# Final report on CADfix developments for computational electromagnetics in ICE NITe

## Introduction

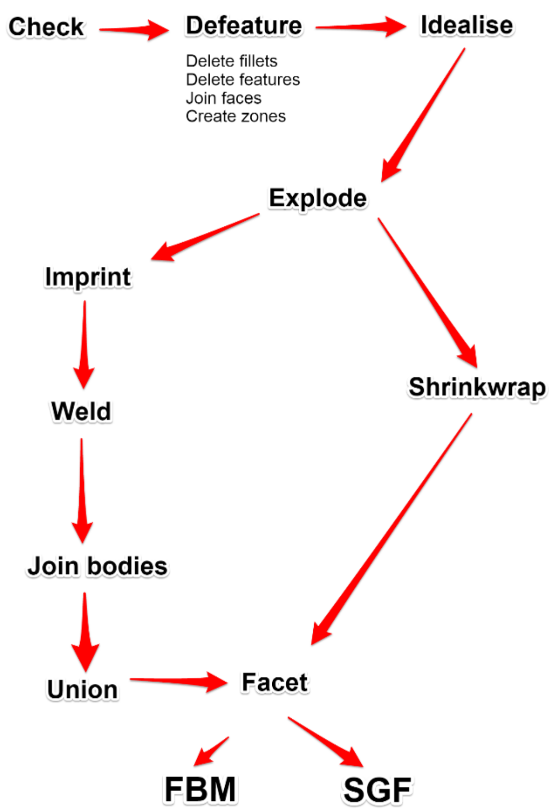
The ICE NITe project aims to significantly improve the connection between CAD geometry and computational electromagnetic (CEM) simulation. Several algorithms, methods, and tools have been researched, developed, and enhanced within the project, to streamline the process of transferring CAD geometry through to CEM simulation, applying the appropriate repair, defeaturing, and idealisation operations, to get a model which is ready to mesh.

## Background

The results detailed in this report have been delivered as extensions to CADfix, a desktop software program for translation, repair, and defeaturing of CAD data for advanced applications. CADfix can import/export from/to a wide array of CAD systems, and has automated routines for detecting and fixing a wide array of common CAD errors and issues. CADfix is commonly used to prepare models prior to meshing, for stress, thermal, fluid, and electromagnetic analysis. CADfix contains both interactive tools, guiding the user through repair, defeaturing, and idealisation processes, and the CADfix Wizard – a suite of automated tools for repairing, preparing, transforming, and exporting models without user intervention.

## Workflow

The tools developed in ICE NITe have been integrated into a CAD to CEM workflow. This workflow is targeted specifically at the CEM methods used by BAE Systems – in particular, the Unstructured Transmission-Line Modelling (UTLM) mesher and solver, developed by University of Nottingham. We take geometry from the design system, and process it with the ICE NITe tools, described below, converting it to a form suitable for CEM simulation, and exporting it to either .fbm (the CADfix geometry format, for use with the CADfix API), or .sgf (a BAE Systems custom geometry format, understood by the UTLM mesher and solver).




The ICE NITe workflow for taking geometry to the UTLM solver.

## Advanced geometry tools for CEM

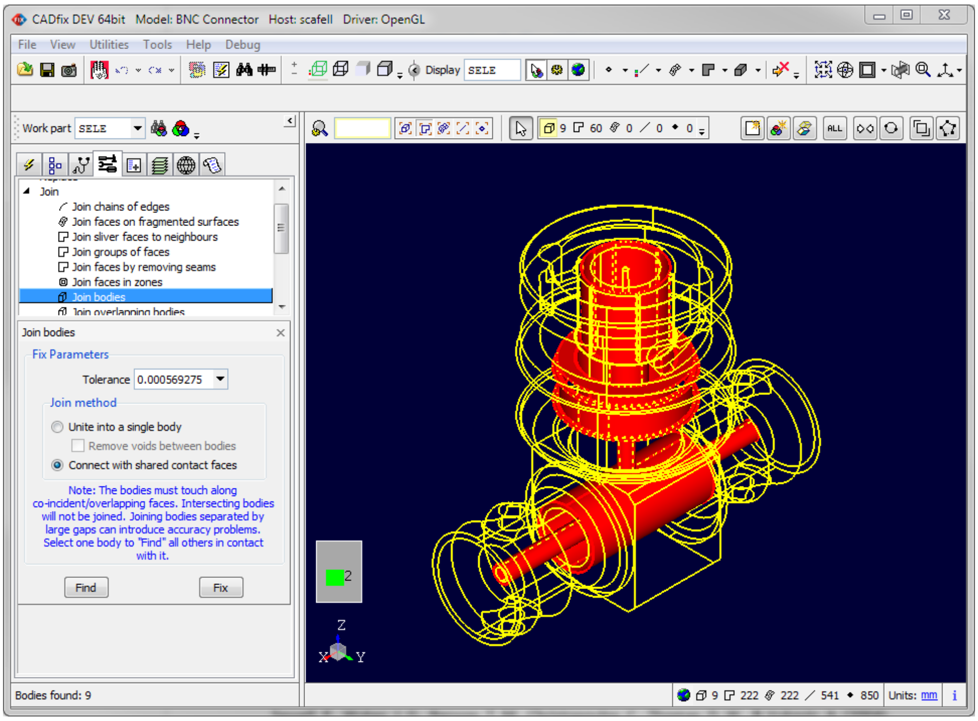
The CEM process used by BAE Systems within the ICE NITe project is based around the Nottingham UTLM solver. This solver requires a Delaunay tetrahedral mesh, which in turn requires that the model is well connected, without small gaps between components, and not excessively detailed. Adapting CAD geometry so that it meets these requirements can be difficult, requiring time-consuming manual work. ITI have researched and developed several new tools to automate this process:

- Imprinting
- Welding
- Fillet removal
- Gross simplification
- Face joining

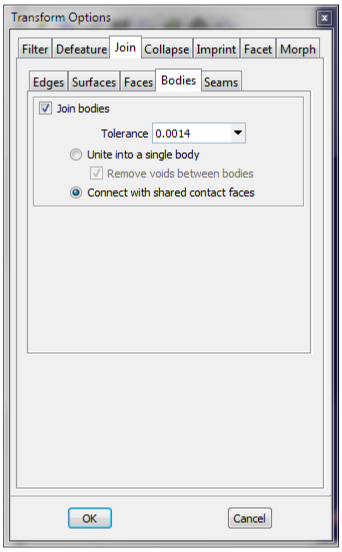
This report will summarise these tools, and show how they have been integrated into CADfix, for use in the overall ICE NITe workflow. For the full details, see the accompanying deliverable document *Advanced geometry tools for CEM.*

### Imprinting

CAD models commonly contain solids which are in contact, but which have no topological connection. Before these solids can be correctly simulated, it must be clear to the CEM solver that they are electrically connected, which means they must share a face over the region in which they are in contact. The CADfix imprinting tool modifies contacting faces, so they share common topology, and has been significantly improved in ICE NITe thanks to research into the underlying geometrical techniques. Once the faces have been imprinted, it is straightforward to join the contacting solids with a shared face between them. This function has been integrated into CADfix under the “Join bodies” tool, which is also available through the CADfix Wizard transform stage (for fully automatic processing), as shown in the figures below.



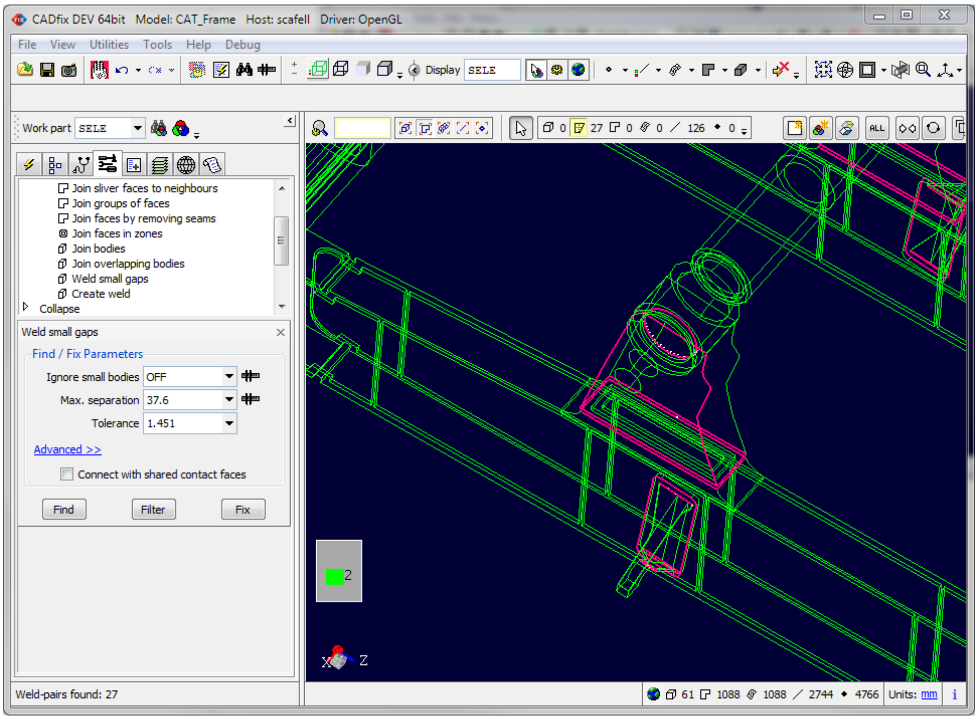

The join bodies tool in CADfix, showing the bodies detected in contact, before imprinting and joining.



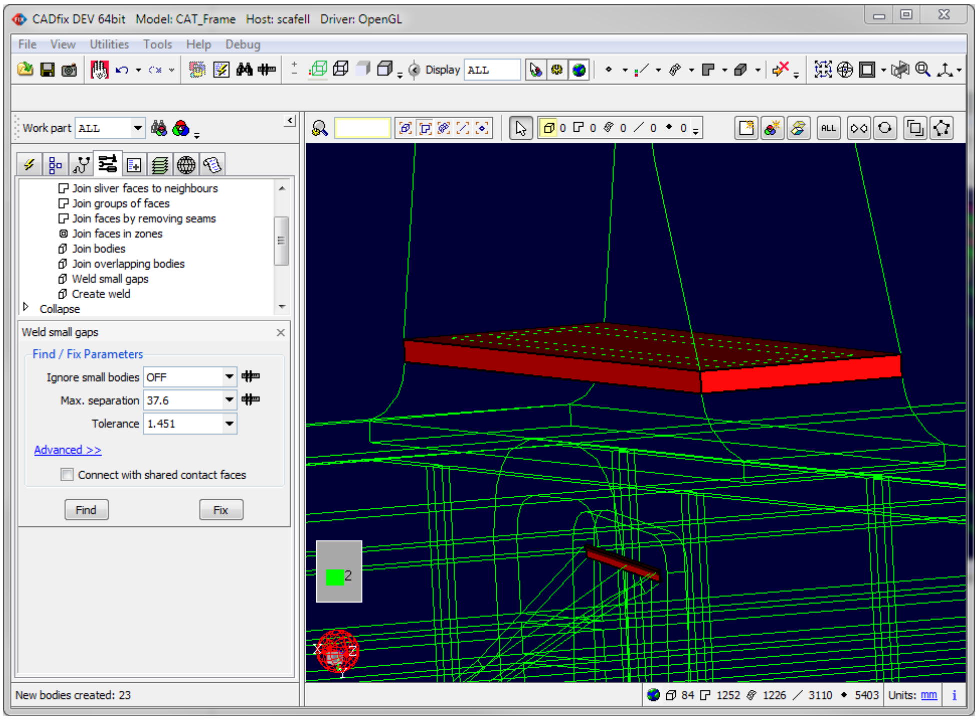

The join bodies tool, available as part of the Transform stage of the CADfix Wizard, for fully automatic processing.

## Welding

Another common scenario is for two components, electrically connected in the actual product as manufactured, to have a small gap between them in the CAD model. This can be due to a missing non-modelled component, such as a washer or sealant, or simply due to an error in the CAD drafting process. These gaps must be detected and bridged for a successful CEM analysis, and ITI have developed the “Weld small gaps” tool within ICE NITe to achieve this – see figures below.



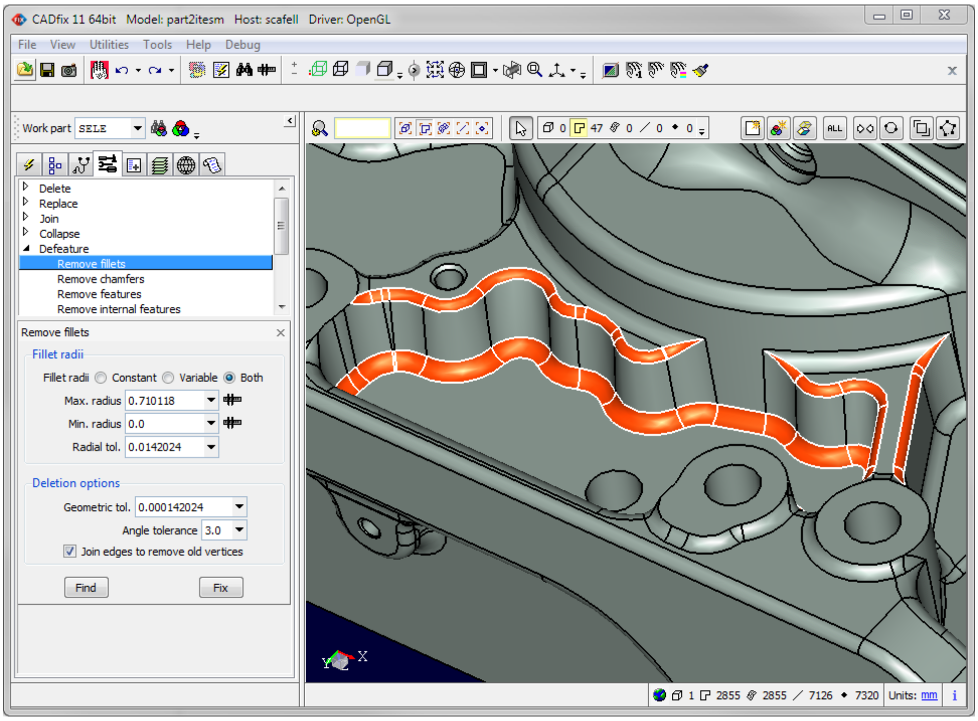

Weldable gaps between nearby components detected using the “Weld small gaps” tool.



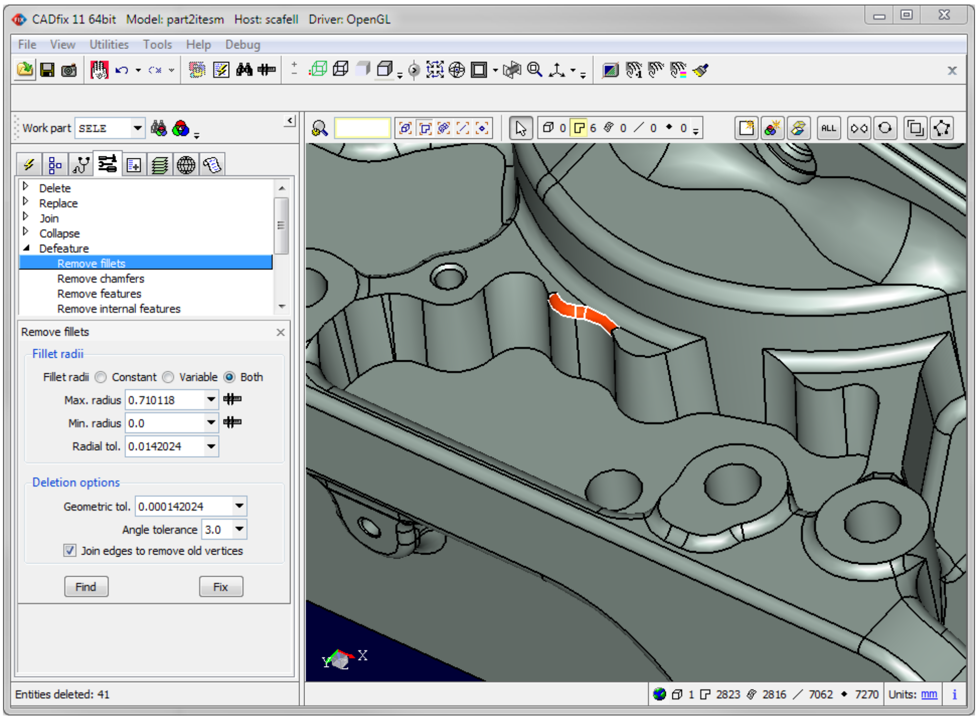

An example weld automatically created by the “Weld small gaps” tool.

## Fillet removal

Before a CAD model can be successfully used for CEM simulation, it’s frequently necessary to simplify the model, to make it easier to mesh, and to reduce the complexity of the simulation, to make it tractable. Fillets are a ubiquitous feature of CAD models which can be difficult to mesh, and are tightly curved, requiring many mesh elements to represent accurately. Removing fillets often has little effect on solution accuracy, but can significantly reduce the degrees of freedom in the simulation. Within ICE NITe, ITI have researched and developed a completely new fillet removal engine, which is faster, more capable, and more fault tolerant than the old fillet removal tool. This is available through the CADfix GUI as the “Remove fillets” tool, and is shown in the figures below.



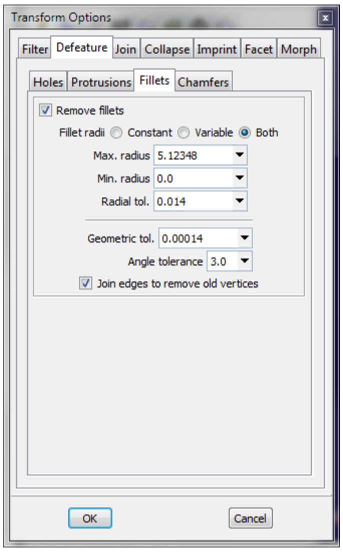
The “Remove fillets” tool, with chains of fillets detected.



The model with the selected fillets removed. Note that one sub-section of the fillet could not be removed – it has been isolated, without affecting the rest of the fillet removal process.



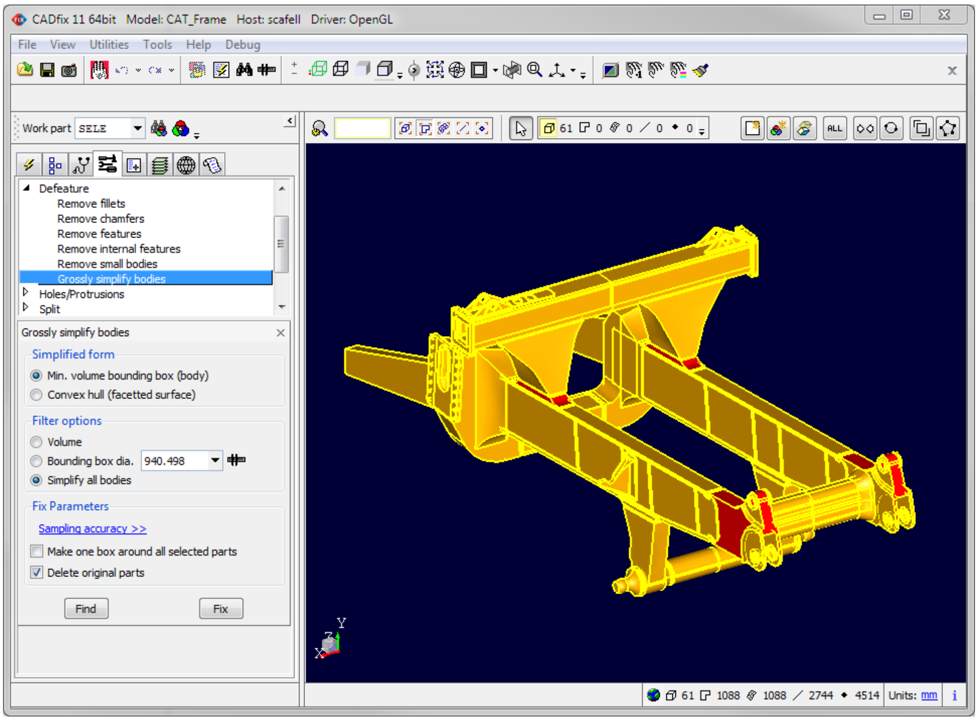
 



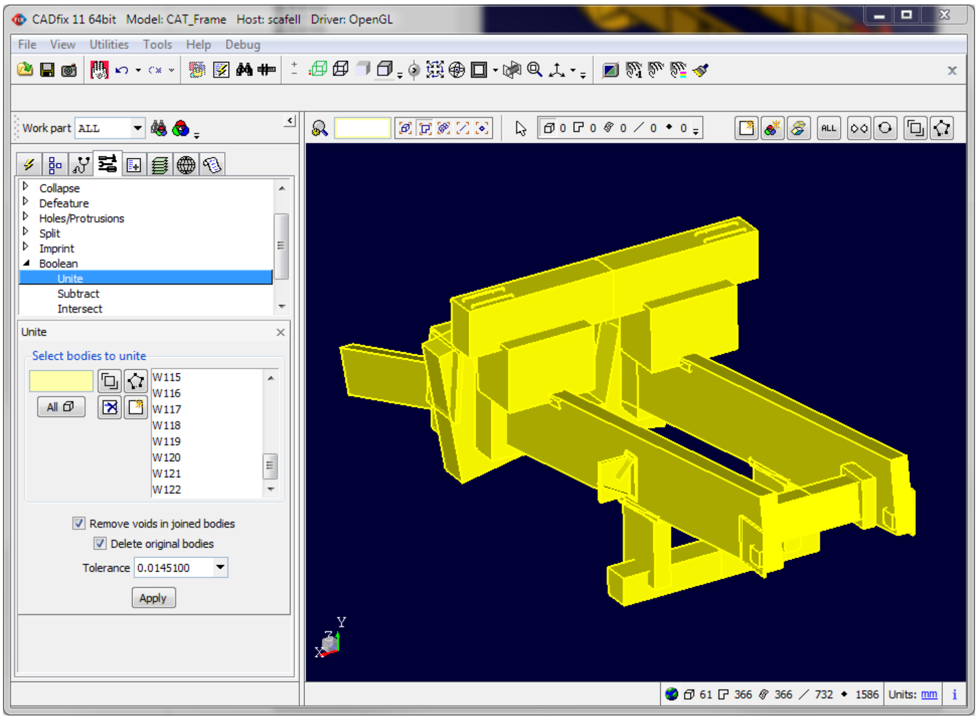

Fillet removal can also be performed completely automatically, during the Transform stage of the CADfix Wizard.

## Gross simplification

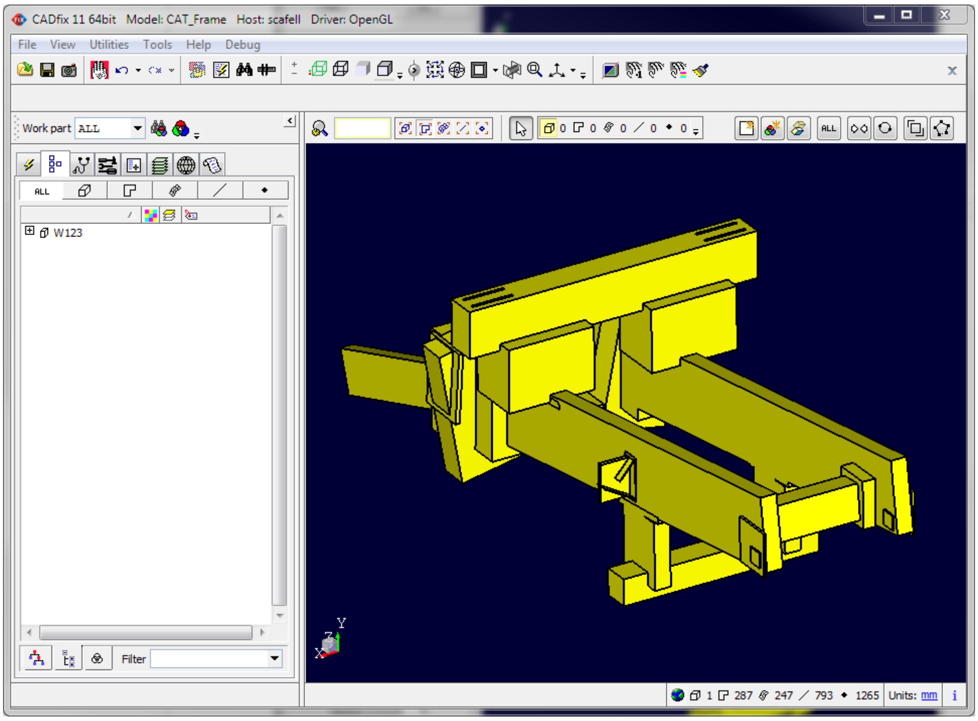
As CAD models are developed for design purposes, they usually contain a high level of geometric detail. However, the detail required for CEM simulation may vary significantly – whilst in some areas, accurate detail is essential, in other areas, less interesting from an electromagnetic point of view, only a very rough approximation of the geometry is necessary. Removing all of this excess detail from a CAD model can be very time consuming, which is especially annoying for the analyst, as these are areas they are specifically not interested in! To automate the creation of drastically simplified models, we have provided two new tools in ICE NITe: “Grossly simplify bodies”, and “Boolean unite.” The first replaces each solid with its minimum volume bounding box, and the second unites all intersecting solids into a single volume. See the figures below.



The “Grossly simplify bodies” tool in CADfix, which replaces each solid with its minimum volume bounding box.




The “Boolean Unite” tool, which combines intersecting solids into a single solid.

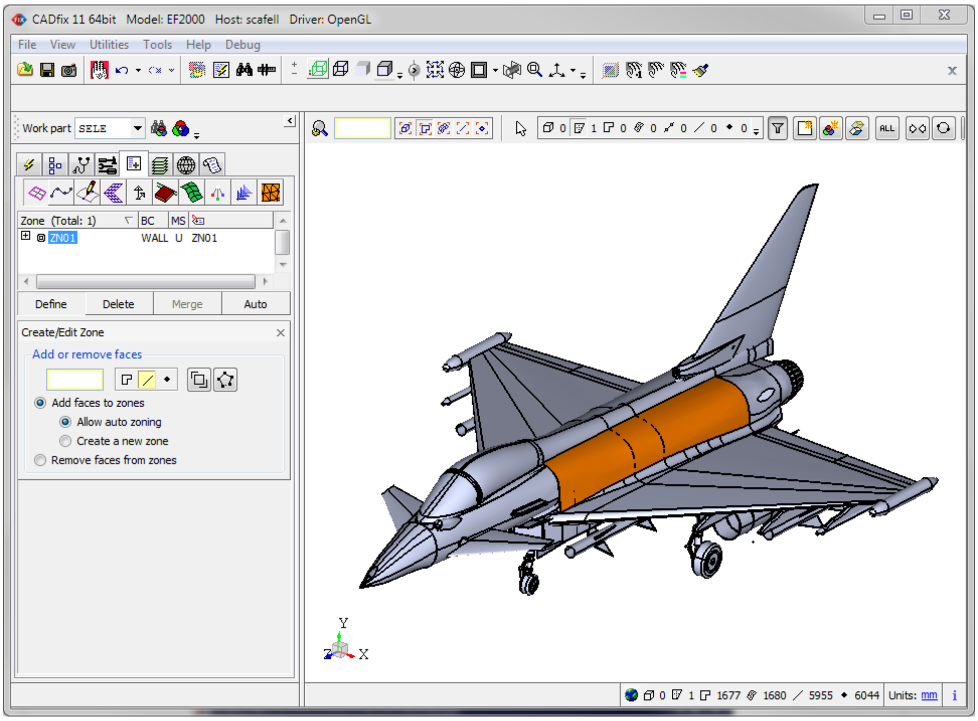



The result of the Boolean unite tool – a single solid with a face count of 25% of that in the original model.

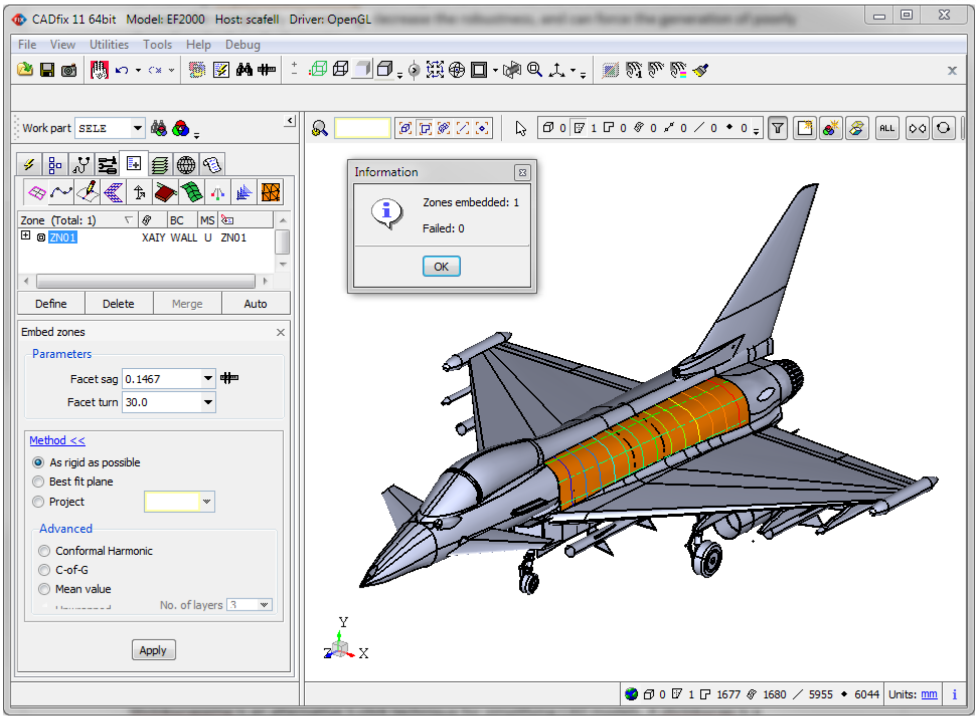
## Face joining

Another common source of excess complexity in CAD models is the way in which solid bodies are divided into faces. CAD engines will generate multiple faces to represent a piece of geometry, as is convenient for the geometrical representation, but typically this division into faces is not convenient for meshing. In particular, meshing must respect face boundaries, so excessive numbers of faces increase the complexity of meshing, decrease the robustness, and can force the generation of poorly shaped or sized mesh elements.

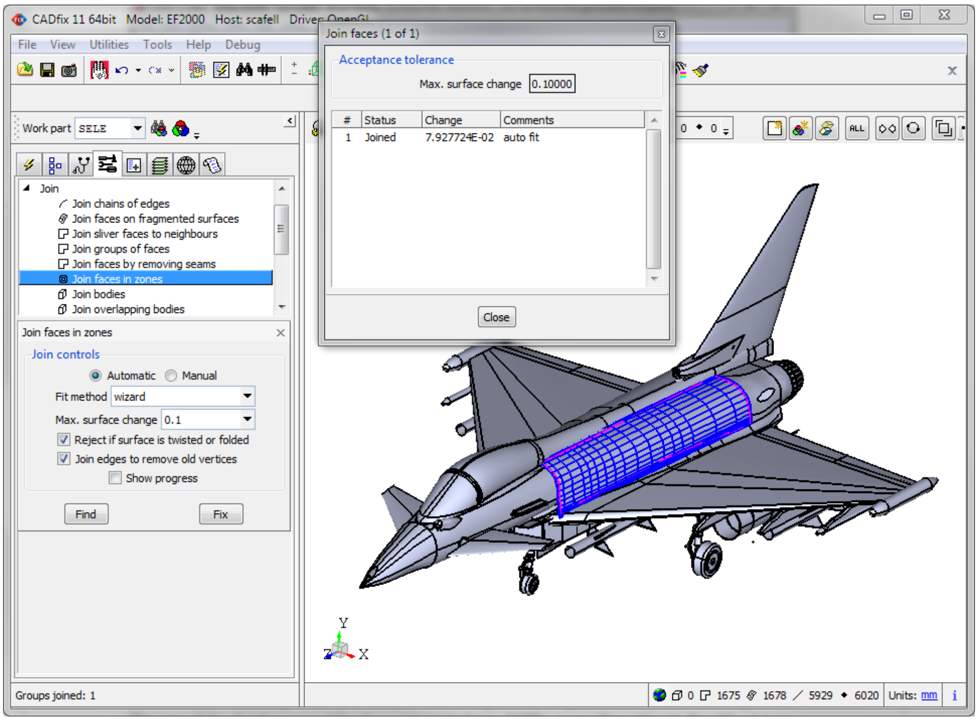
Within ICE NITe, ITI have researched improved methods for joining faces together to remove these constraints on meshing – improved parameterisation for joined faces, better curved triangle construction to represent the geometry of a joined face, and more robust conversion of joined face geometry to NURBS. These improvements are accessed through the "Zoning" and "Join faces in zones" tools, as shown in the figures below. Faces can also be joined fully automatically using the "Join faces" option in the "Transform" stage of the CADfix Wizard, as shown in the final figure below.



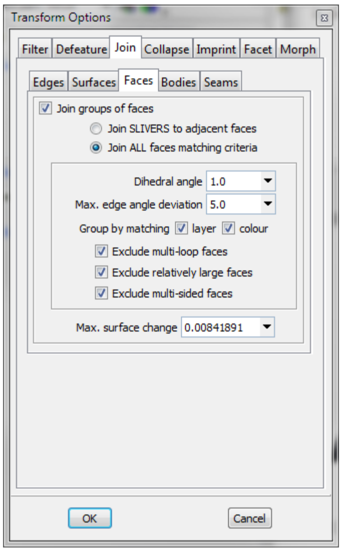

Defining a zone (virtual face) over the fuselage, shown in orange.




Parameterising this zone using the new “As rigid as possible” algorithm.



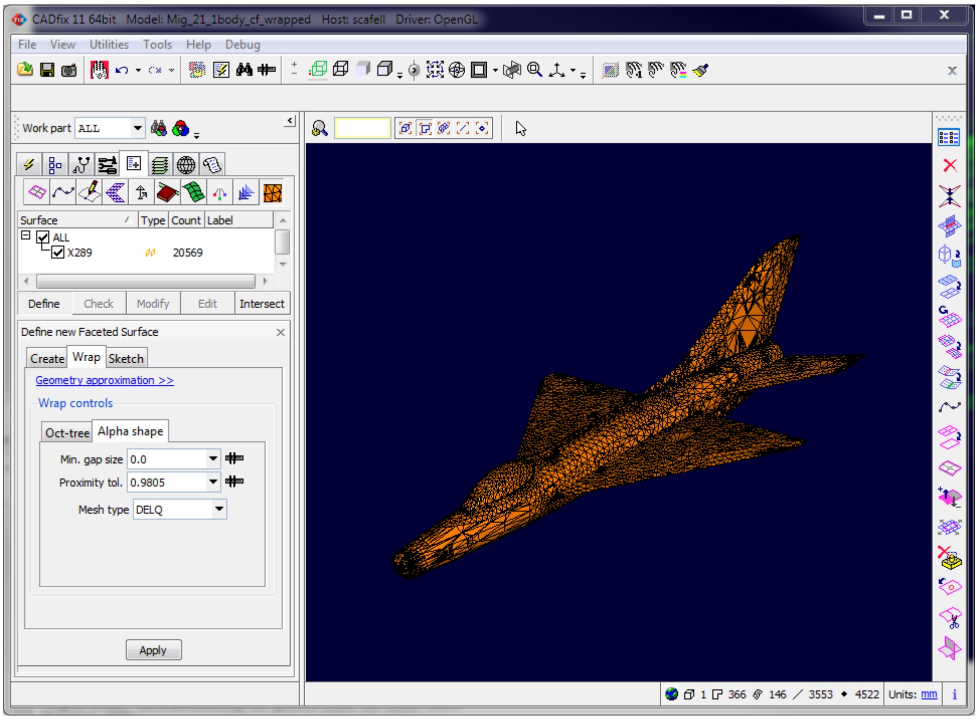

Constructing joined face by creating a NURBS surface over this zone.




Fully automatic face joining in the “Transform” stage of the CADfix Wizard.

## Shrinkwrapping for CEM

Shrinkwrapping is an alternative 1-click technique for simplifying CAD models. A shrinkwrap is a facetted representation of a geometry, with all small gaps and details below a certain tolerance suppressed, and can provide a simple way to prepare models where complete accuracy is unnecessary, but gross defeaturing is too aggressive. A completely new shrinkwrap technique, based on the concept of an alpha shape, has been researched and developed in ICE NITe. As well as providing several intrinsic benefits over other shrinkwrapping techniques – such as the oct-tree method previously explored by ITI – the alpha shape wrapper is paired with a remeshing stage, which re-uses the CAD geometry where possible, and generates high quality equilateral triangles. The new alpha shrinkwrap tool has been integrated into CADfix, as an alternative to the oct-tree method, as shown in the figure below. See the deliverable document *Shrinkwrap developments for computational electromagnetics in ICE NITe* for more details.




Public

The ICE NITe "Alpha shape" shrinkwrap tool applied to a simple fighter aircraft.

## Geometric idealisation for CEM

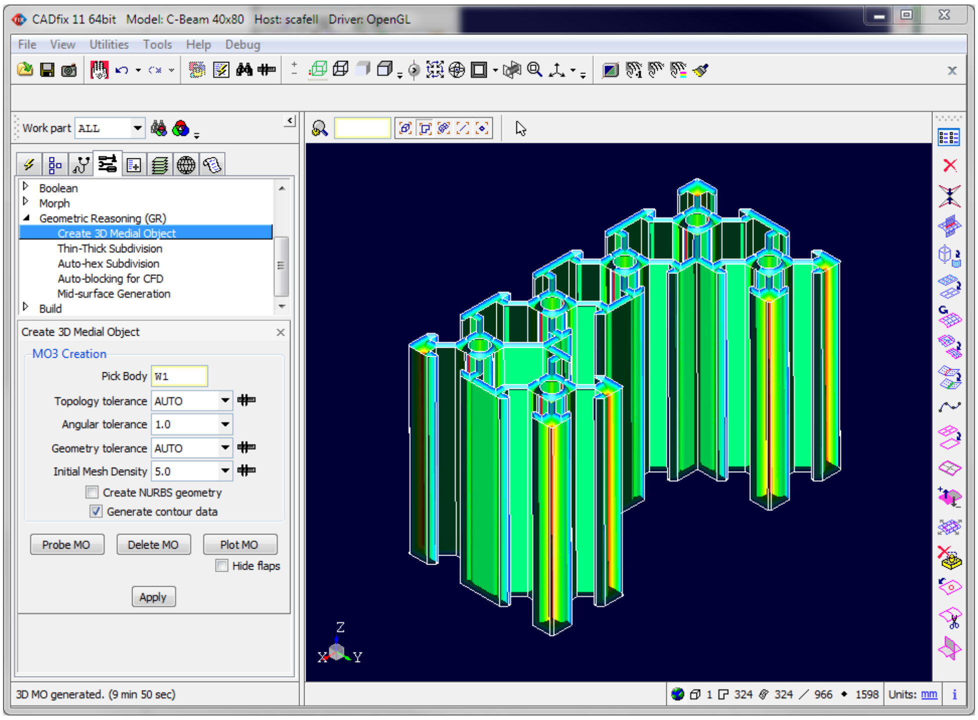
As well as defeaturing, sometimes models need to be idealised for CEM – their geometric form altered in a way which still describes the physics accurately, but with fewer degrees of freedom required in the subsequent simulation. A common idealisation is mid-surface reduction, where thin walled structures are reduced to a mid-surface of zero thickness (but with the original thickness carried as an attribute on the surface). This can massively reduce the number of mesh elements required to accurately simulate a thin walled structure, but constructing mid-surfaces can be difficult and time consuming, even with state of the art tools.

In ICE NITe, ITI have investigated a fully automatic mid-surfacing method, based around the 3D medial object. The 3D medial object is the set of all points which are equidistant from two or more points on the boundary of the CAD model, and thanks to a sustained research program – outside of ICE NITe – ITI's CADfix tool contains the only commercial implementation of a 3D medial object algorithm. Once a medial object has been calculated, the mid-surface is extracted by identifying key medial faces which form the seeds of mid-surfaces, and then extending these medial faces to represent the whole geometry. See the deliverable document *Mid-surface developments for computational electromagnetics in ICE NITe* for more details.

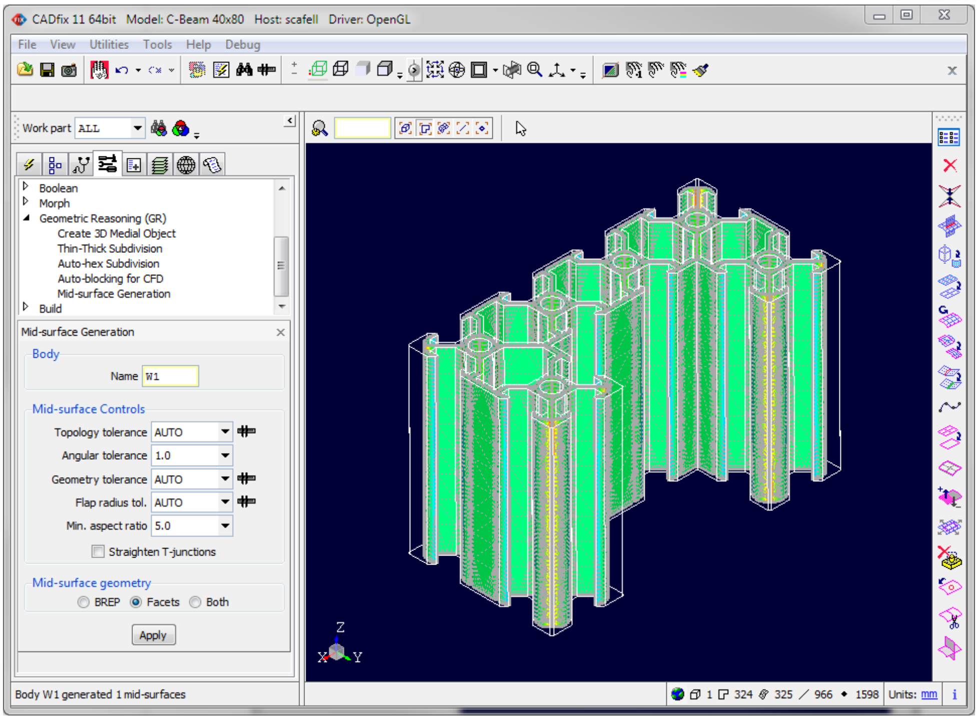
The prototype mid-surfacing tool has been integrated into CADfix in two pieces:

1. Create 3D medial object – to calculate the 3D medial object of a body
2. Mid-surface generation – to compute the mid-surfaces once the 3D medial object has been calculated.

See the figures below to see how these tools look in CADfix.




The "Create 3D Medial Object" tool in CADfix, with a calculated medial object visible. The colours indicate medial radius – the distance between the medial surface, and the boundary of the model.




The “Mid-surface Generation” tool, with a calculated mid-surface visible.

## Conclusions

Within the ICE NITe project, ITI have researched and developed a series of tools to automate the CAD to CEM process, as part of an overall workflow, aimed at producing models suitable for meshing and simulation using the University of Nottingham UTLM software. These tools have all been integrated into ITI’s CADfix product, and are available for ICE NITe partners and wider customers to preview and evaluate.