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Reduced Order Modeling of Automotive Crash Events via Proper Orthogonal Decomposition and Parametric Shape Morphing

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Objectives
Crash simulations based on explicit finite element solvers are widely used in the automotive industry to assess structural performance under impact conditions. However, their high computational cost limits their applicability in design exploration and real-time analysis. The objective of this work is to develop a reduced order modeling (ROM) framework for the rapid reconstruction of crash events, based on the combination of parametric geometry variation, high-fidelity simulations, and Proper rthogonal Decomposition (POD) applied to time-dependent responses.
Methodology
The proposed approach builds upon a parametric generation of geometrical configurations using Radial Basis Function (RBF) mesh morphing, allowing simultaneous variation of component shape and thickness while preserving mesh quality. For each configuration, high-fidelity crash simulations are performed using an explicit solver, generating time histories of displacement and deformation fields. The transient response is sampled at selected time instants, and a POD is applied to the resulting dataset, treating each time frame as a snapshot. This procedure enables the extraction of dominant spatial modes associated with the crash dynamics. The temporal evolution is then represented in the reduced space, allowing the reconstruction of the full crash event through a limited number of modal coefficients. The resulting ROM can be queried to approximate the structural response for new configurations within the explored design space.
Results
The methodology is applied to an automotive crash case based on a parametrically morphed bonnet model. The results show that the proposed POD-based ROM is able to accurately reconstruct the deformation history of the structure with a significantly reduced computational cost compared to full explicit simulations. The approach captures the main deformation patterns and impact dynamics using a limited number of modes. Furthermore, the reduced representation enables fast visualization of the crash evolution, which can be exploited for interactive inspection of critical phenomena such as local penetrations and folding mechanisms.
Conclusions
The study demonstrates that the integration of parametric morphing, explicit crash simulations, and POD-based reduction provides an effective framework for the fast reconstruction of impact events. The proposed approach opens the way to real-time or near-real-time analysis of crash scenarios and supports advanced applications such as digital twins and immersive visualization environments. In particular, the reduced model can be integrated with virtual reality tools to enable frame-by-frame inspection of deformation mechanisms, offering new perspectives for design evaluation and decision-making in crashworthiness analysis.

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