Aeroelastic Simulation on SST with Multiblock Moving Grid Algorithm

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1. Introduction

As the development of computational methods and computer techniques, multiblock grid has been extensively used for the steady flow simulation on complex aerodynamic configuration. However, most of aeroelastic calculations are only done for an isolated wing. One of the reasons is that the aeroelastic simulation is very expensive. Another is that it is hard to establish an efficient multiblock grid deformation. For accurate dynamic analyses, a coupled method between fluid and structure is necessary and the grid deformation is required at every time step.

Recently, Potsdam and Guruswamy [1] put forward a multiblock moving grid approach, which uses a blending method of a surface spline approximation and nearest surface point movement for block boundaries, and transfinite interpolation (TFI) for the volume grid deformation. Wong et al. [2] also established a multiblock moving mesh algorithm. The spring network approach is utilized only to determine the motion of the corner points of the blocks and the TFI method is applied to the edge, surface and volume grid deformation.

In the present paper, the aeroelastic characteristics for the wing-body configuration of SST containing aileron oscillation are investigated. For the SST wing-body configuration, appropriate multiblock grid topology is selected so that the corner points and the block boundaries away from the flexible surface can be fixed. The grid deformation needs to be performed only for the blocks adjacent the deforming surface. The grid moving technique, combined with the tightly coupling method and modified data transformation approach between fluid and structure, are performed for the aeroelastic calculations.

2. Solution Method

The multiblock aeroelastic solver is developed based on the tightly coupled aeroelastic code for an isolated wing [3], which solves the thin-layer Navier-Stokes equations with the LU-SGS subiteration algorithm. For accurate multiblock-grid aeroelastic calculation, the tightly coupling method is much more important not only for removing the sequencing effects between the fluid and structure but also for eliminating the lagged flowfield induced by lagged multiblock boundary condition.

A multiblock grid with 30 blocks is generated by the elliptic method with boundary control for the wing-body model of SST shown in Fig.1. Because only the blocks adjacent to the flexible surface need to be deformed, the computational cost for the grid deformation can be decreased largely. It is unnecessary to use the blending method [1] or the spring analysis [2] for the nearest surface point or corner point movement. For the aileron deflection, a simple sheared mesh is used and a gap is introduced between the ends of the aileron and wing to allow sufficient space for the moving sheared mesh. The present solver assumes the aileron oscillation of small amplitude. For aeroelastic analyses, the tendency of flow stability can be analyzed from the dynamic response of small aileron deflecting oscillation.

The data of structural mode of SST were provided based on a plate model and its deformation was only considered in the normal direction, where the standard MSC/NASTRAN interpolation method is applied to transform the data between fluid and structure. The fluid simulation is carried out for the full geometry. In order to interpolate the deformation of the structural grid to the fluid grid, the fluid grid needs to be projected to the structural surface. Since deformation is discontinuous between the zones of the aileron and wing, interpolations are applied on the aileron and wing separately. After deformations on the projected fluid grid points are interpolated, the new geometry can be obtained by adding the deformation in the normal direction to the old one. For the data transformation of aerodynamic loading, the principle of virtual work is applied, which guarantees the conservation of energy between the fluid and structural systems.

3. Results and Discussion

Aeroelastic simulations are performed for two structural models of SST at three transonic Mach numbers of 0.95, 0.98 and 1.05 under the fixed total pressure of 85 Kpa and angle of attack of 0 degree. In the experimental model, fuselage and main wing are rigid, however, the aileron is attached to the main wing by a spring to simulate the hinge stiffness. The main difference of the two structural models is the model 1 has a small aileron oscillating frequency with lower spring-hinge stiffness in contrast to the model 2. Table. 1 summarizes the stability characters of all solutions, which indicates the flow is stable for the model 2 at all calculated cases, but unstable for the model 1 at the Mach number of 0.98 and 1.05. The solution at Mach number of 0.98 is further discussed in the following. The steady pressure contours are depicted in Fig. 2. There is a strong transverse shock wave on the upper surface of the wing at the trailing edge as well as at the aileron. As the aileron oscillates, the shock wave moves

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on the aileron, which induces the flow instability referred to as aileron buzz. Dynamic responses of generalized displacement for the two structural models are shown in Fig. 3. For the model 1, the dominant mode, which corresponds with the aileron mode with the lowest oscillating frequency, diverges rapidly as the increase of time. For the model 2, the dominant response is the bending mode of wing, which conserves nearly a steady oscillatory mode with small amplitude. The oscillating response of aileron corresponds to the third mode and its oscillating amplitude is smaller than others, and thus cannot influence the stability of the whole flow. The responses of aileron angles shown in Fig 4 can further verify the explanation. For the model 1, the amplitude of the aileron oscillation becomes larger and larger until the calculation breaks down due to the use of a simple sheared grid deformation for the aileron deflection. For the model 2, the amplitude is only about 0.03 degree and the response also appears a steady oscillatory mode.

The above results are calculated without structural damping. In fact, the structural damping always exists in the practical aeroelastic phenomenon. A small modal damping coefficient of 0.02 is added in the calculation at Mach number of 1.05, without structural damping, which appears the strongest limit cycle oscillation for the model 2 in the three Much numbers. The comparison of dynamic responses with and without structural damping is shown in Fig. 5. With the small structural damping, all responses decay with time, which further reveals the aeroelastic system for the model 2 is stable for all computational cases.

Table 1. Aeroelastic stability of SST at total pressure $P_0 = 85Kpa$ and angle of attack $\alpha = 0^0$

Mach	0.95	0.98	1.05
Model 1	Stable	Unstable	Unstable
Model 2	Stable	Stable	Stable

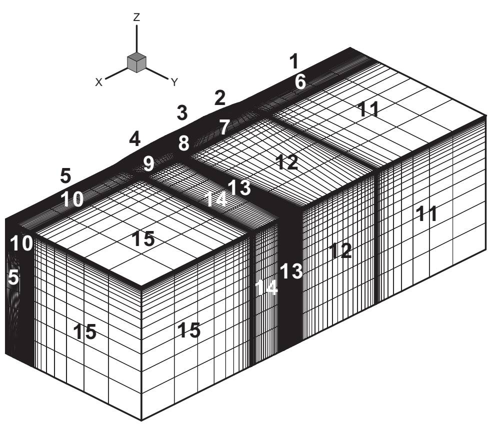

Fig. 1 Multiblock grid with 30 blocks for SST

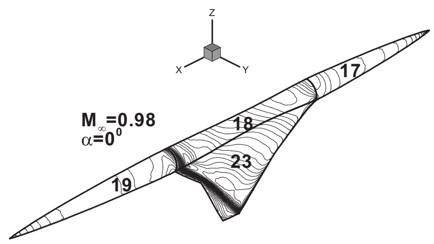

Fig. 2 Pressure contour of steady flow for SST

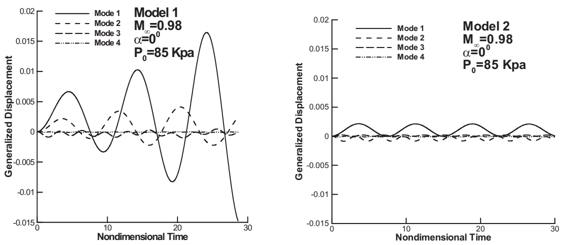

Fig. 3 Dynamic responses of generalized displacement for Model 1 and 2 at $M_\infty = 0.98, \alpha = 0^0, P_0 = 85Kpa$

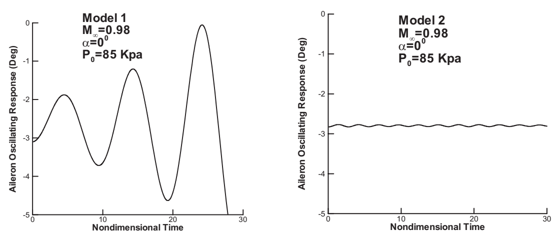

Fig. 4 Dynamic responses of aileron oscillation for Model 1 and 2 at $M_\infty = 0.98, \alpha = 0^0, P_0 = 85Kpa$

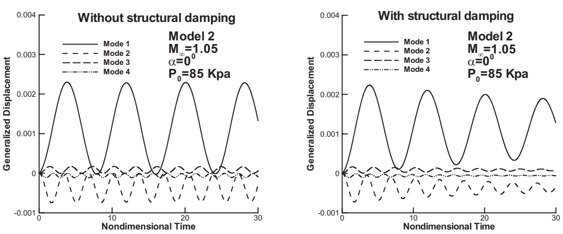

Fig. 5 Dynamic responses with and without structural damping for Model 2 at $M_\infty = 1.05, \alpha = 0^0, P_0 = 85Kpa$

References

[1] M. A. Potsdam and G. P. Guruswamy, AIAA-2001-0716, 2001.
[2] A. S. F. WONG, H. M. Tsai, J. Cai, Y. Zhu and F. Liu, AIAA-2000-1002, 2000.
[3] G. W. Yang and S. Obayashi, Aeronautical Numerical Simulation Technology Symposium 2001, Tokyo, June, 2001.

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