ISOGEOMETRIC BOUNDARY-CONFORMING BODY-IN-WHITE CRASH MODEL CONSTRUCTION, ANALYSIS, AND COMPARISON WITH FEM MODEL

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ABSTRACT

In this paper, we discuss model generation to rebuild the body-in-white of a 1996 Dodge Neon finite element model into a isogeometric conforming analysis-suitable crash model. We then perform the first known boundary-fit isogeometric body-in-white crash analysis of the vehicle and compare results achieved by traditional finite element methods. Results indicate the value and potential of high-order meshes in analysis.

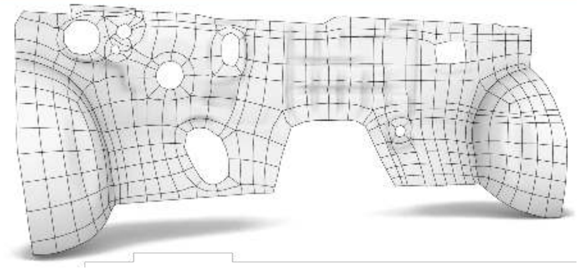
Keywords: mesh generation, isogeometric analysis, body-in-white, crash, quadrilateral, splines

1. INTRODUCTION

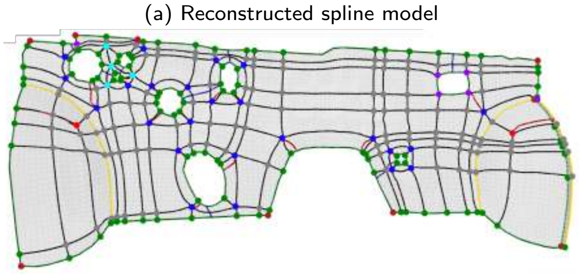
Crash analysis of a vehicle is an integral step to determining the safety and viability of a proposed vehicle. Of particular interest in these models is the integrity of the structural frame, or body-in-white, when subject to crash loads. Such an analysis requires an efficient explicit time integration scheme, robust connectivity between parts, a full elasto-plastic analysis of deformation, and discretized geometry of sufficient quality to address the extreme levels of deformation. As a result, engineers spend a significant amount of time not only performing crash analysis, but also creating models suitable for use in crash analysis.

The automotive design-through-analysis framework typically requires that engineers convert a computer-aided design (CAD) model generated from non-uniform rational B-spline (NURBS) surfaces into a set of analysis-suitable meshes, each suitable for its intended analysis. Distinct analyses—including disparate crash analyses—may require creation of new meshes for use in that particular analysis. Care must be made not only to generate meshes of sufficient quality that they will not pollute the analysis, but also of high enough geometric integrity that the meshes accurately capture the geometry. This mesh generation process is time-consuming and labor-intensive [1, 2], and there is significant interest in improving the process, both for higher accuracy and for better speed.

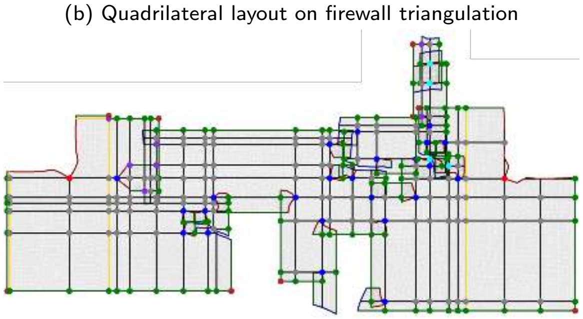
Isogeometric analysis [3] shows significant promise in improving this design-through-analysis framework, from the model generation process to increased accuracy [4] and speed of analysis. Indeed, though typical high-order and high-accuracy C^0 finite element methods are not used for explicit dynamics because of modal analysis errors that pollute the maximal stable time step, high-order smooth isogeometric methods are prone to less error for modal analyses [5]. Additionally, CAD models themselves are based on the the same B-spline and NURBS basis functions used in many isogeometric techniques, giving rise to the hope of a streamlined model generation process that avoids the pitfalls of computing auxiliary faceted meshes for analysis. Despite this promise, however, analysis-suitable isogeometric model generation from CAD geometries has remained a challenge because trimming operations, which are ubiquitous in CAD models, severely complicate (and frequently impede)



(a) Reconstructed spline model



(b) Quadrilateral layout on firewall triangulation



(c) Immersion inducing the quadrilateral layout

Figure 1: Above, the firewall of a 1996 Dodge Neon is rebuilt as a union of B-spline patches that are defined based on a quadrilateral layout computed and defined on the triangulation in the center. This quadrilateral layout is induced by the immersion map below, and is the result of Ricci flow with metric optimization.

downstream analysis [6].

In this work, we leverage the recently developed framework of using Ricci flow with metric optimization [7, 8] to semi-automatically reconstruct the body-in-white of a 1996 Dodge Neon into an crash analysis-suitable geometry. Not only does the work demonstrate the potential of the method in reconstructing analysis-suitable complex geometries, but it represents first boundary-fit body-in-white crash analysis of vehicle using isogeometric methods.[1] Crash results are then compared to analysis using traditional finite element methods.

[1]The first body-in-white crash analysis of a trimmed vehicle was completed by Honda in 2019, but was publicly announced in 2022.

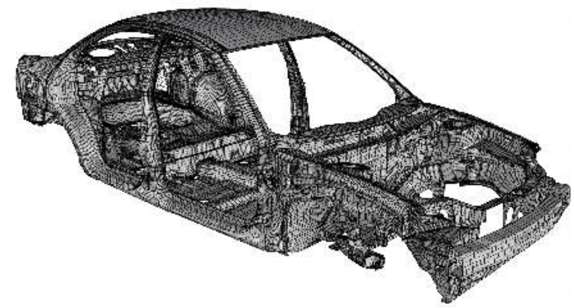


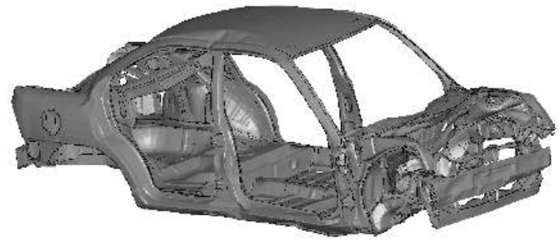
Figure 2: Reconstructed isogeometric model of the George Washington University 1996 Dodge Neon body-in-white finite element model [9].

2. MODEL GENERATION

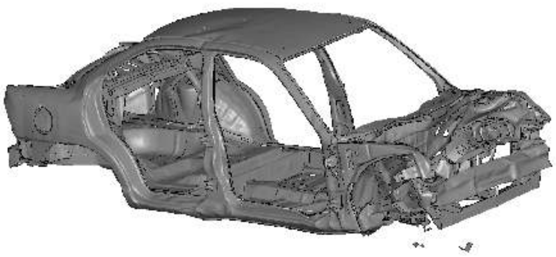
We follow the general procedure outlined in [7, 8] to rebuild the car geometry from an initial finite element model [9]. First, a frame field is computed on a feature-aware triangulation of each body-in-white part [10, 11, 12] to introduce a set of cone singularities that satisfy a discrete Gauss-Bonnet equation needed to induce a quadrilateral layout [13, 14]. These cone singularities will become the so-called "extraordinary points" in the spline representation. If singularities are in suboptimal positions, they can be relocated manually. The selected cones are then used as input for discrete surface Ricci flow [15] to generate a flat metric with cones on the part. The resulting metric will generally only satisfy some of the requisite properties to induce a quadrilateral layout, so subsequent optimization is performed to satisfy necessary boundary alignment and holonomy constraints [8, 14].

Though the above method will generally yield a quadrilateral decomposition on the midsurfaces of parts, connectivity between singularities will generally be suboptimal, producing a mesh with poor aspect ratios. As a result, additional singularity connectivity constraints are introduced semi-automatically [10, 16]. Finally, the quadrilateral layout is refined for more uniformity and to better represent features, after which quadrilateral patches are rebuilt as bicubic B-spilne patches using Coons patch interpolation. A depiction of the final resulting spline space for the firewall, the quadrilateral layout inducing these splines, and an immersion mapping representing the computed flat metric that induces the quadrilateral layout [14] is shown in Figure 1.

Each of the 170 reconstructed body-in-white parts was then verified for analysis-suitability through a modal analysis in LS-DYNA. The model as a whole was also evaluated to ensure that surface penetration was not introduced between parts as a result of the spline fitting process: where necessary, parts were further re-



(a) Original FEM model [9]



(b) Isogeometric analysis model

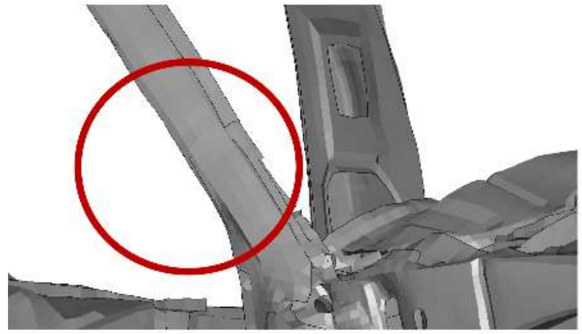
Figure 3: Deformations of body-in-white crash analyses for a 1996 Dodge Neon finite element model from George Washington University [9] are compared with those using bicubic B-spline functions created herein.

fined to remove part penetration introduced by spline fitting. Finally, spotwelds between parts were reintroduced using Beta-CAE's ANSA, and each body-in-white part of the original finite element model was substituted out from the original analysis for its isogeometric counterpart. A depiction of the final body-in-white geometry is shown in Figure 2.

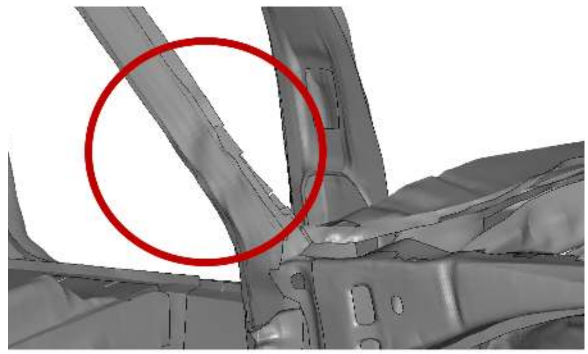
3. CRASH ANALYSIS AND RESULTS

The final crash model used 14,479 bicubic B-spline patches (209,765 Bézier elements) on 170 parts. It was performed using LS-DYNA on 128 CPUs, each of which was equipped with a 64-core AMD EPYC 7763 (2.45 GHz) processor. Total runtime for the simulation was approximately 45 hours using double-precision arithmetic, and 32 hours using single precision. Because this was the very first boundary-fit crash analysis of a body-in-white vehicle, it is anticipated that these runtimes will drastically improve with further development.

Images of both the crashed isogeometric model, as well as the original finite element model, are shown in Figure 3. Qualitatively, the results on both are similar. However, it should be noted that the spline-based model experiences additional deformation, such as in its A-pillar near the fender (see Figure 4) and in the roof near the top of both the A- and B-pillars (see Figure 5). This may be expected because the original coarse FEM model lacks the ability to represent this deformation without additional refinement. Additional studies will compare deformation of the isogeometric model with a further-refined finite element mesh.



(a) Original FEM model [9]



(b) Isogeometric analysis model

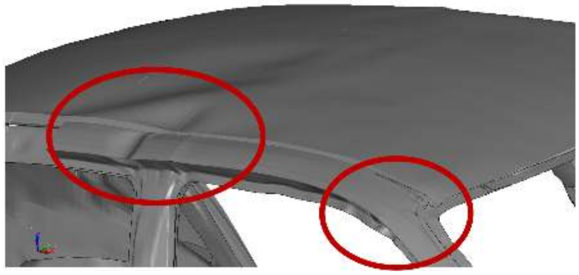
Figure 4: Crash deformation of the A-pillar near the fender in original finite element crash model of [9] is compared to that in the rebuilt isogeometric model.

4. CONCLUSION

In this work, we demonstrate the viability of an isogeometric model reconstruction framework for crash analysis through the first boundary-fit body-in-white crash analysis of a vehicle. The generated model performs comparably to the original model in many respects, but with larger element sizes. Further refinement studies will be necessary to better understand the differences in deformation between results.

Based on the results of this work, subjects of future research will include the following: improved penetration detection and avoidance while reconstructing multiple parts; better spline fitting methods that the preserve the original geometry and the computed quadrilateral-inducing metric; the use and investigation of better solvers that leverage the abilities of high-order methods; and the exploration of crash analysis using unstructured splines with high global continuity.

(a) Original FEM model [9]



(b) Isogeometric analysis model

Figure 5: Crash deformation near the roof in the original finite element crash model of [9] is compared to that in the rebuilt isogeometric model.

5. ACKNOWLEDGEMENTS

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