HIGH-RATE TESTING AND MODELLING OF AEROSPACE LAP-SHEAR FASTENER JOINTS USING A SPLIT HOPKINSON TENSION BAR

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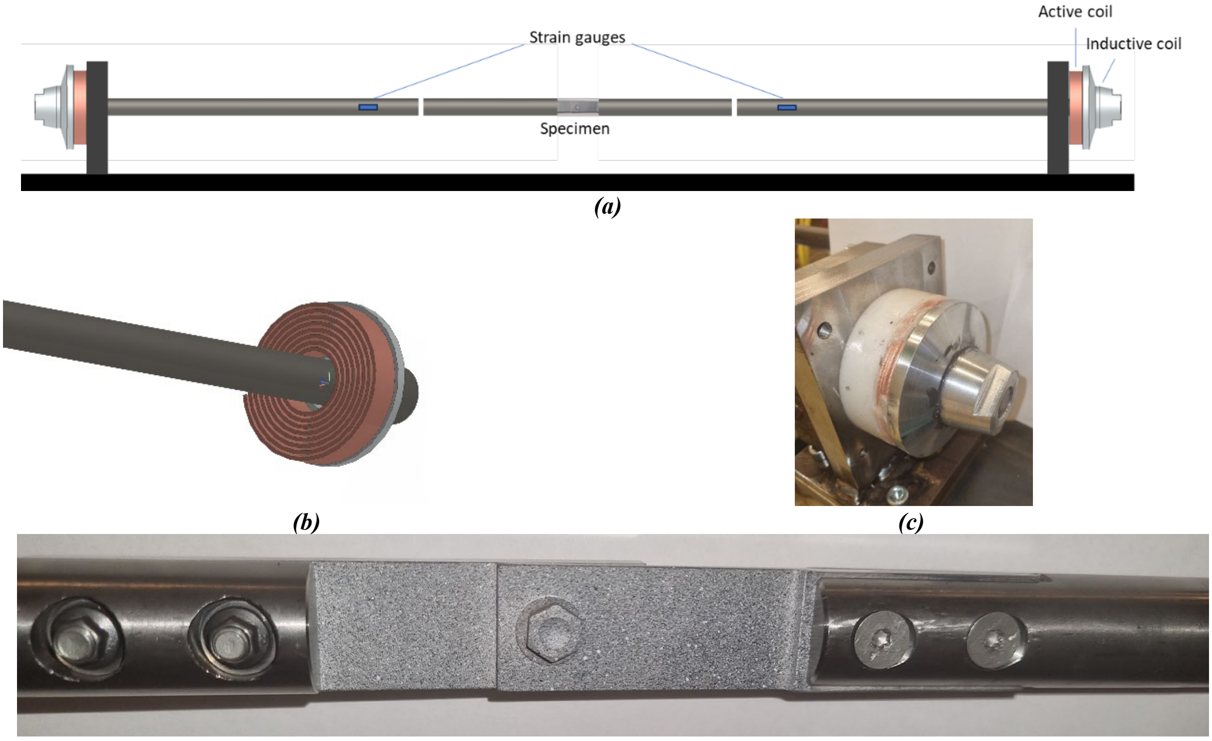
ABSTRACT

A large number of bird and debris impact analyses are conducted throughout all stages of aircraft development. Impact-induced deformation and intrusion assessments based on bird strike analyses are required for flight-critical components such as vertical tails and control-surface structural installations. Typical debris scenarios include tire fragment impacts during landing or taxi operations, when landing-gear bays are open and critical aircraft system components are exposed. Unlike classical load and stress analyses, bird and debris impact analyses do not allow for the application of conventional conservatism. Structural failure or survival during an impact event can fundamentally alter the impact response, and controlled failure is often an intentional mechanism to protect essential flight-safety systems. Failures are likely to appear at fastener positions where the local load distribution is complex. At the same time, model resolution needs to be kept as simple as possible due the normally large number of fasteners in an aircraft structure and the requirement of time efficient models. Fasteners are today modelled as simple beam/bar elements with an associated failure criterion including mechanical properties of both the fastener itself and the surrounding structural parts and are based mainly on engineering judgments derived from structural/material data for quasi-static conditions, which for high-speed loading events are not yet verified.

Despite the widespread use of split Hopkinson pressure bar (SHPB) methods for characterizing materials at high strain rates, comparatively few studies have focused on dynamic testing of structural fasteners and joints under tensile loading. This work presents a synchronous Split Hopkinson Tension Bar (SHTB) apparatus experimental approach, tailored specifically for evaluating the high-rate behaviour of lap-shear screw joints. The apparatus enables symmetric loading of mechanically fastened specimens, minimizing bending effects and enabling accurate force-displacement characterization of the joint failure process at strain rates in the order of 1000 s^{-1}.

The investigated joint configuration is representative of lightweight aerospace assemblies and consists of 7075-T6 aluminium alloy plates connected using a titanium screw and a stainless-steel nut. To provide a baseline for comparison and to isolate strain-rate effects, a series of quasi-static tensile lap-shear tests were first performed using displacement-controlled loading. High-rate experiments were then conducted on the synchronous SHTB at a strain rate of approximately 1000 s^{-1}. The symmetric design of the apparatus ensures that loading is applied simultaneously from both ends of the specimen, thus mitigating spurious bending moments and reducing uncertainties arising from point mass rigid body motion. Force equilibrium across the specimen was verified through incident, transmitted, and reflected wave analysis. High-speed digital image correlation (DIC) was employed to complement the force measurements by capturing deformation fields and strain history up until failure.



(a)

(b)

(c)

(e)

Figure 1: Schematic diagram of synchronous split Hopkinson tensile bar (a). Schematic diagram of active coil design (b). Active and conductive coils (c). Bolted joint specimen with speckles and its attachment to the Hopkinson bars (d).

A direct comparison of the quasi-static and high-rate force-displacement responses was performed to highlight important differences. However, the complex interaction between for example bearing deformation, screw bending, interface friction, and inertia required deeper analysis than experimental observations alone could provide. To better interpret the experimental results, the joint system was further investigated by modelling in LS-Dyna, in which both quasi-static and dynamic loading scenarios were modelled. The simulation framework included rate-dependent constitutive model for 7075-T6 aluminium. Contact behaviour between plates and fasteners was represented using frictional contact algorithms, and the LS-Dyna specific GISSMO damage model was applied to capture the onset and progression of failure. The dynamic simulations replicate the double-sided loading conditions of the SHTB and incorporate the effects of wave propagation, inertia, and high-rate material behaviour.

The combined experimental-computational approach provides new insight into how mechanically fastened lap-shear joints behave when subjected to high-rate tensile loading. The study aims at demonstrating the key force transfer mechanisms which drive differences between quasi-static loading and dynamic loading. The developed double-sided SHTB apparatus proves effective for isolating the dynamic effects and provides a robust platform for future investigations of more complex joint configurations.

This work contributes to the broader objective of improving dynamic structural models for aerospace applications, particularly for assemblies where joints represent critical load paths. The combination of controlled high-rate experiments and validated simulations models offers a foundation for developing more accurate predictive models, supporting the design of lighter, more reliable structures capable of withstanding extreme loading scenarios.