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Fast and Accurate Computationnal Nonlinear Aeroelasticity for Wing Optimization

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ABSTRACT

In the first stage of aircraft wing design, the variation of several parameters related to the structure surrounded by a flow requires numerical simulations in aeroelasticity. The fluid-structure problem can be calculated in the frequential field or the temporal field. In the last approach, the structure and the fluid constitute a continuous medium governed by the laws of conservation. Those are then discretized in space and time. Thus, for each flying condition (Mach numbers, Reynolds number and dynamic pressure) computation is required to obtain the evolution of the coupled system. If the system, known as aeroelastic is unstable, then for any disturbance around a state of balance the structure produces divergent displacements. One generally fixes the Mach number and varies with each execution of the code the dynamic pressure until the critical pressure corresponding to the flutter point of the wing is obtained. This requires a great number of simulations and confirms the need for an aeroelastic code being able to give the dynamic response within a sizeable time.

There are several mathematical models governing transonic flows, however, some have limited applications such as the solution of the linearized compressible potential equation or the solution of the small transonic disturbances (TSD) model. Higher order models such as solving the Euler or the Navier-Stokes (NS) equations represent more accurately the physical phenomenon. But given the number of equations to be solved, they require a too large computing time to be used during a preliminary stage of design. The full potential equation (FP) is able to reproduce the phenomena of shocks and gives a pressure field relatively precise with a sizeable computing time. This single equation is a simplification of the Euler equations and gives practically identical results for subsonic flows and transonic flows without separation. The major advantage of the simpler model using FP approach over those based on Euler and NS formulations is the large reduction in computational cost requirements making them suitable for the preliminary design stage. For this reason the numerical method used for fast computational aeroelasticity is based on the numerical resolution of the full potential equation.

We noticed that the consistency of the space discretization was a major factor in order to obtain accurate solutions and to guarantee its stability. Moreover, the convergence of a triple approximate factorization scheme was insufficient to solve an aeroelastic problem. A nonlinear GMRES algorithm with an ILUT preconditioner was thus implemented.

We carried out the structural resolution by modal superposition. The conventional serial staggered (CSS) coupling algorithm and the improved serial staggered (ISS) coupling algorithm were compared. The CSS algorithm must be iterated in order to accurately capture non-linearities when the flow is

transonic. The ISS algorithm is constructed with a leap-frog scheme where the fluid system is always computed at half time stations while the structure subsystem is always computed at full time stations. Although the results of the CSS coupling algorithm with a predictor-corrector and of the ISS coupling algorithm are practically identical, the computing time of the CSS method was roughly 1.75 times more important. For this reason the ISS algorithm should be preferred.

The transfinite interpolation (TFI) was used in order to regenerate the mesh at each time step. The use of quaternions in the layer close to the wing was used to preserve mesh orthogonality.

Parallel processing was implemented in order to reduce the computing time. The code is able to carry out 10000 time steps per hour by distributing the computation load on 24 AMD 248 processors on an Infiniband network for a mesh of approximately 225k nodes. Because the domains overlap, the efficiency of the parallel code depends on the size of the problem. For a problem of medium size, the efficiency remains higher than 80% for up to 8 processors whereas for a problem of large size, the efficiency remains higher than 80% up to 16 processors. The computing time for each Mach number computed using 12 AMD 248 processors is presented in table 1. One can realize that the flutter speed indices for an operating range of Mach numbers can easily be found within one day for a given wing configuration.

Table 1: Computing time CSS and ISS coupling algorithm

Mach number	Number of time steps	Computing time CSS	Computing time ISS	Ratio CSS/ISS
0.499	2000	0:35:01.4	0:19:26.4	1.80
0.678	3000	0:50:24.2	0:27:32.1	1.83
0.901	6000	1:42:27.3	1:00:52.4	1.68
0.960	10000	2:58:50.4	1:45:12.4	1.70

The flutter speed indices calculated on the AGARD 445.6 wing are very close to the experimental values. This enables us to conclude that the code developped is very fast, robust and accurate enough to achieve the goals of this work.

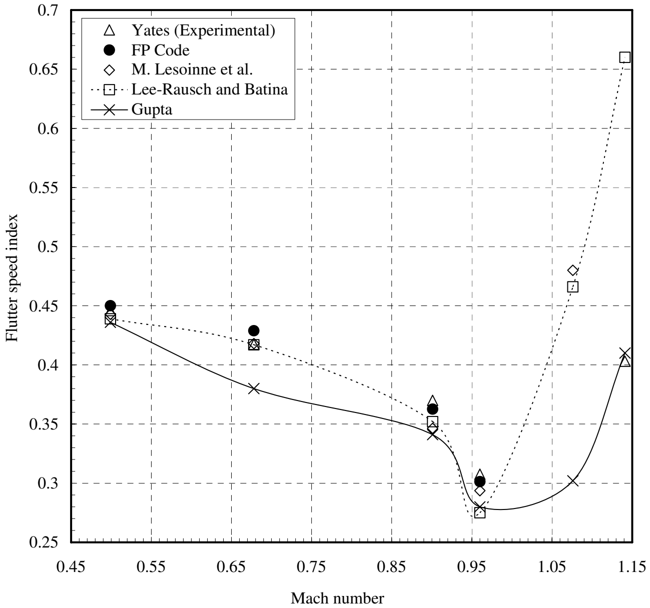

Figure 1: Agard 445.6 wing flutter speed indices

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