

# Modelling the Mechanical Behaviour of Next-Generation Aircraft Joints using an Explicit Dynamics Approach

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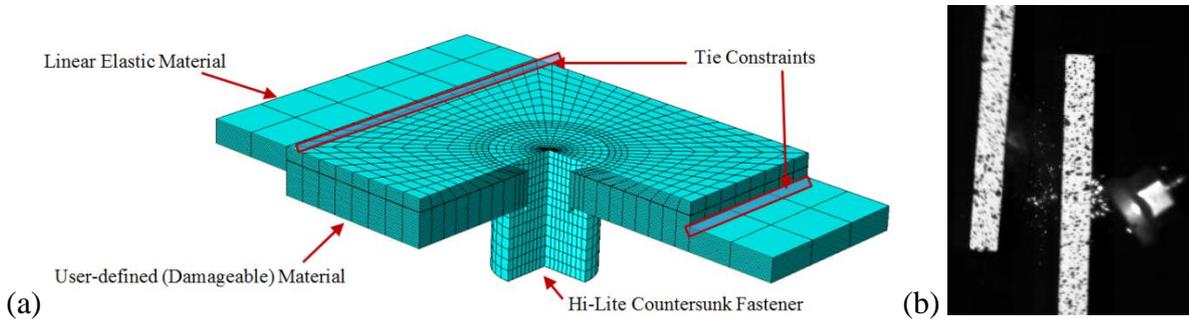
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Extending the use of composites in next-generation aircraft is seen as crucial in order to achieve desired future efficiencies in the aeronautical sector. A lack of computational tools at present has led to extensive physical testing programs and overly-conservative airframe designs. A key area within airframe design is the connection of panels. Bolted connections between brittle materials such as fibre-reinforced composites have a limited structural efficiency, due to the presence of high stress concentrations at a loaded hole. Bonded joints offer an alternative but compromise on accessibility, while production, testing and maintenance costs of a bonded joint are typically much higher than for an equivalent bolted joint (Pearce et al. 2010). With a limited achievable efficiency, additional conservatism in the design of bolted joints can lead to excessive weight in aircraft structures. If joints can be optimised using computational tools, major weight-savings can be achieved. Furthermore, accurate finite element (FE) modelling of joint behaviour can reduce the cost of aircraft testing/certification programs.

Though possessing aerodynamic benefits over protruding-head bolts, countersunk fasteners have had limited use in joining composite aircraft structures. Previous experimental studies have found that a countersunk joint exhibits damage-onset at a much lower applied load, compared to an equivalent protruding-head setup (McCarthy et al. 2002). However, with a similar ultimate load achieved by each joint, it was proposed that the more damageable behaviour of the countersunk joint could be beneficial for crashworthiness applications. Currently there is a very limited amount of work published on numerical modelling of countersunk composite joints. This is due to convergence issues associated with this type of model, resulting from both the complex nature of the contact modelling and the strain-softening behaviour of fibre-reinforced composite. A highly-detailed investigation of *elastic single-bolt* joint behaviour has been recently completed using Abaqus/Standard (Egan et al. 2012). However, large *multi-bolt* joints, where material softening is to be included, the authors have found Abaqus/Explicit to be a much more viable solution technique.

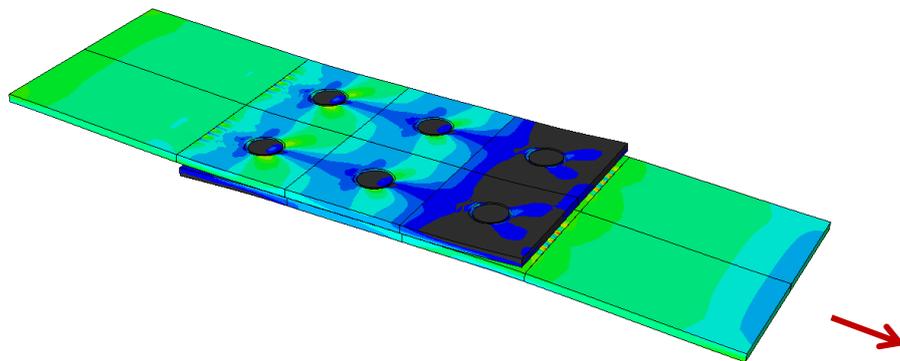
The work presented here is being carried out in Abaqus/Explicit, a commercially-available finite element software. Countersunk joints in carbon-epoxy laminates (typical of aircraft skin material) are modelled (see Figure 1 & Figure 2), using the *explicit dynamics* finite element method. Though normally used for high-speed loading events, it has been found that adequately ‘slowing down’ the rate of loading (to the point where kinetic energy is negligible) gives good agreement with the quasi-static joint response (Egan et al.). A state-of-the-art composite damage model (see Figure 3) has been developed to facilitate accurate predictions of joint bearing failure. This is an in-house coded Fortran subroutine (VUMAT), which has the ability to capture complex failure phenomena at the level of the composite ply. In addition to its ability to model

dynamic events, the explicit approach is much more robust than the implicit method, thus eliminating convergence issues experienced previously. Highly-instrumented experimental testing has been carried out at UL to characterise the behaviour of a large number of joints. Tests are currently underway in which joints are being loaded at speeds of up to 10m/s. The resulting vast amount of experimental data will be used to vigorously validate the modelling carried out here.

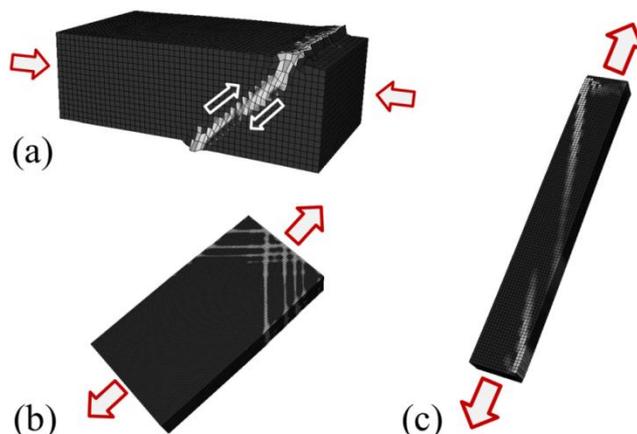


**Figure 1 (a) Cut-away showing meshing scheme & geometry in the overlap region of a typical FE countersunk joint model. (b) Image from experimental high speed (10m/s) test showing fastener failure.**

In comparison to previously published work, this project can introduce three-dimensional, *explicit dynamics* joint simulations including composite damage to the literature for the first time. The approach will also facilitate the simulation of damageable multi-bolt joints which are much larger than those published previously. This will move the current modelling state-of-the-art from single-bolt problems which are largely of academic interest, to large multi-bolt problems which have real industrial relevance.



**Figure 2 Initial multi-bolt joint simulation.**



**Figure 3 Behaviour of the VUMAT damage model, developed with the aid of a previous ‘Class C’ ICHEC project. (a)  $[90]_{16}$  specimen showing failure on the action plane under compressive loading (b)  $[+/-45]_{8s}$  showing in-plane shear failure under tensile loading (c)  $[10]_8$  showing in-plane shear failure under tensile loading.**

## References

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