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The computational post-buckling analysis of fuselage stiffened panels loaded in shear

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Abstract

Fuselage panels are commonly fabricated as skin-stringer constructions, which are permitted to locally buckle under normal flight loads. The current analysis methodologies used to determine the post-buckling response behaviour of stiffened panels relies on applying simplifying assumptions with semi-empirical/empirical data. Using the Finite Element method and employing non-linear material and geometric analysis procedures it is possible to model the post-buckling behaviour of stiffened panels without having to place the same emphases on simplifying assumptions or empirical data. Previous work has demonstrated that using a commercial implicit code, the Finite Element method can be used successfully to model the post-buckling behaviour of flat riveted panels subjected to uniform axial compression. This paper expands the compression modelling procedures to flat riveted panels subjected to uniform shear loading, investigating element, mesh, idealisation and material modelling selection, with results validated against mechanical tests. The work has generated a series of guidelines for the non-linear computational analysis of flat riveted panels subjected to uniform shear loading, highlighting subtle but important differences between shear and compression modelling requirements.

Keywords: Fuselage buckling analysis; Post-buckling analysis; Non-linear finite element modelling; Stiffened panel shear testing

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1. Introduction

1.1. Background

Fuselage structure consists of longitudinal stiffeners (stringers and longerons), which run the length of the fuselage, distributed transverse elements (frames and bulkheads), which stabilise the structure from within, and the fuselage external skin. The stiffened panel structure is designed to cope with a variety of loading conditions including shear loading. Local skin shear buckling is waving of the fuselage skin between the stringers and frames into visible folds. The structure will not fail with local skin buckling, as the stringers will continue to carry increased load. In addition the skin is still capable of carrying shear load through tension-loaded bands of material located between the buckles. This condition is referred to as a state of incomplete diagonal tension [1] and forms the basis of the conventional post-buckling analysis.

There are well established analysis procedures based on semi-empirical equations which are widely used in industry. However, current trends in developments of materials and joining processes as well as geometric configurations have pushed towards the limits of applicability of these methods. Although, Finite Element (FE) methods have been successfully used to model buckling behaviour the time and expertise required means that they are used only sparingly for these problems despite their promise for providing a means of both understanding the behaviour of these structures and also for enabling trade-off studies to be rapidly and reliably carried out between competing configurations and manufacturing processes.

In order to facilitate more widespread and consistent use of FE for these problems this work attempts to address issues around idealisations, material modelling and element selection to provide a consistent and reliable approach. The methods are of course validated. Section 1.2 reviews key elements of conventional analysis before looking at FE methods and testing.

1.2. Conventional fuselage panel design

The post-buckling behaviour of stiffened shear panels and tension fields was first considered in the late 19th century by Wilson [2]. Wilson's ideas were added to by Rode in 1916 with an early mathematical formulation of a tension field, Basler [3]. In the mid 20th century Wagner [4] developed the 'pure diagonal tension' theory, which Kuhn [5] 20 years later extended to the 'incomplete diagonal tension' theory having carried out an extensive experimental programme [6]. Kuhn expanded the beam web analysis to flat fuselage panels loaded in shear and compression and, to curved panels loaded in shear and compression. Kuhn's approach, based on 'incomplete diagonal tension' theory is still the basis of today's aerospace shear post-buckling analysis procedures, documented in Bruhn [7].

The engineering stress theory of incomplete diagonal tension is based on the assumption that the nominal skin shear stress, τ, comprises two components. A true-shear component, τ_s, and a diagonal-tension component, τ_{dt}. The nominal skin shear stress is related to the true-shear component via the diagonal-tension factor, k, Eq. (1).