Investigation of Boundary Conditions for Vehicle Rollover Simulations

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I. INTRODUCTION

Rollover crashes constitute almost 30% of occupant deaths in highway crashes, although they account for only 3% of all vehicle accidents [1]. Most of the accidents are single-vehicle collisions (68%) after departing the roadway (63%), and almost half of the occupants involved in such accidents are ejected from the vehicle during a rollover accident [1]. Therefore, a FMVSS 226 regulation on ejection mitigation has been established. The most commonly used restraint system is a seatbelt with a rollover-activated side curtain airbag [2].

Designing effective restraint systems requires standardised, repeatable test conditions, which remains a challenge for the rollover scenario. One way to address this challenge is through the use of numerical models that provide repeatability and the ability to investigate a wide range of test conditions. However, simulations of rollover are challenging due to the wide variety of boundary conditions that may result in a rollover, and the long duration of these events (on the order of seconds [3]). Most modelling approaches that involve occupant injury prediction focus on representing physical tests that mimic simplified rollover conditions in roof strength tests [3]. A primary challenge in simulating rollover is that existing numerical vehicle models were not constructed for this purpose and often result in instabilities, or require significant modifications to simulate rollover using simple boundary conditions.

This paper presents a numerical approach to model dynamic rollover conditions using existing vehicle models without any modifications to the vehicle model.

II. METHODS

Vehicle models investigated in this study included a Ford Explorer model (SUV) used as-provided [4], and a Ford Taurus model (sedan) that was previously enhanced and validated in frontal and side impacts [5-6]. Rollover initiating boundary conditions were identified to model the most common rollover types [1]. Different modelling approaches involved a road barrier impact (Fig. 2 (a)), direct velocity application to the vehicle tyres (Fig. 2 (b)), different designs of ramps (Fig. 2 (c)), and initial lateral velocity application (Fig. 2 (d)). Lateral rollover was modelled using an initial lateral velocity and high friction between the vehicle tyres and ground (Fig. 1 (a)). Oblique rollover was modelled using initial longitudinal velocity and a ramp on one side of the vehicle (Fig. 1 (b), Fig. 2 (c)). All simulations were performed using an explicit finite element code (LS-Dyna).

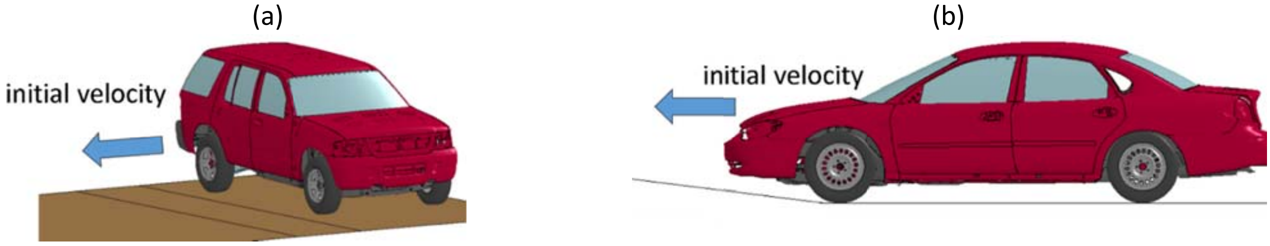

Fig. 1. (a) Ford Explorer (SUV) model in a lateral rollover scenario, (b) Ford Taurus (sedan) model in an oblique rollover scenario.

III. INITIAL FINDINGS

For the road barrier impact, the vehicle deformation was large and led to numerical instabilities (Fig. 1 (a)). Specifically, these conditions exceeded the range for which the vehicle material models were validated, so this scenario could not be used without extensive modifications to the vehicle model. In a similar manner, direct velocity application to the vehicle tyres resulted in failure at the suspension components (Fig. 2 (b)). In contrast,

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the lateral velocity with a high friction coefficient and longitudinal velocity with a ramp demonstrated the ability to initiate vehicle rollover in a controlled fashion.

Application of an initial lateral velocity (Fig. **1** (a)) with a high friction coefficient between the tyres and ground improved repeatability, and initial longitudinal velocity with a ramp (Fig. **1** (b)) reduced the overall simulation time from multiple seconds to one second or below. Different susceptibility to rollover was observed between the sedan and SUV models. The SUV model was more prone to rollover (Fig. 2 (d)), as expected, whereas the sedan could only achieve rollover for the ramp load case (Fig. 2 (c)).

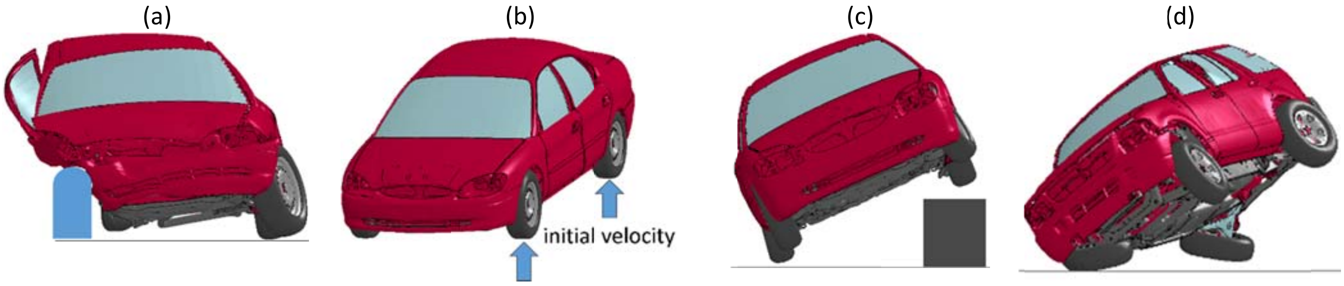

Fig. 2. (a) Sedan impacting a road barrier – simulation terminated; (b) lateral velocity applied to sedan tyres – simulation terminated; (c) sedan initiating the rollover with use of longitudinal velocity and a ramp; (d) SUV initiating the rollover with use of lateral velocity and high friction coefficient method.

IV. DISCUSSION

Rollover is an important crash scenario and numerical simulations enable investigation of different boundary conditions in a systematic and repeatable manner. However, due to the long duration associated with these events, it may be computationally prohibitive to model the full event for large parametric studies. In addition, the application of boundary conditions to reduce the simulation time often results in model instabilities since these models were not initially developed and validated considering this crash scenario.

Different boundary conditions and methods were investigated to generate vehicle rollover conditions. Many currently available vehicle models (e.g. the NCAC vehicle models [4]) were not developed specifically for rollover, which resulted in modelling challenges for some boundary conditions. Boundary conditions generating large local deformation (such as the road barrier lateral impact) required significant modifications to the vehicle model and were not pursued further. The recommended approaches include initial longitudinal velocity with a ramp to generate an oblique rollover scenario, and application of an initial lateral velocity and high friction coefficient between the ground and tyres, to generate a lateral rollover scenario. With these approaches it was possible to create rollover conditions for both the SUV and sedan, without major modifications to the vehicle models.

The initial lateral velocity vector had both lateral and longitudinal velocity components as would be the case in actual rollover scenarios, where the maximum vehicle roof deformation occurs at the front and side of the vehicle roof, between the A and B pillars [1].

Next steps include the investigation of injuries using occupant human body models suitable for omni-directional loading and coupled with the vehicle and restraint systems in lateral and oblique rollover scenarios.

V. REFERENCES

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