ATD head motion relative to the vehicle: the effect of vehicle inertial sensor mounting location.

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I. INTRODUCTION

In vehicle crash testing, tracking occupant body segments kinematics is critical to the assessment of restraint functionality and injury risk. The occupant motion inside a vehicle has been investigated widely using either video tracking or 3D optical motion capture systems such as Vicon (Vicon MX, Vicon, Los Angeles, CA, USA) [1-4]. Both of these methods, though, can be costly, time-consuming, and they require constant line of sight between the cameras and tracked markers throughout the whole event. In tests where motion of the occupant is obscured by the vehicle's interior components or safety systems, e.g., deployed airbags, neither video tracking nor optical systems can provide accurate information about the body segments orientation and position.

Anthropomorphic Test Devices (ATDs) used in crash testing nowadays are instrumented with sensor packages consisting of linear accelerometers and angular rate sensors. These sensor packages are usually mounted in several different body regions, including the head or the spine. Using the data from the sensors, time histories of 3D kinematics of each instrumented body part can be reconstructed. The same type of sensor package can be installed inside a vehicle to capture its motion [5]. The data from the two sets of sensors permit description of the body segments motion relative to the vehicle. However, if, during the impact, the vehicle structure deforms at the sensor mounting location, this local deformation will affect the calculated orientation and position of the car, and, subsequently, the occupant's relative trajectory.

The goal of this study was to examine how vehicle deformations at sensor mounting locations affect predicted head (treated here as an exemplar body region being tracked) relative to vehicle kinematics in a full scale oblique offset frontal crash test.

II. METHODS

Occupant head motion relative to vehicle was calculated based on the data from a frontal oblique offset test of a pickup truck [6]. In the test, a moving barrier was driven into the front-left side of the vehicle at approx. 90 km/h. The THOR ATD was positioned in the driver's seat, and its head was instrumented with the stock sensor package of three linear accelerometers and three angular rate sensors. Four identical 6 degree-of-freedom (DOF) sensor packages were mounted inside the truck to obtain the head motion relative to each of the four vehicle reference points. The mounting sites included the vehicle's centre of gravity (CG), the bottom of the left and right B-pillars, and the truck bed. Prior to testing, the initial orientation of the THOR's head and the mounting plates for the vehicle sensor cubes – in the global frame – were determined with a Coordinate Measuring Machine (CMM). During the test, the sensor data were recorded at 10 kHz.

Upon testing, a numerical algorithm with an input in the form of filtered local linear accelerations and angular rates was utilised to obtain the global acceleration vectors for the head and the four vehicle points. Next, the global acceleration vectors were double integrated to determine the position time-history of the head CG and the vehicle reference locations. Finally, using the vehicle reference frame (VRF) defined according to [7], the excursion of the ATD's head relative to each of the four truck points was obtained.

III. INITIAL FINDINGS

All four calculated head trajectories followed a similar *loop-like* pattern. After the impact, THOR's head moved forward (in positive X), outward (in negative Y) and downward (in positive Z) towards the driver's side A-pillar

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(Figure 1). After the contact with the frontal airbag, the head reached its maximum excursion and then rebounded. In the vehicle's XY plane, the four responses varied slightly in terms of the overall curve shape, with the *Veh CG* (red curve) having the smallest, and the *Left B-pillar* (blue) biggest *loop*. In the XZ plane, all four curves were close to each other until the peak Z value, with the *Left B-pillar* trajectory deviating noticeably from the other three after reaching the peak.

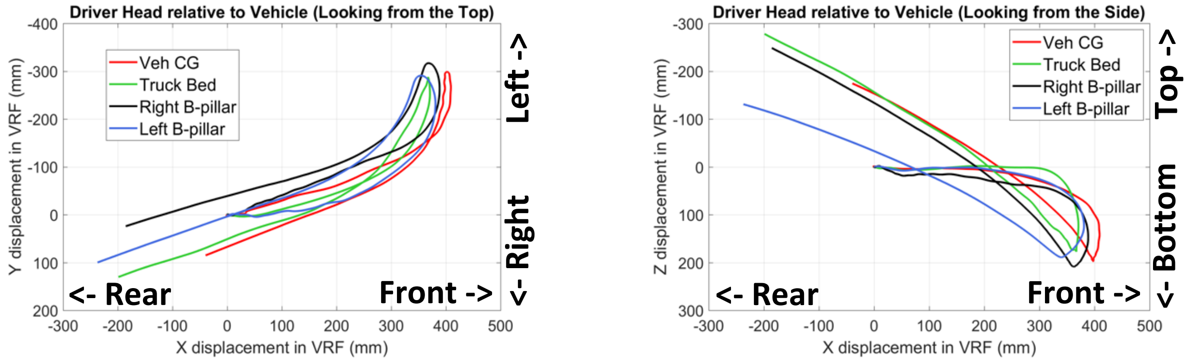

Fig. 1. THOR's head excursion in vehicle's XY plane (left) and XZ plane (right) relative to four different locations inside the car.

The highest absolute value of the maximum excursion was 409 mm in X-axis (Veh CG), 317 mm in Y-axis (Right B-Pillar), and 209 mm in Z-axis (Right B-pillar) (Table I). The average values of the maximum excursion were (value/standard deviation): 387 mm/±16.1 mm (X), -299 mm/±13 mm (Y), and 193 mm/±13.6 mm (Z). The largest maximum relative difference between the components of the four different trajectories was found to be 38 mm in the X-axis, while the lowest was 29 mm in the Y-axis.

TABLE I

MAXIMUM EXCURSION OF THOR'S HEAD RELATIVE TO THE FOUR VEHICLE LOCATIONS

	Veh CG	Truck Bed	Right B-pillar	Left B-pillar	Max relative difference
X (mm)	409	371	388	381	38
Y (mm)	-299	-288	-317	-291	29
Z (mm)	198	177	209	189	32

IV. DISCUSSION

Assuming that a vehicle is a rigid body connecting the instrumented car sites, one would expect that the 3D trajectories calculated for the occupant would be the same independently from the vehicle location used as the reference. However, all four head's trajectories calculated in this study differed slightly from each other. One of the contributing factors is the local deformation, both dynamic and permanent, of the area around the sensor mounting plate's attachment points. The sensor package at the vehicle's CG was installed on top of the vehicle's centreline tunnel, a region composed of relatively thin sheet metal (high local deformation possible). On the other hand, the sensors at the bottom of the B-pillars were attached to a stiff, multilayer structure of hot stamped metal sections (smaller deformation expected). The trajectory calculation process also might have been influenced by the sensors characteristics, e.g., noise-to-signal ratio, or test measurement inaccuracies, e.g., the initial orientation error resulting from the accuracy of the CMM measurement. Overall, though, the maximum relative difference between the four trajectories was 39 mm, which is in the order of magnitude of permanent local deformation seen for the A-pillar and rocker panel in post-frontal-oblique-crash vehicles [8].

The presented method is a promising alternative to optical capture systems for calculating vehicle and body segments position and orientation but further validation – using optical 3D motion tracking – is required to determine how these sensor predictions vary from actual trajectories.

V. REFERENCES

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