The Effectiveness of Pediatric Seatbelt Adjust Systems in Crash Scenarios

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I. INTRODUCTION

A new type of device has emerged in the Child Safety Restraint (CSR) market, which differs from traditional child booster car seats. These devices are designed primarily to lower the shoulder belt from a child's neck to the collarbone. Because of this function, they are often referred to as *Seatbelt Adjusters* (SA), as they adjust the position of the seatbelt to reflect the adult's belt route. These devices are much more affordable than traditional child car seats, which may motivate consumers to purchase them [1]. Some of these products have official certifications and are legally approved for use [2], while others don't but, they are marketed in a way that suggests they are intended specifically for children [1].

This study builds on a previous study [3], which focused on analysing the impact of booster seat design parameters on occupant response and the risk of submarining. Miller *et al.* conducted a large parametric simulation study, where a neural network metamodel was developed, enabling the characterisation of booster-seat design effects across the entire design space. The analysis revealed that the most important parameters impacting submarining outcome included booster stiffness, occupant posture, total seat cushion length, and the lateral position of the shoulder belt guide. The best performing boosters were the ones with high stiffness, a high backrest, a deep seat cushion, a long total cushion length, with an inboard shoulder belt guide position, and a low lap belt guide position.

The authors of this study were unable to find any similar prior research addressing the effectiveness of SA. Therefore, the primary goal of this research is to fill this gap in knowledge, by evaluating generic SA models in the context of methods developed in [3] to provide a coherent evaluation platform in the context of previous booster design evaluation work. Specifically, this study focuses on the evaluation of difference in submarining risk between traditional boosters and SA considering booster design features and child's posture.

II. METHODS

Three main types of SA types were identified: *Additional Belt* – an extra strap that connects the shoulder belt to the lap belt; *Sleeve* – a piece of fabric through which the seatbelt is threaded; and *Positioner* – a rigid device that locks the seatbelt in a fixed position. Finite element models representing each SA identified were developed for the purpose of this study (Fig. 1). All simulations were run utilizing open source updated FMVSS 213 bench model available from UVA's website [4] and Piper child model [5]. Each SA design was evaluated with respect to occupant posture (no slouch, 25 mm slouch, 50 mm slouch), buckle length (75 mm/150mm), and anchor position (forward/aft). These parameters, without buckle length, were informed by previous work presented in [3][6]. Additionally, a scenario with belt only was considered in this study. Four belt configurations, with three occupant postures with two anchor lengths and two anchor positions resulted in a total of 48 simulations for the evaluation of SA.

In order to evaluate SA in the context of booster-seat design, booster simulations were also conducted. Booster seat finite element models were developed following the methodology described in [3]. Booster parameters were selected to represent the average booster as documented in the market sample study presented in [3]. Additionally, the parameters that were identified as having the biggest impact on submarining outcome were varied [3]. These included booster type (full/backless), cushion depth (min/mean/max), and booster material (stiff/soft). With the three child postures previously considered, a total of 36 simulations were conducted for boosters.

The simulation process consisted of three key stages: settling simulation, seatbelt routing simulation, and final simulation. In the settling simulation, HBM and restraint parameters were configured to align with the parameter space defined in [3], ensuring that HBMs were positioned to match the previous study. Next, an automated seatbelt routing simulation was developed to establish a consistent and representative belt route for each CRS. For booster seats, this process closely followed the methodology outlined in [3]. Finally, the final simulation was conducted using methods and parameters described in [3], ensuring consistency with established procedures. The pulse was taken from FMVSS 213, were Δv= 13.6 m/s and a_{max}=23g. Submarining was defined as the lower edge lap belt node directly in front of either ASIS node having a larger global Z coordinate than the ASIS while the

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two nodes were less than 25 mm apart in the global X direction. Pre-submarining was defined as a state in which the initial belt route had already triggered submarining detection conditions before the simulation began.

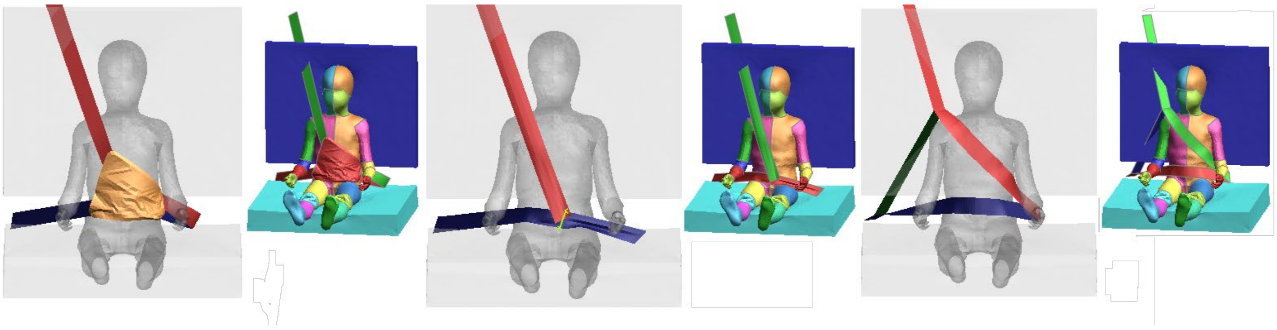

Fig. 1. SA types identified (from left): Sleeve, Positioner and Additional Belt.

III. RESULTS

All considered SA devices failed to protect the child occupant from submarining. This response was similar to the belt-only case. Submarining occurred in all cases with SA, but only in some booster cases. Pre-submarining occurred only in SA cases and was not detected for any boosters in this study. For SA cases, pre-submarining was more prevalent in the aft belt anchor locations. For booster cases, submarining was more prevalent in soft boosters and with more slouched postures. Only in no slouch postures selected soft boosters were able to protect the occupant from submarining. No submarining was observed for stiff boosters (Fig. 2 and Fig. 3).

Slouch / SA Configuration	No Slouch	25 mm Slouch	50 mm Slouch
Sleeve_aft_150	Sub	Pre-Sub	Pre-Sub
Sleeve_aft_75	Sub	Pre-Sub	Pre-Sub
Sleeve_forward_150	Sub	Sub	Sub
Sleeve_forward_75	Sub	Sub	Sub
BELT_aft_150	Sub	Pre-Sub	Pre-Sub
BELT_aft_75	Sub	Sub	Pre-Sub
BELT_forward_150	Pre-Sub	Pre-Sub	Sub
BELT_forward_75	Pre-Sub	Sub	Sub
P_aft_150	Sub	Pre-Sub	Pre-Sub
P_aft_75	Pre-Sub	Pre-Sub	Pre-Sub
P_forward_150	Sub	Sub	Sub
P_forward_75	Sub	Sub	Sub
AB_aft_150	Pre-Sub	Pre-Sub	Pre-Sub
AB_aft_75	Pre-Sub	Pre-Sub	Pre-Sub
AB_forward_150	Sub	Sub	Pre-Sub
AB_forward_75	Sub	Sub	Sub

Fig. 2. SAs submarining: P-Positioner, AB-additional belt, Belt-plain seatbelt, 150/75-buckle length, aft/for-aft or forward anchor point.

Slouch / Booster Configuration	No Slouch	25 mm Slouch	50 mm Slouch
backless_low_soft	Sub	Sub	Sub
backless_low_stiff	No	No	No
backless_mid_soft	Sub	Sub	Sub
backless_mid_stiff	No	No	No
backless_up_soft	No	Sub	Sub
backless_up_stiff	No	No	No
full_low_soft	No	Sub	Sub
full_low_stiff	No	No	No
full_mid_soft	No	Sub	Sub
full_mid_stiff	No	No	No
full_up_soft	Sub	Sub	Sub
full_up_stiff	No	No	No

Fig. 3. Boosters Submarining; backless/full- type of booster, low/mid/up-min,mean,max cushion depth, soft/stiff-material stiffness.

IV. DISCUSSION

In all evaluated cases SA systems failed to protect child occupants against submarining, while traditional boosters' simulations resulted in submarining only for higher slouch postures and softer boosters. These results are in line with the observations produced by [3]. Pre-submarining occurred only in SA cases. This is likely due to the lack of lap belt guides, which in boosters ensure an appropriate lap belt route over the pelvis.

This shows that these devices do not guarantee occupant safety and are not a suitable replacement for car booster seats. Also, in terms of submarining, no improved performance was detected using SA over the belt-only restraint. This indicates that they may also not provide added safety in situations without car seats, such as taxis [2].

V. REFERENCES

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