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Structural Analyses and Margins of Safety

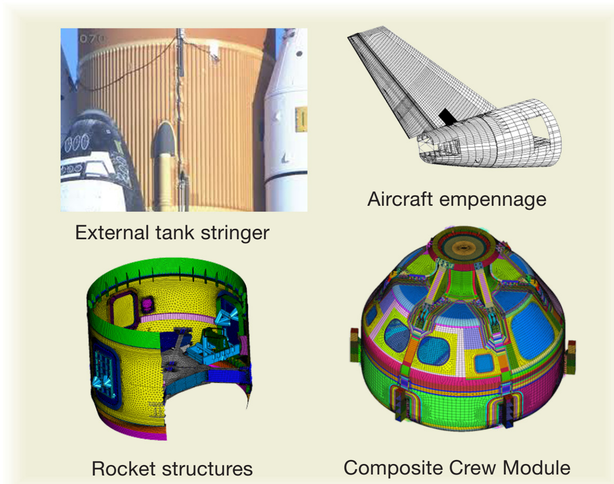
There is an increasing reliance on modeling and simulation to verify, quantify, and certify designs of complex structures. The availability of a range of commercial modeling and simulations tools and packages with a variety of capabilities, in conjunction with increased computational resources, is allowing analysts to rapidly perform detailed analyses. However, care should be taken to understand specific tool limitations, assumptions, and boundary conditions as erroneous results can be generated without being recognized by the analysts. In addition, the reported margins of safety should be carefully interrogated to identify any false positive or negative margins and highlight any areas for structural concern.

Applicability

Structural analysis Agency-wide.

Background

Advances in modeling and simulation, new finite element software packages, modern computing platforms, computing engines, and powerful computers are providing opportunities to interrogate complex designs in a very different manner and in a more detailed approach than ever before. The current trend in the structural design process is increasing reliance on modeling and simulation to assess local stress states and evaluate margins of safety. In addition, there is also a tendency to perform three-dimensional (3D) analyses under the assumption that detailed 3D models inherently provide higher fidelity and more accuracy than two-dimensional (2D) and shell models. Furthermore, aerospace structural components are inherently complex; typically local stress concentrations, free edges, skin-stiffeners, varying thickness shells, etc. are par for the course. Global- or system-level structural models of these components often include connections between and among finite elements of different dimensionality (e.g., beam element connected to a plate/shell/solid element). Quite often negative stress margins are calculated and reported from these analyses. The reported negative margins raise questions about the adequacy of the structural design and may, in fact, initiate separate independent assessments of the design, a redesign of the component(s), or both. Alternatively, in many instances these stress values may be prescribed as input to a life-prediction analysis and tools, and the predicted outcome may be an inadequate design life, driven in part by these artificially high local stress values. As a consequence, schedule delays may result and costs may increase due to perceived necessity to redesign.



Examples of complex structural analysis models

Findings and Conclusions:

Recent studies show that in some, but not all cases, these negative stress margins computed using local stresses are inaccurate and are artifacts of modeling and analysis. The areas where negative margins are frequently encountered are often near stress concentrations; point loads and load discontinuities; near locations of stress singularities; in areas having large gradients but with insufficient mesh density; in areas with modeling issues and modeling errors; in areas with connections and interfaces; in areas of 2D-3D transitions; near bolts, due to details of bolt modeling; and near areas of complex boundary conditions. Now, more than ever, structural analysts need to examine, interrogate, and interpret their analysis results and perform basic "sanity checks" to determine if these negative margins are, in fact, real or they are just artifacts of modeling and analyses. Knowledge of the behavior of structures and the theory of elasticity, the ability to formulate an estimate of expected results before they are obtained, the awareness of consequences of modeling assumptions, etc. are essential to interpret the numerical results.

Another disturbing aspect noted in the recent past is the inability to prescribe appropriate boundary conditions by widely available desktop software packages. The reported positive margins by these software packages may, in fact, be false positive. These packages are inexpensive and may not have all the analysis options and capabilities that the widely used general-purpose software packages (such as NASTRAN, ANSYS, ABAQUS, etc.) offer. The margins evaluated with these desktop packages need to be confirmed by performing a reanalysis with the widely used packages and also ensuring that proper boundary conditions are prescribed.

References

Raju, I. S.; Lee, D. S.; and Mohaghegh, M.: "Negative Stress Margins – Are They Real?", AIAA-2011-1808-588, Paper Presented at the 52nd AIAA SDM conference, Denver, Colorado, April 4-7, 2011.

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