# The Influence of Initial Static Seat-belt Loads on Posture in Human Body Model Crash Simulations

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## I. INTRODUCTION

Human body models (HBMs) are used to study injury risk in vehicle crashes and may aid in future vehicle safety design. Simulations that evaluate vehicle safety are complex, and HBM positioning and initial conditions may affect predicted injury outcomes [1,2]. Vehicle occupant simulations typically involve pre-simulation positioning, gravity settling, and the dynamic crash event. Aspects of the pre-crash simulation setup have received increased attention in recent years [3], however the initial tension applied to the seat-belt has not. The goal of this study was to quantify the effect of initial static seat-belt load applied through a pretensioner on model location and seat interaction to identify best practices for applying initial static belt load.

## II. METHODS

The Total Human Model for Safety (THUMS) v4.1 and one of the National Crash Analysis Center (NCAC) full-scale vehicle models were used. To make comparisons, THUMS was gravity settled into the seat for 400 ms and then an initial static belt load was applied for 20 ms. For comparison, a gravity settling simulation of equivalent time (420 ms) was run without a belt applied to assess how adding initial static belt load affected HBM position (Fig. 1). All simulations were run using LS-DYNA R.11.0 on an HPC cluster.

Simulations were run in two postures: an upright driver posture and a reclined occupant posture [3]. The upright driver posture reflects nominal driver posture, with joint angles as expressed in [4]. The reclined occupant posture reflects a vehicle occupant with a 53° seatback angle [5]. For each posture, the simulations were run with three seat foam stiffnesses: a nominal seat foam stiffness, 0.1x scaled and 10x scaled. The seat foam load curve was optimized to match Patalak *et al.* [6]. Three initial static belt loads were tested based on values in the literature: 2 N, 20 N and 100 N [7-9]. A total of 24 simulations were conducted (3 foams x 3 belt loads x 2 postures) Control simulations with no belt (n = 6, 3 seat foam stiffness x 2 postures) were also conducted (Fig. 1).

To perform gravity settling and belting, the HBM was first settled into the seat without any belt and nodes were extracted. Then the seat belt was applied to the settled model using LS-PrePost, thus creating a seat belt that corresponds to a specific settling time. A three-point seat belt was used with shell elements to represent the webbing and 1-D seat-belt elements at the retractor and buckle ends. A slip ring was applied to connect the lap belt and shoulder belt to create a continuous three-point seat belt. The D-ring location was on the NCAC vehicle pillar for the upright model. For the reclined posture it was placed 30 mm above the seat in a location that provided sufficient fit over the shoulder. The HBM and vehicle nodes were then reset to their initial, pre-settling position (with belt nodes remaining the same). The simulation then began, and the seat-belt contact was applied at the specified settling time. The seat belt is fixed to not move until the end of the settling time, and the seat belt and HBM contact activates at the end of settling time.

The HBM was thus gravity settled and the seat belt was in contact with the model and allowed to move. At this instant, the initial static load was applied using an ELEMENT_SEATBELT_PRETENSIONER card using a load curve that began with the specified initial static load. This generates the belt force to apply tension to the belt. This force was held for 20 ms to properly tension the seat belt and apply force to the HBM. After this time, the simulation ended and output measures were taken. Measurements of vertebral landmark location, H-Point location and seat contact area were measured.

## III. INITIAL FINDINGS

Spinal landmarks were compared against the gravity settling-only locations to quantify the seat belt's displacement of the HBM. The C1, T1, L1 and L5 landmark positions in the sagittal plane were measured. The relative displacement of these landmark positions vs. the gravity settling locations are reported in Table I. The reported values are averages of the three stiffness values due to the low variation with seat stiffness (standard deviation < 5% of mean and < 0.05 mm in all cases).

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Fig. 1. Upright driver posture and reclined occupant posture in the simulation test matrix.

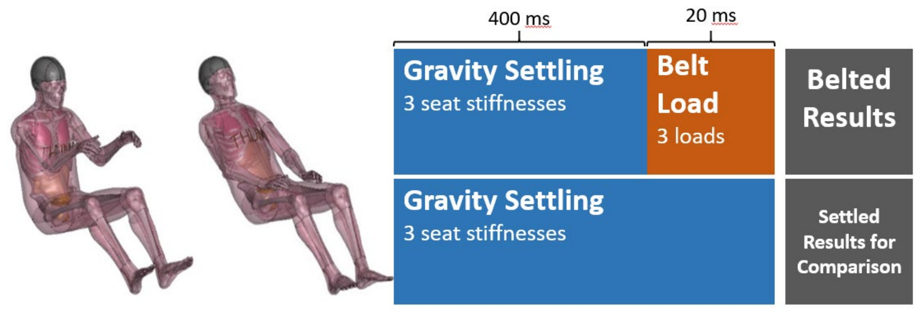


TABLE I

SPINE LANDMARKS AND H-POINT RELATIVE DISPLACEMENT FROM PURE GRAVITY SETTLING SIMULATIONS TO INITIAL STATIC BELT LOAD SIMULATIONS

| Posture | Belt Load | Landmark Relative Displacement [mm] | | | | |
|---|---|---|---|---|---|---|
| | | C1 | T1 | L1 | L5 | H-Point |
| Upright Driver | 2 N | 0.06 | 0.18 | 0.05 | 0.03 | 0.06 |
| | 20 N | 0.06 | 0.22 | 0.11 | 0.09 | 0.06 |
| | 100 N | 0.04 | 0.22 | 0.11 | 0.04 | 0.04 |
| Reclined Occupant | 2 N | 0.25 | 0.26 | 0.15 | 0.05 | 0.07 |
| | 20 N | 0.05 | 0.35 | 0.16 | 0.08 | 0.07 |
| | 100 N | 0.07 | 1.13 | 0.08 | 0.36 | 0.10 |

Seat contact area was measured by contact nodal forces. Each element that had 3 or more nodes in contact with the seat was counted as in contact with the HBM. The sum of the area of all elements in contact was the contact area. The percent increase in seat contact area of the belting simulations was compared to the gravity settling simulations (Table II).

TABLE II

PERCENT INCREASE IN SEAT CONTACT AREA BETWEEN PURE GRAVITY SETTLING SIMULATIONS AND INITIAL STATIC BELT LOAD SIMULATIONS

| Posture | Seat Foam Stiffness | Percent Increase Seat Contact Area (%) | | |
|---|---|---|---|---|
| | | Load: 2 N | 20 N | 100 N |
| Upright Driver | 0.1x | 7.6 | 7.7 | 7.6 |
| | 1x | 8.6 | 8.5 | 8.2 |
| | 10x | 8.0 | 8.0 | 7.8 |
| Reclined Occupant | 0.1x | 11.5 | 11.5 | 11.6 |
| | 1x | 12.3 | 11.8 | 11.9 |
| | 10x | 10.9 | 11.2 | 9.9 |

## IV. DISCUSSION

We systematically tested the influence of initial static belt load on HBM model initial position. In the crash research literature, initial static belt load is not frequently reported [10], and when it is reported it is not common to justify the value selected [11]. In post-mortem human subjects testing, crash tests commonly involve hand tightening belts, with static tension provided sporadically [12]. Because it has been reported that initial conditions have an influence on results [1], understanding the influence of initial belt tension is important to understand its influence on initial conditions, and simulation outcome. A belt tension that significantly changes HBM posture or position may make the results not applicable to the desired application.

That said, the results indicate that values of initial static belt tension up to at least 100 N do not significantly influence model quality and model location. Low relative displacement between settling HBM and belting HBM simulations for spine landmarks and H-Point indicate that applying an initial static belt tension does not displace the model significantly or change its posture in a meaningful way. The small change in model position does increase contact area, increasing the coupling between the HBM and the seat. Subsequent perturbation pulse tests confirmed these results, finding no difference in landmark locations following a 0.5g, 200 ms duration pulse.

A limitation of the study was the use of a single belt routing configuration for each of the upright and reclined postures and a single seat geometry. It is unknown how modifications to belt routing or seat design might affect findings, but given the low magnitude of changes observed, coupled with a broad range of seat foam stiffnesses tested, the results are thought to be representative of a wide range of seats.

## V. ACKNOWLEDGEMENTS

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