

# AEROELASTIC SIMULATIONS OF COMPLICATED CONFIGURATION USING OVERSET UNSTRUCTURED CFD SOLVER

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**Keywords:** aeroelastic simulations, CFD

**Abstract:** This paper describes that a new aeroelastic simulation code based on the unstructured CFD solver is developed. Computations are performed for AGARD 445.6 wing model and BSCW wing model. The Flutter boundary predicted by the developed code are presented and compared with the experimental data.

## 1 INTRODUCTION

Air traffic in worldwide is predicted to increase considerably over the next decades. By 2034, both air passenger traffic and air freight traffic are expected to more than double, compared to 2016. Passenger traffic is expected to reach over 14 trillion RPKs with a growth of 4.5 per cent per annum, and freight will expand by 4.2 per cent annually over the same time period, to 466 billion FTKs [1]. It is essential to establish technology to realize efficient and speedy development of aircraft. JAXA has been promoting a research program to build a multidisciplinary integrated simulation platform from 2018. This program is aimed at enabling sophisticated look ahead designs that can be used with full flight envelopes as well as cruise conditions currently used in aircraft design. In this program, the development of simulation technology and the acquisition of validation data on the following themes: (1) high/Low speed buffet prediction, (2) flutter prediction, (3) outside aircraft/cabin noise prediction, (4) water spray prediction, (5) control effectiveness and dynamic stability prediction and (6) Reynolds number effects prediction.

JAXA has been developing a fast unstructured flow solver FaSTAR [2]. FaSTAR solves the full Navier-Stokes equations using a cell-center finite volume method. The Harten-Lax-van Leer-Einfeldt-Wada (HLLIW) method [3] used for numerical flux computations. The spacial accuracy is second order with the Unstructured Monotonic Upstream-centered Scheme for Conservation Laws (U-MUSCL) method [4]. The gradients are computed with GLSQ method (a hybrid method of Green-Gauss and Least-Square) [5] and Hishida's limiter (a Venkatakrishnan-like limiter that is complementary with difference of neighboring cell size) [6]. The viscous terms are evaluated by edge-normal scheme. For time integration, the Lower/Upper Symmetric Gauss-Seidel (LU-SGS) implicit method [7] with a preconditioning method is used in order to avoid the stiffness problem associated with solving low Mach number flows using compressible

flow solvers. As for the turbulence model, Sparlart-Allmaras model (SA) [8] and Menter's shear stress transport k-omega model (SST) [9] can be used.

In recent yeas, in order to meet the needs for fluid analysis around moving/deforming body problems, FasTAR-Move which is an overset unstructured CFD code has been developing based on FaSTAR. The objectives of developing FaSTAR-Move are to enhance the current CFD capability for moving/deforming body problems and to establish basic technologies for aircraft development. FaSTAR-Move uses the unstructured overset grids to compute a fluid flow and an equation of motion around complex geometries. Due to the implementation of Alternating Digital Tree (ADT) algorithm [10] and the parallelization of the hole-cut process, the computational time for the hole-cut process which was a critical problem in the overset process could be shorten. FaSTAR-Move has been successfully applied to a store separation problem and showed reasonable results. This paper presents the modification of FaSTAR-Move for the aeroelastic simulations and the results of validation.

## 2 MODIFICATION FOR AEROELASTIC SIMULATION

The aeroelastic equations are needed to solve the dynamic aeroelastic problems. The following subroutines are added to FaSTAR-Move; (1) read the vibration characteristics, (2) calculate pressures on the surfaces, (3) solve the aeroelastic equations, (4) move surface grids, (5) move spatial grids. The subroutines from (2) to (5) are used in each time step. The governing aeroelastic equations motion are solved using the modal approach. These equations of motion are derived by assuming that the deformation of the body under consideration can be described by a separation of variables involving the summation of free vibration modes weighted by generalized displacements. The time integration of the governing equations is employed the Wilson's theta method.

The non-dimensional form of aeroelastic equations for modal method is as follows:

$$\ddot{q}_i + 2\xi_i k_i \dot{q}_i + k_i^2 q_i = \frac{l_0^3 Q_\infty}{m_i a_\infty^2} \iint_S (\Delta C_p + C_f) n \Phi_i dS \quad (1)$$

which  $q_i$  is generalized coordinates,  $\xi_i$  is Structural damping,  $k_i$  is reduced frequencies,  $l_0$  is reference length,  $Q_\infty$  is dynamic pressure,  $m_i$  is generalized mass,  $a_\infty$  is sound of speed  $n$  is unit vector,  $\Phi_i$  is eigenvectors,  $i$  is mode number.

When the above equations are solved, new body surface grid points are determined.

$$\mathbf{x}_S^{\text{new}} = \mathbf{x}_S^0 + \sum_{i=1}^{\text{mode}} q_i \Phi_i \quad (2)$$

The spatial grid points are determined by inverse distance weighted interpolation.

$$\mathbf{x}^{\text{new}} = \mathbf{x}^0 + w \Delta \mathbf{x}_S \quad (3)$$

which,  $\mathbf{x}_0$ ,  $\Delta \mathbf{x}_S$  and  $w$  are non deformed grid points, moving distance of nearest grid points on body surface and weighted function determined according to the distance from the body surface, respectively.

### 3 RESULTS

#### 3.1 AGARD 445.6

AGARD 445.6 wing model [11] is used for the validation of modified FaSTAR-Move. This wing model is widely applied to validate the flutter prediction. This wing is a semispan model made of the NACA 65A004 airfoil that has a quarter-chord sweep angle of 45 degree, a panel aspect ratio of 1.65, and a taper ratio of 0.66. It was tested in the Transonic Dynamics Tunnel at NASA Langley Research Center. Figure 1 shows the surface grid which is generated using HexaGrid [12]. The number of grid points of around wing grid and background grid are 1.2 million and 3.4 million.

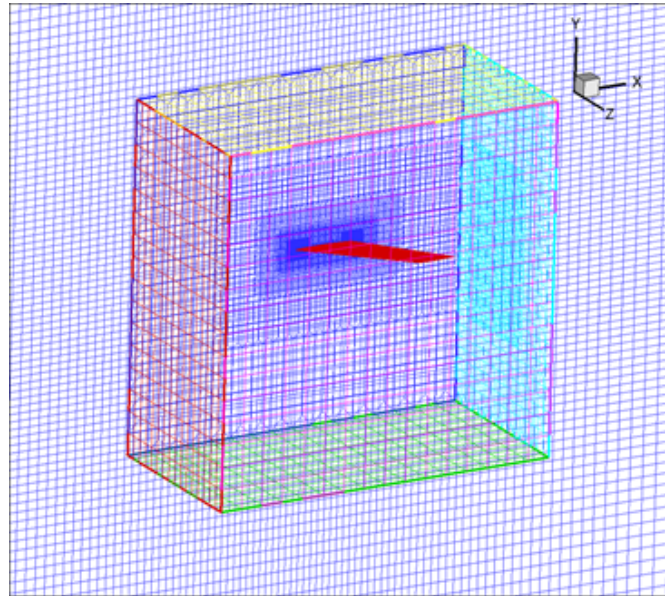


Figure 1: Computational grid around AGARD 445.6 wing model.

The mode shapes are interpolated to the surface grid using Thin Plate Spline method [13] from FEM model. The interpolated surface grids are shown in Figure 2. Up to 10th mode were used for aeroelastic simulations. Figure 6 show the results of flutter simulation at Mach number 0.678. The damping ratio is calculated from these results and the flutter boundary is determined. Figure 4 shows the comparison of simulated and experimental flutter boundary. The results of the predicted flutter boundary agree well with the wind tunnel experimental results.

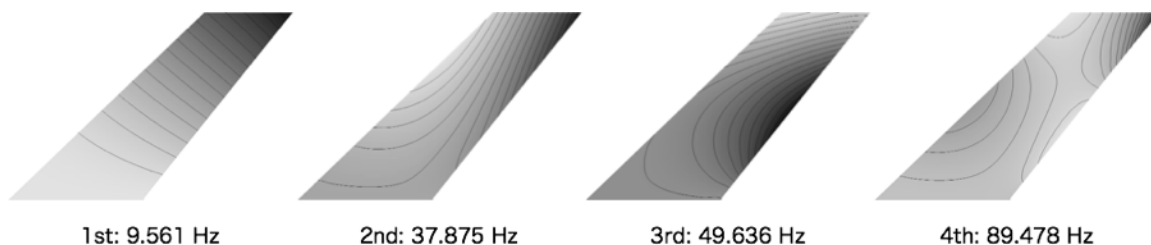


Figure 2: Vibration characteristics of AGARD 445.6 wing model.

#### 3.2 Benchmark Supercritical Wing

The Benchmark Supercritical Wing (BSCW) model was chosen the AIAA Aeroelastic Prediction Workshop [14]. This model has a rectangular planform with a NASA SC(2)-0414 airfoil [15]. The chord length is 16 inches and span length 32 inches. The wing was designed with the goal of being rigid; the spanwise first bending mode of the wing cantilevered at the

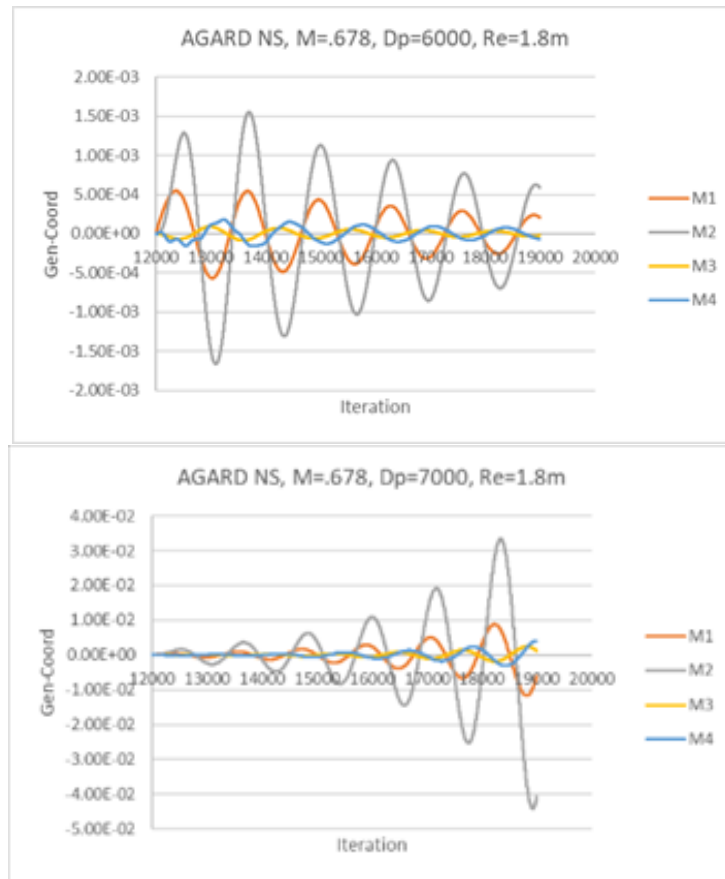


Figure 3: Time history of generalized modal displacements.

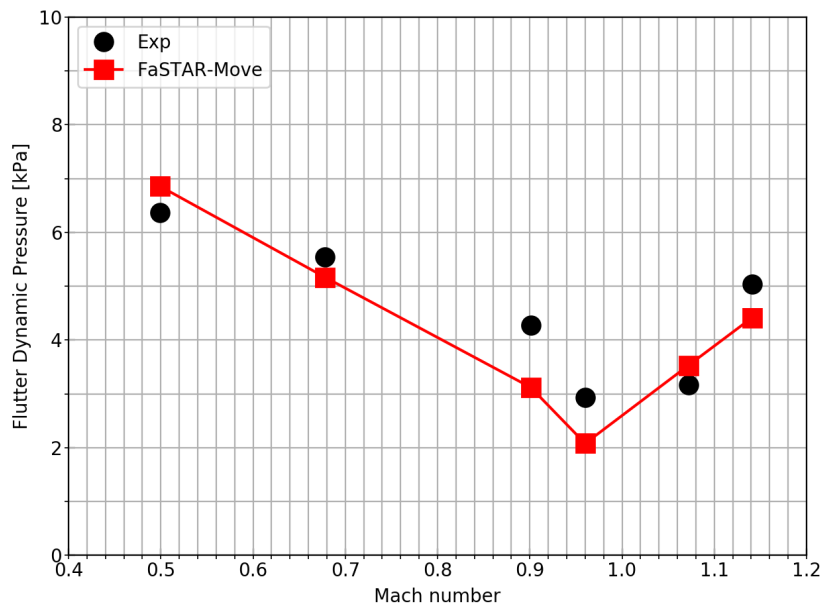


Figure 4: Flutter boundary of AGARD 445.6 wing model.

30% chord of the wing root has a frequency of 24.1 Hz, the in-plane first bending mode has a frequency of 27.0 Hz and the first torsion mode has a frequency of 79.9 Hz. The flexible modes that will be modeled in the current effort are provided through the flexible mount system. Figure 5 shows the surface grid which is generated using HexaGrid. The number of grid points of around wing grid and background grid are 1.4 million and 3.4 million.

Figure 6 show the results of flutter simulation at Mach number 0.85 and Reynolds number 4.13 million.

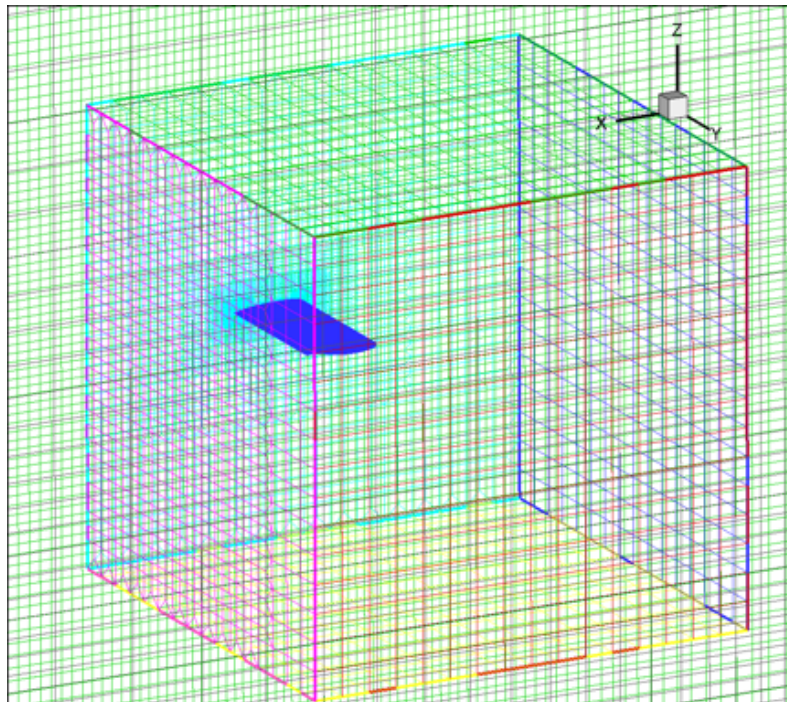


Figure 5: Computational grid around BSCW wing model.

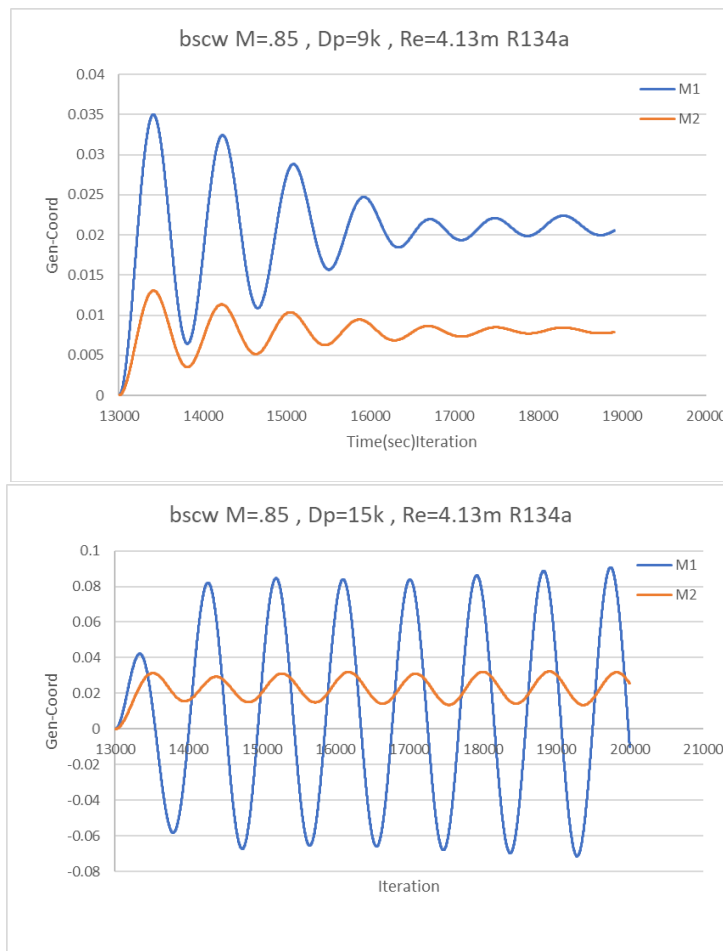


Figure 6: Time history of generalized modal displacements.

#### 4 CONCLUDING REMARKS

A new aeroelastic simulation code based on FaSTAR-Move is developed and validated using AGARD 445.6 wing model and BSCW wing model. The results of the predicted flutter boundary of AGARD 445.6 agree well with the wind tunnel experimental results. For the future, the unsteady aerodynamics will be validated using the results of Aeroelastic Prediction Workshop and other experimental results.

#### 5 REFERENCES

- [1] ICAO (2016). Icao long term traffic forecasts. <https://www.icao.int/safety/ngap/NGAP8%20Presentations/ICAO-Long-Term-Traffic-Forecasts-July-2016.pdf>.
- [2] Hashimoto, A., Murakami, K., Aoyama, T., et al. (2012). Toward the fastest unstructured cfd code "fastar". In *50th AIAA Aerospace Sciences Meeting*, AIAA Paper 2012-1075.
- [3] Burg, C. O. (2005). Higher order variable extrapolation for unstructured finite volume rans flow solvers. AIAA Paper 2005-4999.
- [4] Obayashi, S. and Guruswamy, G. P. (1995). Convergence acceleration of a navier-stokes solver for efficient static aeroelastic computations. *AIAA Journal*, 35(6), 1134–1141.
- [5] Shima, E., Kitamura, K., and Haga, T. (2013). Green-gauss/weighted-least-squares hybrid gradient reconstruction for arbitrary polyhedra unstructured grids. *AIAA Journal*, 51(11), 2740–2747.
- [6] Hishida, M., Hashimoto, A., Murakami, K., et al. (2011). A new slope limiter for fast unstructured cfd solver fastar. Tech. Rep. JAXA-SP-10-012, JAXA.
- [7] Men'shov, I. and Nakamura, Y. (1995). Implementation of the lu-sgs method for an arbitrary finite volume discretization. In *9th Japanese Symposium on CFD*.
- [8] Spalart, P. R. and Allmaras, S. R. (1992). A one-equation turbulence model for aerodynamic flows. In *30th Aerospace Sciences Meeting and Exhibit*, AIAA Paper 92-0439.
- [9] Menter, F. R., Kuntz, M., and Langtry, R. (2003). Ten years of industrial experience with the sst turbulence model. In *Turbulence, Heat and Mass Transfer IV*.
- [10] Roget, B. and Sitaraman, J. (2010). Robustness and accuracy of donor search algorithms on partitioned unstructured grids. In *10th Symposium on Overset Composite Grids and Solution Technology*.
- [11] Yates, Jr., E. C. (1989). Agard standard aeroelastic configurations for dynamic response. Nasa tm-19246, NASA.
- [12] Hashimoto, A., Murakami, K., Aoyama, T., et al. (2010). Drag prediction on nasa crm using automatic hexahedra grid generation. AIAA Paper 2010-1417.
- [13] Smith, M. J., Hodges, D. H., and Cesnik, C. E. S. (2000). Evaluation of computational algorithms suitable for fluid-structure interactions. *Journal of Aircraft*, 37(2), 282–294.
- [14] Heeg, J., Chwalowski, P., Schuster, D. M., et al. (2015). Plans and example results for the 2nd aiaa aeroelastic prediction workshop. In *56th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, AIAA Paper 2015-0437.

- [15] Dansberry, B. E., Durham, M. H., Bennett, R. M., et al. (1993). Physical properties of the benchmark models program supercritical wing. Tech. Rep. NASA TM 4457, NASA.

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