in the loose coupler (from seat motion and windstream forces) presenting a potential injury hazard. We recommend that careful consideration be given to the decoupling mechanism.

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