# Mid-surface developments for computational electromagnetics in ICE NITe

## Introduction

As computer systems become ever more powerful, and computer aided engineering (CAE) software becomes more sophisticated, it is now possible to run detailed simulations on larger and more complex designs. However, it is still desirable to idealise models – reducing them to simpler geometric forms – in all but the simplest cases, for several reasons:

- Faster answers – although it may be possible to simulate the complete model, it will take too long to get the results;
- Highly complex problems – ambitions for CAE simulation are moving faster than the available computational power, and such complex problems cannot be solved without idealisation;
- Meshability – it may not be possible to build a high enough quality discretisation of the geometry without some idealisation.

Replacing a component with its mid-surface representation is a common idealisation for structural analysis, and due to the highly accurate geometry-conforming nature of the Nottingham CEM solver used in ICE NITe (Sewell, et al., 2004), is also relevant in ICE NITe. For example, it can be beneficial to collapse a thin skin or rib structure to its mid-surface, as thin walled structures require a large number of near-regular tetrahedral elements to represent them accurately. By reducing them to a mid-surface, you allow them to be meshed by triangles, which can potentially be much larger whilst maintaining an equilateral shape.

Although mid-surfacing is a common idealisation, mid-surface reduction of a solid CAD model remains a manual process, and frequently can be painful. Automatic generation of mid-surfaces is claimed by several CAE vendors, but these capabilities are typically restricted to proposing pairs of faces which may generate a mid-surface, away from junctions or areas of complex geometry.

This report details the work performed by ITI in the ICE NITe project, which concerns the development of a truly automatic one-click mid-surfacing method, based on ITI's 3D medial object technology.

## 3D medial object

The medial axis was first introduced by Blum (Blum, 1967), and is a promising, intriguing, tool for analysing geometric shapes. It can be defined as the locus of the centres of maximally inscribed discs over the object, or equivalently, the set of points equidistant from two or more points on the boundary of an object. This locus of centres, together with the radius function of the corresponding maximal discs, fully describe the original object, and are known as the medial axis transform (MAT) (figures 1, 2).

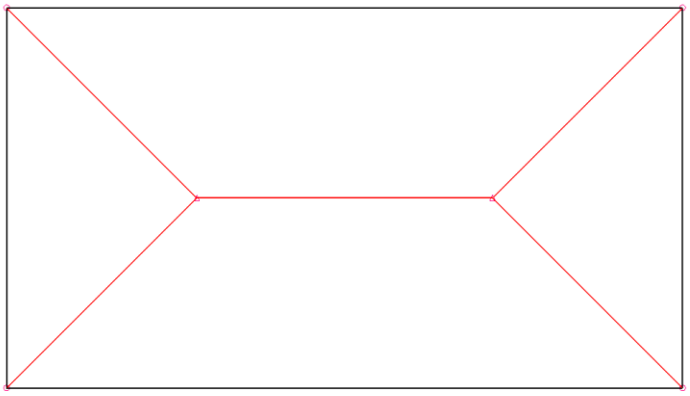

Figure 1. The medial axis of a simple 2D rectangle.

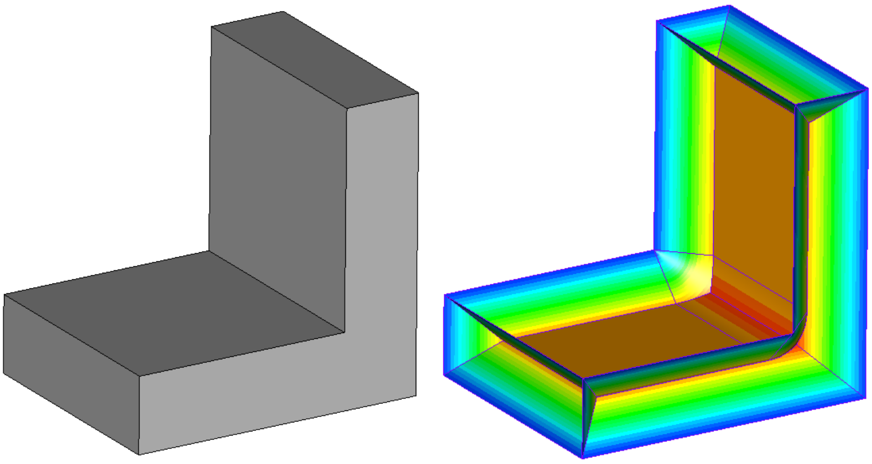

Figure 2. The medial axis transform of a simple 3D solid. Colour contours indicate medial radius.

The MAT is often described as the skeleton of a shape – it is dimensionally reduced, with 3D volumes in the original shape reduced to surfaces in the MAT. As the surfaces of the MAT lie in the middle of the original volume, and the MAT is a well-defined, automatically computable transform, it makes an attractive choice as the basis for automatic mid-surfacing.

Whilst the medial axis is fairly straightforward to compute in 2D, it remains difficult to robustly compute a medial axis of a 3D CAD model. Even more challenging is the medial object: the medial axis transform of a CAD model, held as a CAD model itself, with relationships between the CAD and medial entities. ITI has developed the only commercial implementation of the 3D medial object (3DMO), the result of an extensive research programme (Bucklow, 2014), as part of its CADfix product (ITI Ltd, 2016) (figure 3).

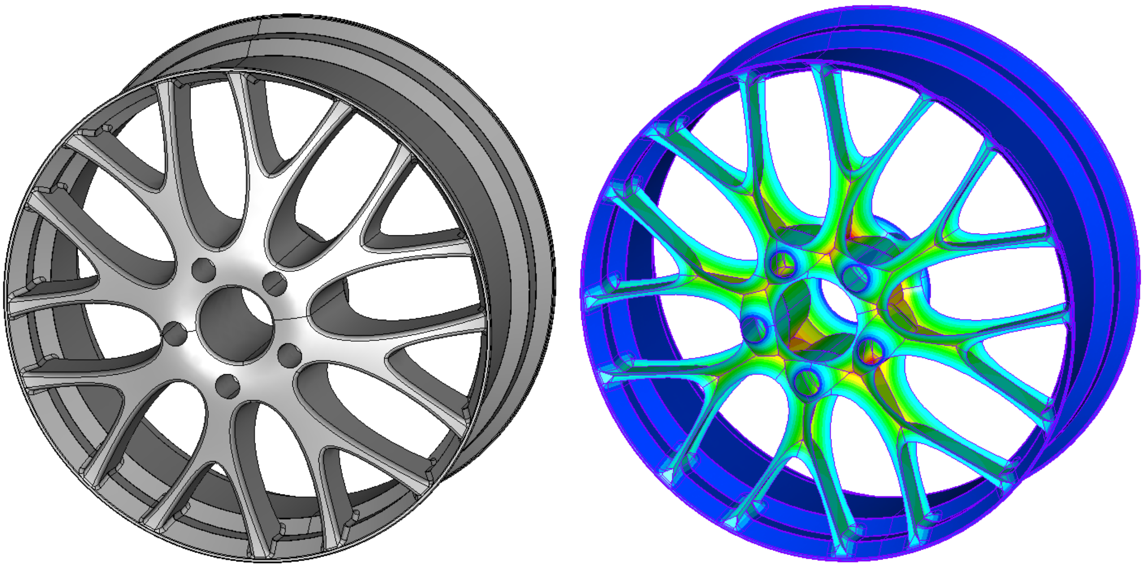

Figure 3. The 3D medial object of an alloy wheel. Colour contours indicate medial radius (thickness).

Although the 3DMO is a dimensionally reduced, surface representation of a model, it's not directly suitable for CAE simulations. This conversion from 3DMO to mid-surface for CAE simulation forms the core of the work performed in ICE NITe.

# Mid-surfaces from medial objects

## Flap removal

The most obvious features of the medial object, which are unwanted in the final mid-surface, are the "flaps" – medial faces which bifurcate near the edges of the domain, and terminate at convex edges. These faces are identified by their connectivity to the surface geometry, and their subtended angle – the angle between the normals of the defining boundary surfaces where they are touched by the inscribed sphere (figure 4). The flap faces are subsequently deleted.

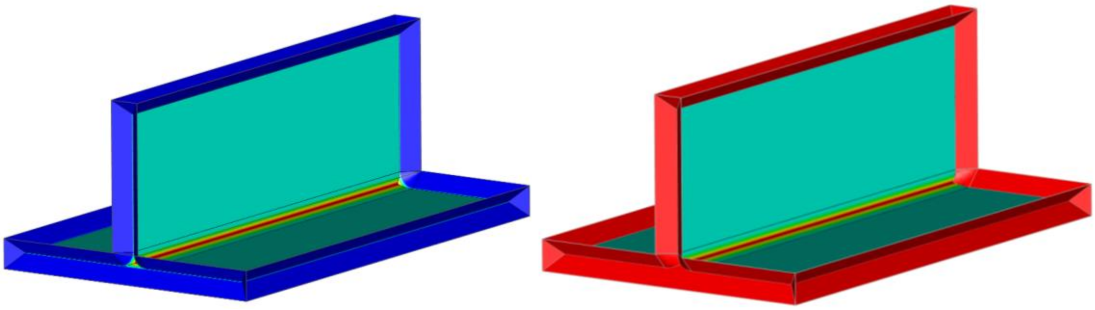

Figure 4. 3D medial object of a simple object (left), with the flaps identified in red (right).

## Surface extension

Once the flaps have been removed, the remaining medial faces must be extended so as to properly represent the whole volume. Each medial face which neighboured a flap face must now be extended towards a "target" face which defines the new extent of the mid-surface (figure 5). Three separate methods have been pursued to do this within ICE NITe:

- Extensions based entirely on the 3D medial object
- Extensions based on the 2D medial object of the target face

- Extensions based on linear extensions of the 3D medial face, using normal to the medial faces

Each of these methods has its own strengths and weaknesses. Evaluating these has been part of our work in the project, but in future, to ensure the best results from the mid-surface algorithm, the appropriate method should be automatically chosen for each face.

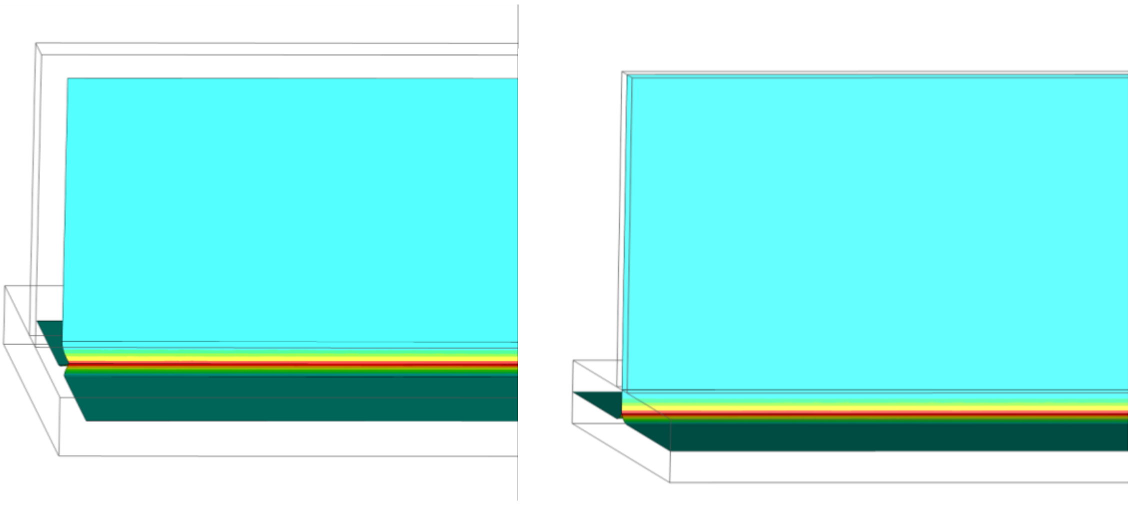

Figure 5. The medial object without flaps (left), and the extended medial faces (right).

## T-junction relaxation

The 3D medial object generates medial faces with a characteristic “cusp” shape at junctions between thin plates. Whilst this is accurately positioned at the mid-point between the boundary faces, this has some disadvantages over the flat t-junction created by most mid-surface tools:

- The curved shape will require more mesh elements to capture it accurately, compared to a flat junction
- Depending on the analysis being performed, the flat t-junction may be a more accurate approximation of the physics involved
- Users have experience with, and expect, flat t-junctions

Fortunately, flat t-junctions can be computed from curved 3D medial object junctions. The medial object is used to identify the connections between mid-surfaces (figure 6), and the geometry of the connecting faces is relaxed onto flat geometry (figure 7), generated by linear extrapolation of the medial faces. The junction geometry is recomputed by intersecting the relaxed mid-surfaces.

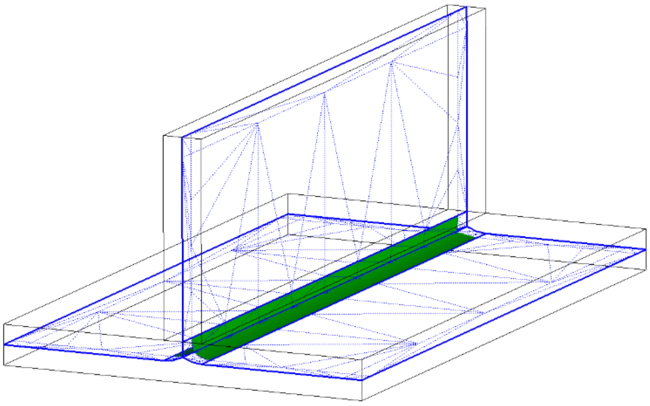

Figure 6. The curved junction faces identified from the medial object.

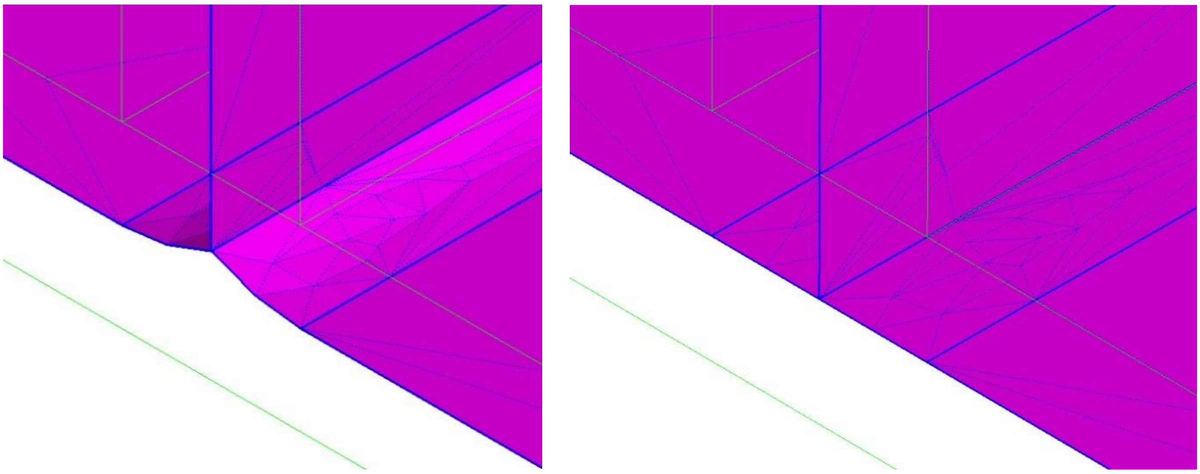

Figure 7. A curved t-junction (left), and the corresponding relaxed, flat, t-junction (right).

## Example

The algorithms described in this report were applied to an example wing rib model, very similar to structures appearing in the CAD models of ICE NITe partners. The 3D medial object and mid-surface tools ran very successfully on this model, automatically generating a complete mid-surface, complete with thickness data (figures 8, 9).

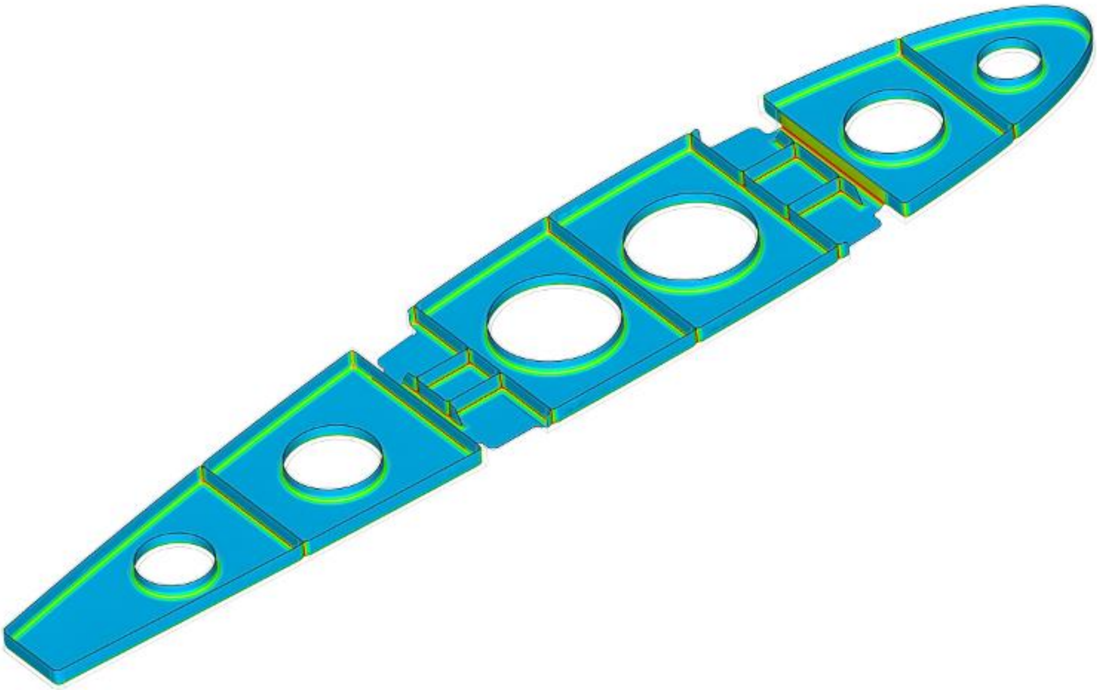

Figure 8. An automatically created mid-surface of an aircraft rib model. Colours indicate the thickness of the original model.

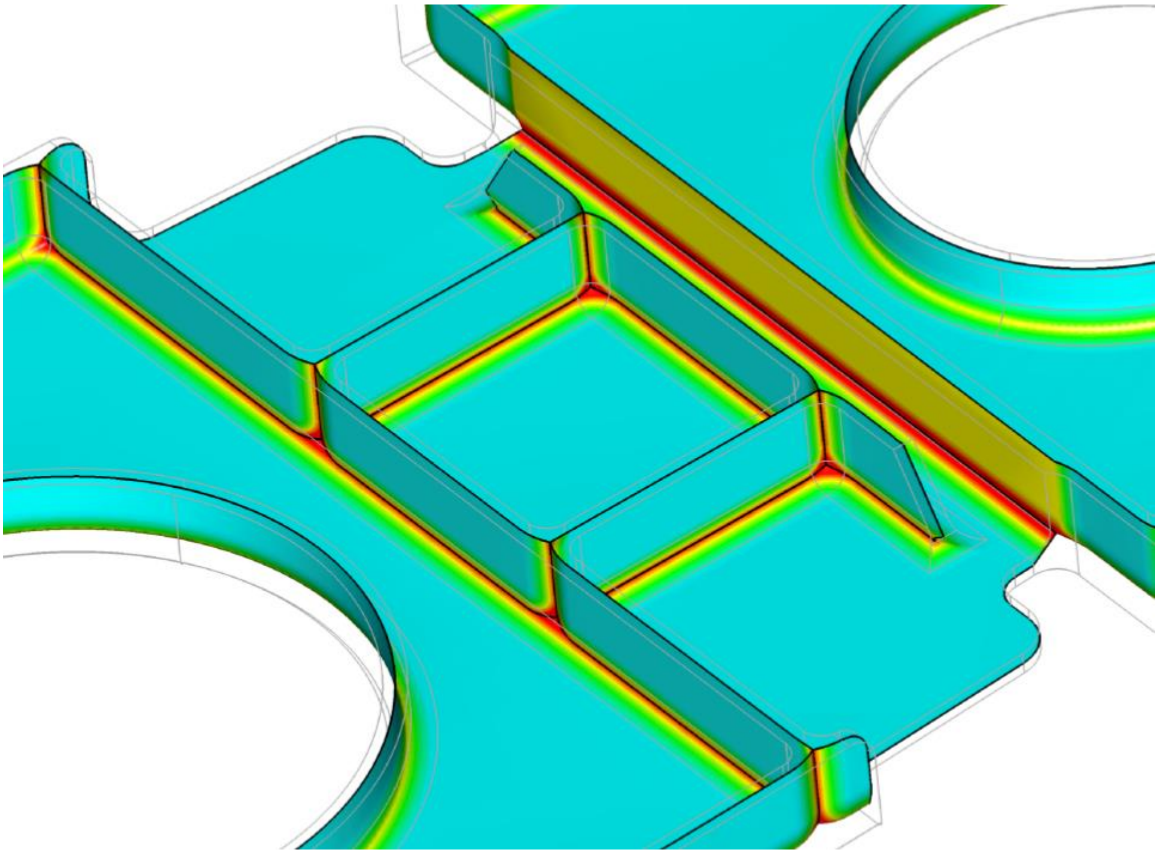

Figure 9. A view of one of the more complex areas of the mid-surface on the aircraft wing rib model. Colours indicate thickness of the original model.

Many other examples were processed during the course of the project, but unfortunately they involve proprietary data, and cannot be shared in this report.

## Open questions

Whilst the 3D medial object provides a solid mathematical foundation for mid-surface calculation, and has been shown to generate good results on CAD models with moderate complexity, this work has raised some questions. These centre around what the desired mid-surface actually should be in various conditions:

- Junctions between plates of varying thickness (figure 10)
- Interactions of thin plates with features which aren't naturally representable as mid-surfaces (figure 11)
- Junctions at edges of thin plates (figure 12)
- Variable sheet thickness (figure 13)
- Coupling between mid-surfaces of neighbouring bodies

The correct answers to these questions require deeper investigation into the solvers and physics being simulated. ITI are engaging in ongoing discussions with industry experts to answer some of these questions.

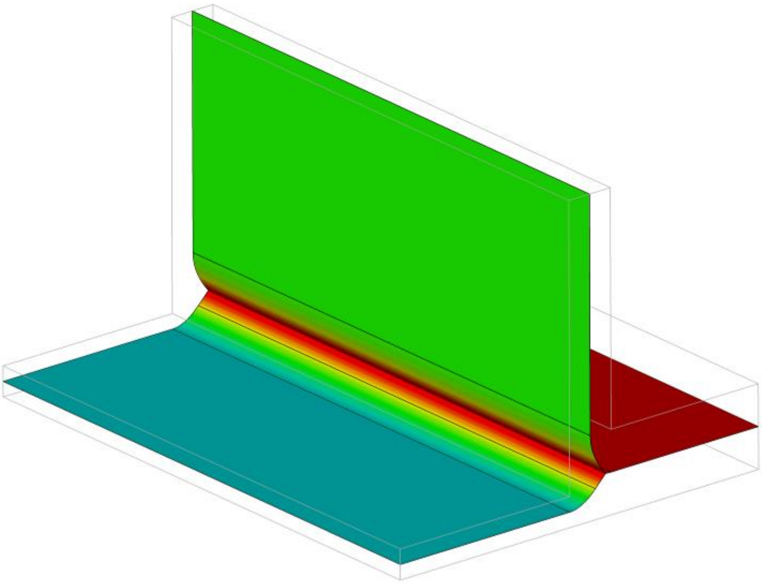

Figure 10. Mid-surface of a junction between plates of differing thickness.

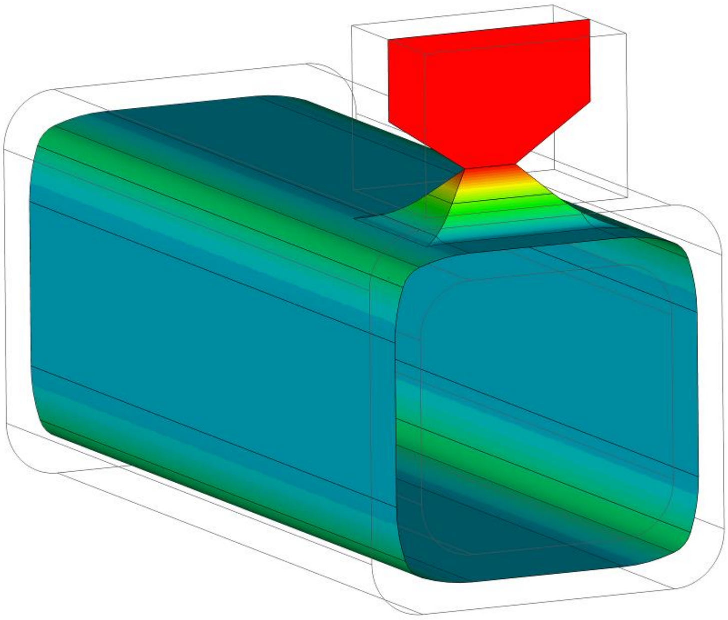

Figure 11. A largely thin structure with a boss that is not well approximated by a mid-surface.

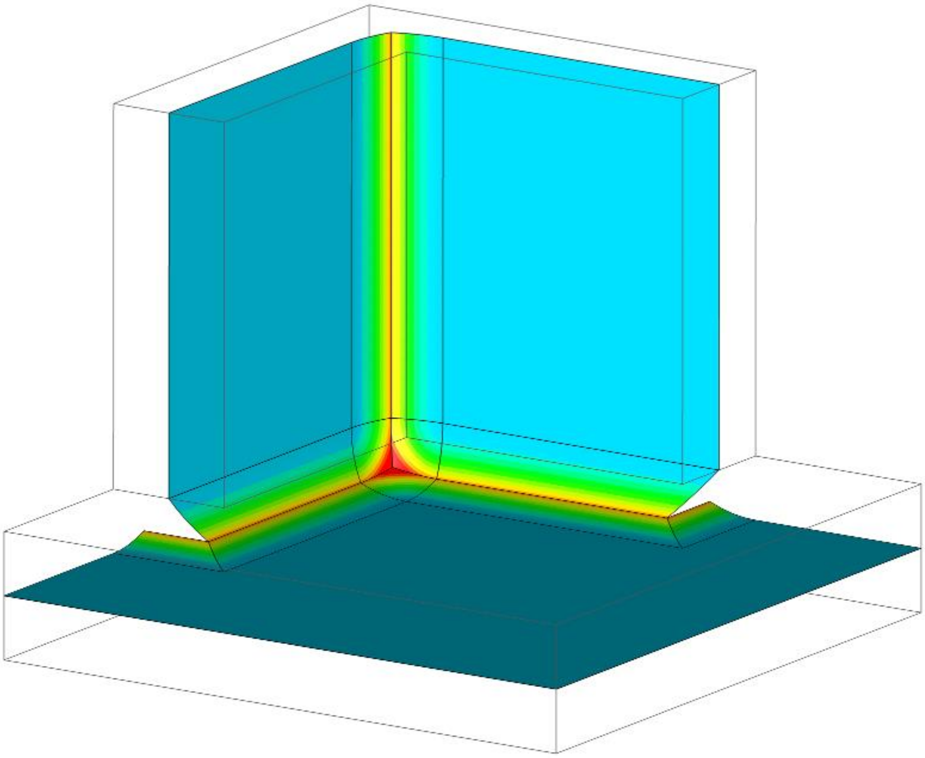

Figure 12. A junction at the edge of a thin plate. Note the “tearing” artefacts between the two plates.

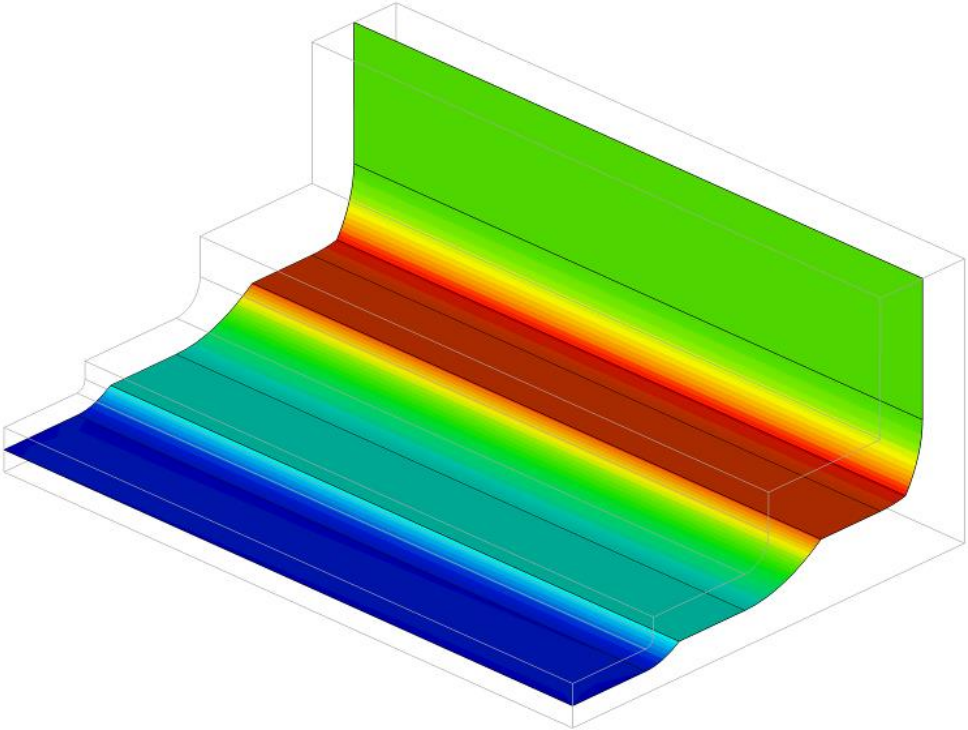

Figure 13. The mid-surface of a plate with varying thickness. Should the result be a smoothed, or even just a simple L-shape?

## Conclusion

The 3D medial object has been successfully used as the basis for a fully automatic mid-surface calculation on CAD models. This has been demonstrated in the ICE NITe project, by the development of a prototype mid-surface capability within ITI's CADfix product, scheduled for inclusion in CADfix 11 Service Pack 1. The prototype tool has been applied to models of moderate complexity, and shown to produce useful results.

The ability to automatically generate mid-surfaces has opened a series of questions, regarding the result that is required by the CAE engineer. ITI are engaging with the CAE community to find answers to these questions, as we also continue to refine the mid-surface tool, and the underlying 3D medial object algorithm.

## References

Blum, H. (1967). A transformation for extracting new descriptors of shape. *Models for the perception of speech and visual form*.

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Sewell, P., Wykes, J. G., Benson, T. M., Christopoulos, C., Thomas, D. W., & Vukovic, A. (2004). Transmission-line modeling using unstructured triangular meshes.