A MULTI-LEVEL NONLINEAR DOMAIN DECOMPOSITION SOLVER FOR THE ANALYSIS OF LARGE AEROSTRUCTURES WITH LOCAL NONLINEARITIES

Philippe CRESTA

EADS Innovation Works
18 rue Marius Tercé, Toulouse, France
philippe.cresta@eads.net
http://www.eads.com

Abstract

Nonlinear simulation of large aerostructures is one of today's greatest challenges in computational mechanics. So far, research works mainly focused on the development of advanced parallel solvers for large linear systems. These different approaches enable the use of increasingly larger parallel computers –mainly distributed memory clusters– for solving linear problems up to one billion of degrees of freedom. Such approaches, while offering tremendously larger resources for simulation, lack with the treatment of nonlinearities, and more particularly the one occurring at some localised area of larger structures: buckling between stringers, damage near holes, etc. The overall convergence process is completely controlled by local nonlinearities, which induces a large number of iterations at global scale, whereas nonlinearities sometimes only occur on some dozens of elements.

In previous works, we proposed a multilevel nonlinear scheme particularly adapted to such issues (Cresta *et al.*, 2007). It consists in adding to classical approaches a nonlinear relocalization step within substructures, enabling to control convergence of local non-linear phenomena at substructure level. Results in terms of number of load increments and number of global iterations for slender structures with local buckling demonstrated the advantages of such strategies. We here present an implementation of this approach making use of Abaqus Finite Element solver to realize local (per substructure) nonlinear computations, condensation of linearized operators (through the concept of substructuring), and solving of global condensed problem. Even if such implementation is not optimal, due to the various constraints from the software, it enables to demonstrate the advantages of the strategy on real industrial structures.

Keywords Nonlinear structural analysis; Domain decomposition methods; Post-buckling; Large structures; Nonlinear relocalization; Multi-level approach.

1. Introduction

Performing nonlinear analysis of large structures at a fine scale is one of the industrial challenges of our times. In aeronautical structures such as airplane fuselages one important nonlinearity that arises is local buckling of slender elements. During the structural tests for certification achieved on complete fuselages of aircraft, we observe local buckling of the skin between stiffeners (see Figure 1). At increasing loads, these nonlinear areas can expand and provoke redistributions of stresses in the structure. For workloads usually met in service, these phenomena are reversible, the material staying in the elastic domain. However, they can provoke concentrations of stress near the bases of stiffeners and may be at the origin of local damages leading to global failure. Taking into account these phenomena for a large structure like a fuselage leads to approximately 10^7-10^8 degrees of freedom (d.o.f.) with an adapted meshing. Because of this large number of unknowns and because of memory and processors limits, computing this kind of problem with a classical direct technique is not feasible at the moment, even with last generation sparse solvers. For this reason, engineers have used approximate methods based on super-elements (linear condensation of inner degrees of freedom) or global-local analysis, constituted in a coarse and linear global calculation followed by fine nonlinear analyses on areas of local interest. If such methods allow for certain computations, they cannot take into account phenomena like stress redistribution or nonlinearity expansion, since they only offer a limited (one-way) dialogue between the introduced scales. As a result, they can only treat localized nonlinearities having no influence on the global response and thus must be used with care.

However, new advances in computer science, using parallel machines and PC clusters, today enable us to spread computational costs and memory requirements over many processors. Increasingly complex problems are becoming calculable, provided the solving method can take advantage of the inherent parallelism of the hardware architecture.

So far, research works mainly focused on the development of advanced parallel solvers for (very) large linear systems. Among these, we can refer to a couple of now famous families like parallel direct sparse solvers (for instance parallel multifrontal solvers like MUMPS (see *http://mumps.enseeiht.fr/*), multi-level condensation