The ANSA / LS-DYNA approach for IGA Simulations

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1 Abstract

Isogeometric Analysis (IGA), is maturing and becoming capable to be incorporated in industrial applications. Widely used in the automotive industry for crash analysis, LS-DYNA is the first commercial solver to provide IGA features. Highest accuracy and shorter run times make IGA effective for crash analysis. Nevertheless, the complexity of the current automotive models and the maturity of the already established methods and processes require the development of the respective IGA tools and processes to reach and exceed the current levels of effectiveness. The new technical challenges offer the opportunity for new solutions and improvements in engineering simulation technology.

BETA CAE Systems and LSTC have joined their efforts to develop all the required tools and workflows that will enable analysts to move to the IGA era. These tools, will allow for the creation and analysis of shell structures models consisting of single or multi patched trimmed surfaces, along with all the necessary functions to apply boundary, and initial conditions for crash load cases. In this presentation these developments are presented.

2 Current Process in the Automotive Industry

The current processes for Finite Element Analysis (FEA) simulation model build up in the automotive industry starts from CAD data import, translation, geometry clean up, and meshing. In the next phase the FE meshes are connected in subassemblies and the subassemblies are assembled to the final models. Meshing is a complex geometric transformation performed by specialized software like ANSA. During the “meshing” procedure a great deal of information from the CAD side is lost, since the discretization that is needed is only an approximation of the original geometry. Moreover, the semantics of the various CAD entities must be mapped onto the new FE entities which is not always possible. The procedure itself is also time consuming. ANSA has been designed from the ground up capable of handling geometry and FE at in the same model in parallel, thus trying to bridge this gap. Unfortunately, the predominant use of FE only processes and data flows have always proved a barrier between the design and analysis worlds.

Various methods have been developed in the past years to avoid meshing. Isogeometric analysis is one of them. The idea behind IGA is that since there is already a mathematical description of the domain's geometry the same description could be used for approximating the solution fields. Specifically, since CAD uses non-uniform rational B-Splines (NURBS) for geometry representation the same functions could be used as basis functions. NURBS have higher continuity and it has been shown that they have very good properties for analysis [2,3]. Thus, analysis can be performed on the CAD geometry, resulting in a much faster procedure that captures in the best way the intentions of the designer and the analyst, while at the same time removes the discretization errors. LS-DYNA first introduced the *ELEMENT_SHELL_NURBS_PATCH in 2010 and since then has been advancing its IGA support.

3 The path from CAD Geometry to IGA Ready Geometry

IGA uses the same basis functions as CAD, namely non-uniform rational B-Splines (NURBS). The automotive parts though, are in a form that is not suitable for IGA. They are not watertight, they are modelled as solid (B-Rep) and contain a very large number of trimmed surfaces. Most of these problems have already been addressed for the classical FE mesh generation. In the already established processes of the industry, robust practices are in place for mid-surfacing (translating the solid B-rep representation to a shell), and geometry clean up.

Fig.1: B Pillar CAD geometry and resulting FE Mesh.

Nevertheless, the remaining geometry representation of a part consists of multiple trimmed surfaces. For example, in the automotive industry some parts can contain 5000 patches (surfaces with different mathematical representations) or even more. Such an example is the B Pillar depicted in Figure 1. Focusing on the detailed area, it becomes obvious that there are many unnecessarily small patches to describe the geometry (Figure 2). IGA though can only be performed on single untrimmed surfaces. LS-DYNA has added the capability to solve trimmed surfaces in 2014. So the problem remains to convert the trimmed multi-patched part into a trimmed single-patched geometry. This is the IGA ready geometry.

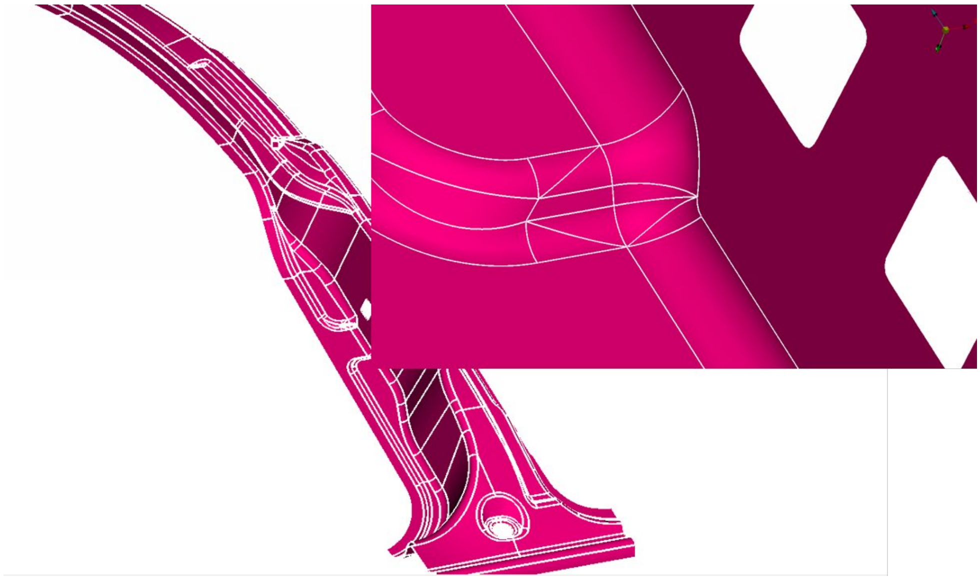

Fig.2: B Pillar with many different patches.

To overcome this issue, we developed an algorithm to minimize the number of patches required for representing the complex physical domain of the industrial applications.

The first step is to create a mapping between the initial geometry and a non periodical surface. Periodical surface is a surface that is periodic in at least one direction. An example of a periodical surface is the cylinder where in one direction the surface is repeated periodically. This mapping is called 2D mapping or parametrization. However, this is not always possible due to topological restrictions. If the starting geometry is not topologically equivalent to a non periodical surface, then this process cannot be performed. In these cases, the starting geometry must be divided into smaller regions. A general example of the physical space and the created underlying surface is shown in figure 3.

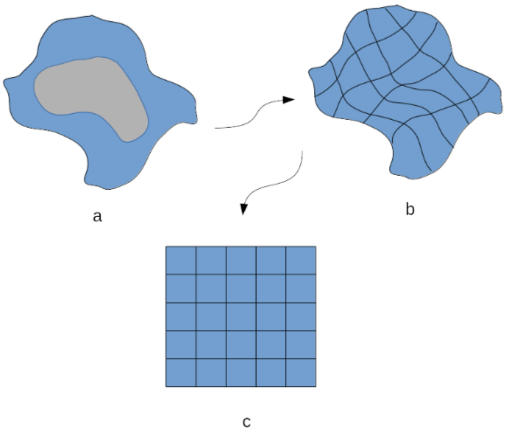

Fig.3: Mapping the initial geometry to a parametric surface. a) The initial geometry in gray color and the underlying mathematical representation. b) The parametric surface that is extracted. c) The structured parametric space of the surface.

The boundaries of the surface can be defined at the extent of the initial geometry. In this case, the physical domain is defined as a part of the resulting surface (trimming). In cases where there are holes or highly non-convex boundaries trimming is unavoidable, or even impossible, if our goal is a good quality mapping. The quality of the parametric space that is extracted determines the speed and success of the whole procedure. In most industrial cases the use of a trimmed surface description is the only feasible way to produce structured surface geometry.

The second step of the process is the representation of the extracted geometry as a parametric surface. Since both CAD and LS-DYNA use B-splines to represent parametric surfaces this is our point of focus. B-spline surface is a widely used surface type that is simple and can be exactly converted to various other surface types. The disadvantage of the B-spline surface is that a local refinement comes with a big increase in stored data. Our algorithm finds the complexity of the underlying geometry and decides the appropriate knot vectors that will be used to maintain the accuracy while minimizing the memory used. The knot vectors determine the size of the resulting elements. There is the possibility for the user to add specific characteristics and limitations about the resulting elements. For example, the user can request a surface with uniform element size (uniform knot vectors) in a specific value range.

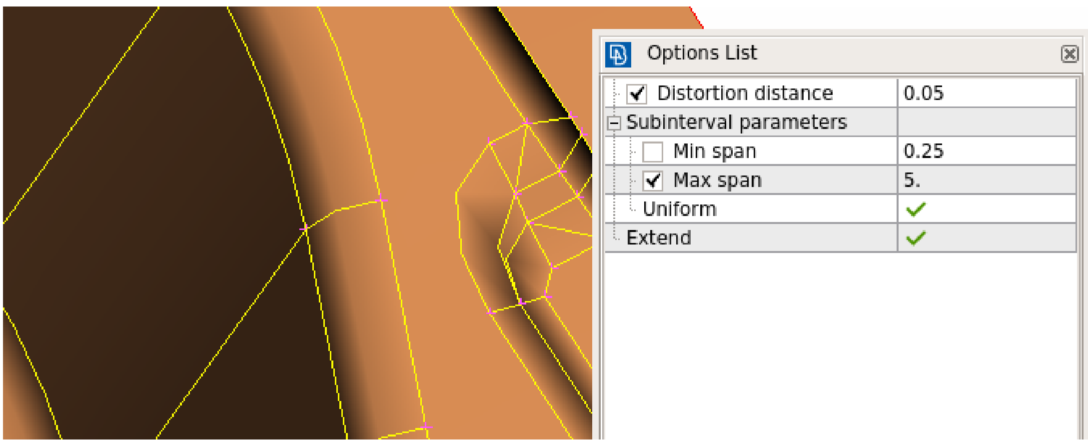

Fig.4: IGA geometry creation options

In the final step, the surface is validated and the initial surface representations are replaced by only one. During this process small geometric discontinuities originated from the translated CAD geometry are fixed. Due to the build-in property of B-spline surfaces, the resulting geometry has a higher order continuity, which will be preserved in the solution with the IGA method. After the creation of the IGA ready geometry, the geometric representation is ready to be exported from ANSA with the new LS-DYNA keywords for IGA.

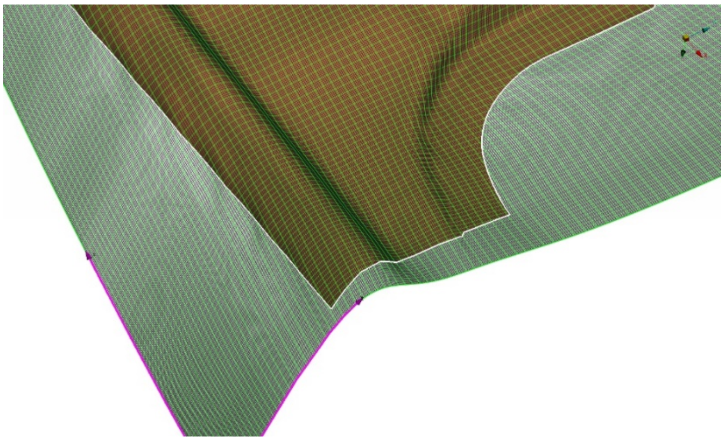

Fig.5: Detail of a IGA ready trimmed surface representation of a B-pillar

Thus, the mesh generation phase of the traditional will be replaced with the IGA ready geometry generation which although computationally complex, is from the user perspective much more automated and offers significant time gains. In the current version of ANSA this is a “one click” operation.

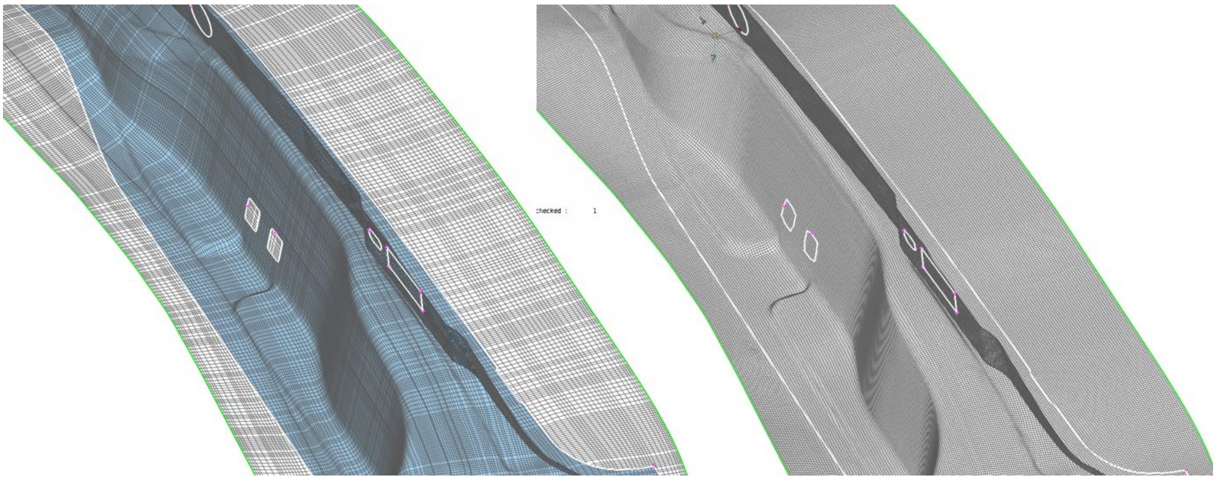

Fig.6: Two different parametrizations of a B-Pillar. Coarse, variable density knot vector and uniform dense knot vector

4 Multi patched parts

The mapping of a complex part to a trimmed surface although tempting and aesthetically desirable due to the inherent simplicity, has its own set of problems.
First and foremost, not all parts can be mapped to one surface. Parts that have cuts and flaps cannot be mapped.

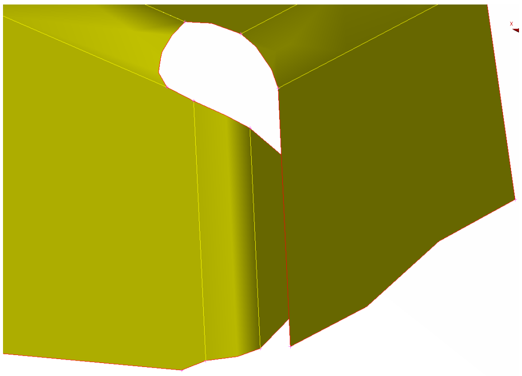

Fig.7: Example of a part that cannot be mapped on a single surface

Moreover, the existence of features that are not aligned with the principal directions of the parametric surface will produce a locally dense knot vector that will be projected across the parametric space and thus result in an overly dense knot vector (see Figure 8 a). This in turn, will increase the computation time during the solution. The way this problem has been tackled until now is by using different kinds of splines, such as T-Splines or Hierarchical splines, that can be locally dense to capture the geometry features. CAD though uses B-Splines and the use of a different spline technology will deviate from the premise of analysis on the CAD geometry.

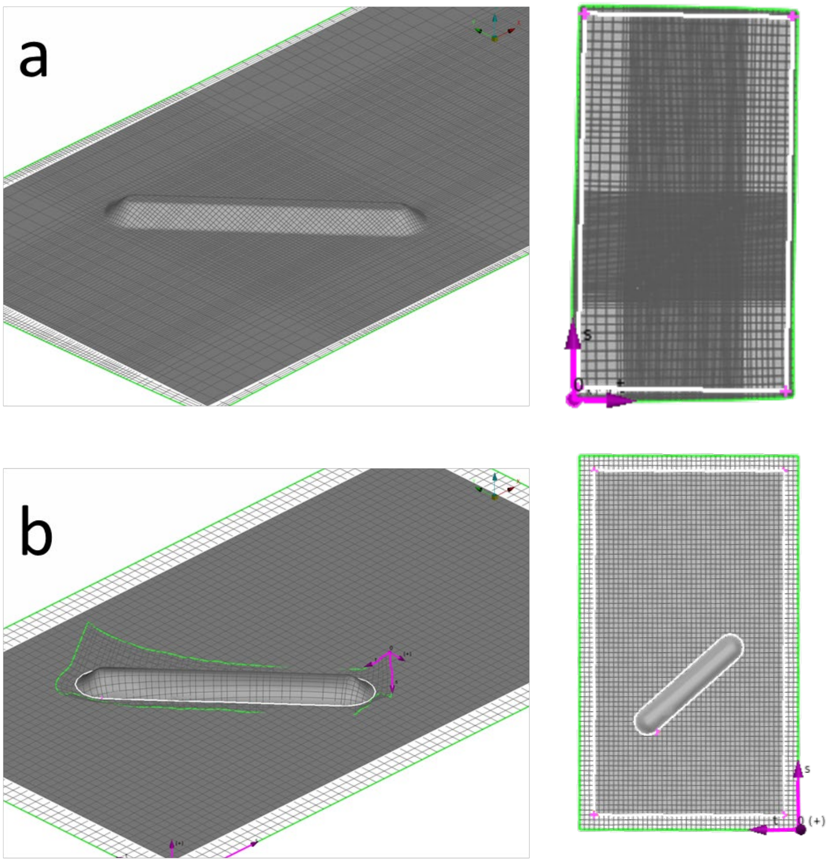

Fig.8: Effect of non-aligned feature on the knot vector density: a) Single surface, b) Multiple surfaces

The approach followed by LS-DYNA in the latest version, implements a penalty method for connecting patches, initially developed and introduced by the TUM group in the IBRA method [4]. The resulting contact connects the neighboring patches albeit with reduced C0 continuity (see figure 8 b).

It is thus important to minimize the number of different patches and resulting contacts since the drop of continuity introduces simulation inaccuracies, that are not consistent with the purpose of IGA.
The introduction of this new method for describing a part with multiple connected trimmed surfaces introduces the need for a new format that resembles a CAD format since it contains not only surface parametric description but topology information as well. New keywords have been introduced and they will be rolled out in the next versions of LS-DYNA and ANSA.

5 The need for new quality criteria and processes

During the last 30 years the FE methodologies have been studied, tested, and matured in a great extend resulting in robust procedures and metrics that produce high quality meshes, for stable simulations. The industry has settled in a set of quality criteria that characterize a mesh and result in stable simulations and high-quality results.

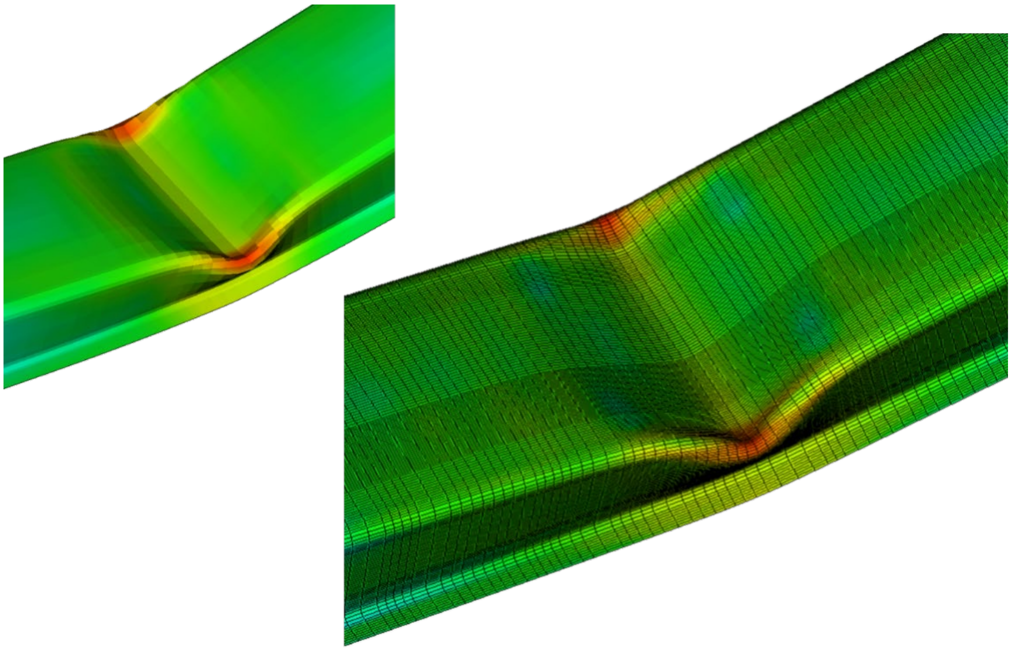

Fig.9: Influence of Knot vector density on results

The same procedure tests and validations need to be made this time for the IGA representations. The new parameters affecting the geometry are the creation of the control points, the knot vector, the polynomial degree, and the orientation of the surface parametric space in relation to the structural part. Nevertheless, the large experience we have from the FE era will allow us to shorten the period needed to calibrate and setup our methods. Automatic procedures are used to setup parametric studies.

6 New pre-processing opportunities

Although in research up until now, a lot of attention has been focused on the meshing procedure and on the simplification an IGA methodology would introduce to the current procedures. One should not underestimate the effort and resources needed for the creation of the final model of such a complex analysis such as this for Crash. Although it is tempting to apply the same methodologies to the new paradigm, we should take advantages of the new possibilities to come up with better ways to setup our model. Having a pure geometric description of the model provides new opportunities for a better definition of all those needed elements that connect the model, apply the loads, and set up the boundary and initial conditions. Not only we can remove the current discretization phase that inserts approximations, but we can better capture the intention of the analyst or the designer when all model entities are defined and attached to the original geometrical entities.

The natural way to do this, is by leaving behind the standard practice of applying constraints and loads on nodes, but rather apply them directly on geometry primitives, such as curves and subsets of surface knot vector spans. This needs new developments both in pre-processors and the solvers. The result though will be the much faster and accurate creation of the model based on the original CAD data and information, and the easier geometry modification and parametrization by the analyst during the development process.

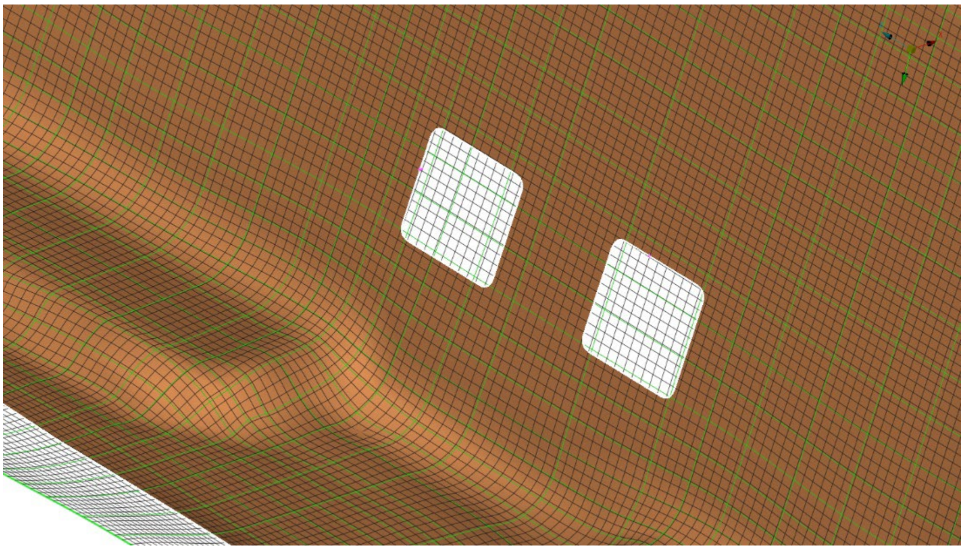

Fig.10: Holes defined by trimming curves. Constraints and Boundary conditions will be referencing them.

The need for such new methodologies leads us to the design of new formats and data structures that will capture the new requirements. Full geometric descriptions must be included in the solver input decks. On the pre-processor side all operations regarding model setup should be applied on the geometry level. Fortunately, ANSA has already such capabilities and the transition to the new paradigm will be easy.

7 Conclusions

LSTC and BETA CAE Systems have been working closely to bring IGA to the FEA community. Our method can automatically create an IGA friendly representation of the CAD geometry and feed that to LS-DYNA. This process can coexist with traditional FEA. New models can be created, compared with existing ones to steadily validate the IGA method. Additionally, the possibility of hybrid models exists. Crucial parts of a model can be modelled with IGA using the exact geometry, while the rest using the traditional FE. In this way we intend to provide a path that will allow gradual adoption of the new methodologies allowing the users to experiment and gain experience.

8 Literature

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