Fluid Structure Interaction Method with Artificial Neural Network Interpolation for Light Aircraft Design

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Abstract

Fluid-Structure Interaction (FSI) analysis is a multi-disciplinary analysis involving the fluid and structure domain. The research analyzed the static fluid-structure interaction of KLA-100, two-seat light aircraft sponsored by Korea government during critical loading. The aerodynamic analysis during critical load condition of KLA-100 aircraft was performed using ANSYS Fluent. It was validated by wind tunnel experiment results. By performing the aerodynamic analysis, pressure distribution on wing surface can be measured. The pressure distribution obtained from CFD analysis was interpolated by using Artificial Neural Network method in order to interpolate the pressure distribution into structural nodes. ANN method was used as an interpolation tool in this research after passing a validation of methods. Structural analysis was performed in MSC Patran – MD Nastran by using the interpolated pressure distribution as input forces. The displacement from structural analysis then transferred to CFD grid. The FSI analysis process then repeated until the difference of displacement converged.

1. Introduction

KLA-100 is a two-seat, low wing VLA aircraft with a 620 kg maximum takeoff weight powered by a 100 hp Rotax engine which has been developed by Konkuk university and other 12 Organizations under Korean government project named The Light Aircraft Development Program.

This thesis addresses the Fluid-Structure Interaction analysis of KLA-100 aircraft. This FSI is required to calculate the structural strength when the aircraft is in operation.

FSI analysis process in this research is a two-way analysis with loosely coupled method. The analysis started with load analysis, and then continued with computational fluid dynamic based on critical load condition. The next step is interpolation using Artificial Neural Network method to transfer the pressure distribution on the fluid grid to structure nodes. This FSI process is an iteration process. The iteration is over when the difference in displacement converges.

2. Fluid Structure Interaction Method

In fluid structure interaction (FSI) analysis, fluid and structure problem coupled by scheme to determine interaction between two models. This coupling scheme is important part of FSI analysis.

To solve a coupled fluid structure problem it is not sufficient to be able to compute the solution of the structural and the aerodynamic model separately, it is also necessary to exchange information between the two models: the modification of boundary conditions must be transferred from the deformable structure to the aerodynamic boundary, and conversely, the loads developed in aerodynamic field must be applied to the discretized structural model. The way of using the information exchange during a time integration or a frequency domain simulation gives rise to further distinctions in the class of partitioned methods among explicit or implicit coupling, “weak” or “strong” coupling.

2.1 Weakly Coupled Fluid Structure Interaction

Two different solvers which use different computational grid are used in weakly coupling method in order to get the solution of fluid and structure problems. Because of difference in computational grid, generally fluid and structure gri ds do not coincide. In this case a method to transfer information from fluid to structure and vice versa is needed.

Weakly coupling method gives flexibility in choosing solver for fluid and structure problem. While this method can give advantage in selecting appropriate solver in CFD and FEM, it also comes with disadvantage which accuracy of d ata transfer between fluid and structure problem can be reduced.

2.2 Strongly Coupled Fluid Structure Interaction

Strongly coupling method is an advanced Fluid Structure Interaction analysis method. Structural and fluid equations are combined into a single set of governing equations which are solved in single iteration loop. This process is worki ng simultaneously in order to get accelerated convergence rates and more stable solutions.
The disadvantage of this coupling method is computational difficulties during the solution process because a Lagran gian and an Eulerian system should be solved together.

2.3 Artificial Neural Network for Interpolation

Two different solvers which use different computational grid are used in weakly coupling method in order to get the solution of fluid and structure problems. Because of difference in computational grid, generally fluid and structure grids do not coincide. In this case a method to transfer information from fluid to structure and vice versa is needed. This process is to connect the data between CFD and FEM analysis.
In this research, Artificial Neural Network (ANN) was used for interpolation. ANN is a computational model that mimics a biological central nervous system, especially the brain system. This model is designed to solve any computational problems. It based on simulated neurons, which are joined together in a various ways to form a network.
In this research process, feed-forward back-propagation ANN algorithm is used. Feed-forward mechanism is used to calculate the output. Back-propagation algorithm is used to reduce the error during the weights calculation.

3. KLA-100 FSI Analysis

Weakly coupled two way FSI method was employed for KLA-100 FSI analysis. In order to start an analysis, input files for fluid solver and structural solver must be prepared. The process is begins with load analysis.
Load analysis is performed to obtain critical load condition of the aircraft based on the certification. The critical load condition then used as input condition of computational fluid dynamic analysis on ANSYS Fluent. For the fluid flow problem solution domain must be generated in ICEM and should be transferred to FLUENT. After the fluid domain is imported to FLUENT, case and data file including flight conditions and solver types are generated. Also the user defined function that will be used for mesh deformation process is compiled for FLUENT. For the structural problem geometry in Patran and Nastran script is prepared likewise.
The first step in the FSI simulation loop is the solution of fluid flow. The case and data files generated before for rigid, steady state conditions are now ready to be solved by FLUENT. After the convergence criterion determined for FLUENT is met, solution is terminated and pressure distribution at the fluid-structure interface is exported to a file.
Since different grids are used for structural and fluid flow problems, nodes at the interfacing boundaries do not coincide. Using the ANN method described before, nodal pressure values are interpolated from the file exported from FLUENT in the previous step to structural grid, which is written in a separate file after the interpolation is completed.
The interpolated pressure value is used as the input load for PATRAN geometry. By using NASTRAN structural problem is solved. The result from structural analysis is wing displacement. This displacement then becomes input for CFD re-mesh to do next iteration. In structural analysis part, nodes displacement is used as the initial displacement for next iteration.

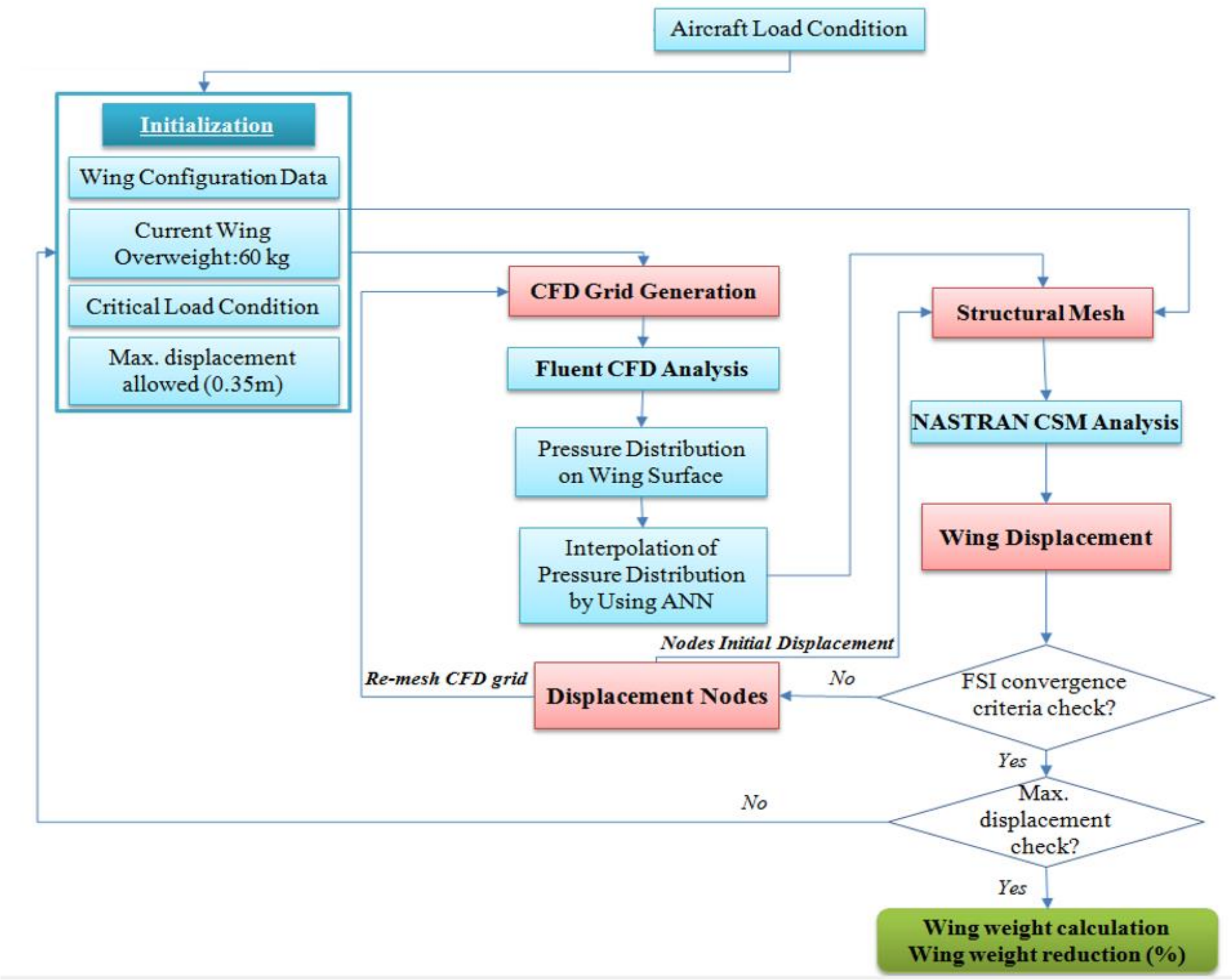

Figure 1 - FSI analysis process for KLA-100

FSI analysis will stop when the convergence criteria met. Convergence criteria used in this research is as follows.

$$\frac{\|u_s^{i+1}-u_s^i\|}{\|u_s^1\|} = \varepsilon \tag{1}$$

3.1 CFD Analysis

The aerodynamic analysis in ANSYS Fluent was performed and CFD mesh was deformed when the wing has displacement on structural analysis.

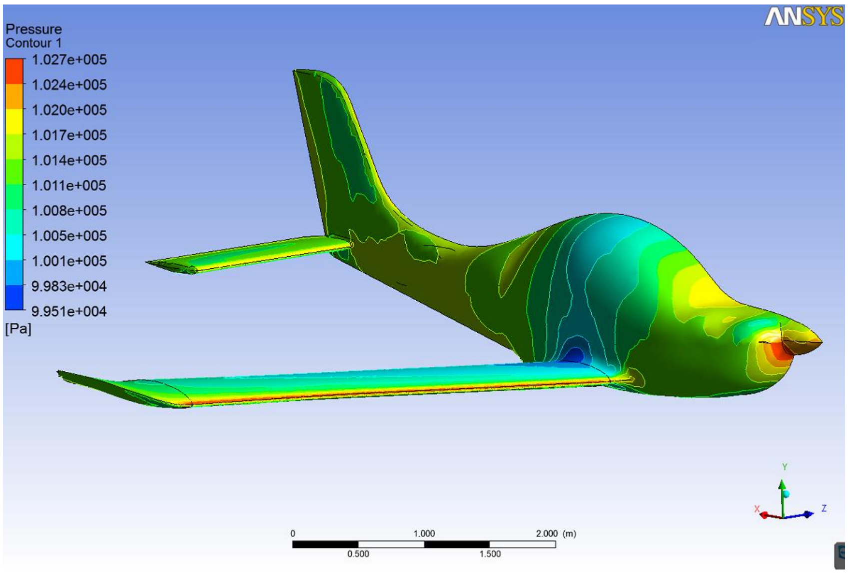

Figure 2 - CFD result of pressure distribution over KLA-100 surface

3.2 Structure Analysis

Structural analysis part of Fluid-Structure Interaction (FSI) analysis for KLA-100 aircraft is performed by MSC Patran – MD Nastran software. The model of aircraft structure was built in MSC Patran based on the geometry data of the aircraft. External structural force comes from aerodynamics coefficient of pressure distribution which has been interpolated to structural nodes from aerodynamics grid.

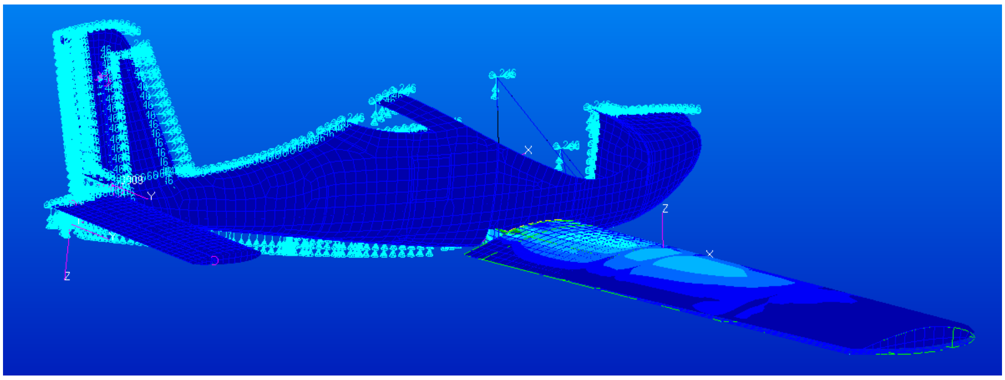

Figure 3 - KLA-100 structure analysis result

3.3 FSI Result

The result of KLA-100 FSI analysis shows a good trend to a convergence result. The Artificial Neural Network can interpolate the pressure from CFD into FEM nodes smoothly.

The FSI process in this thesis was performed in seven iterations. The second CFD and structural analysis was performed on the deformed model. CFD analysis wass performed on the new mesh and the pressure from this analysis was interpolated to FEM nodes, same process with the first iteration.

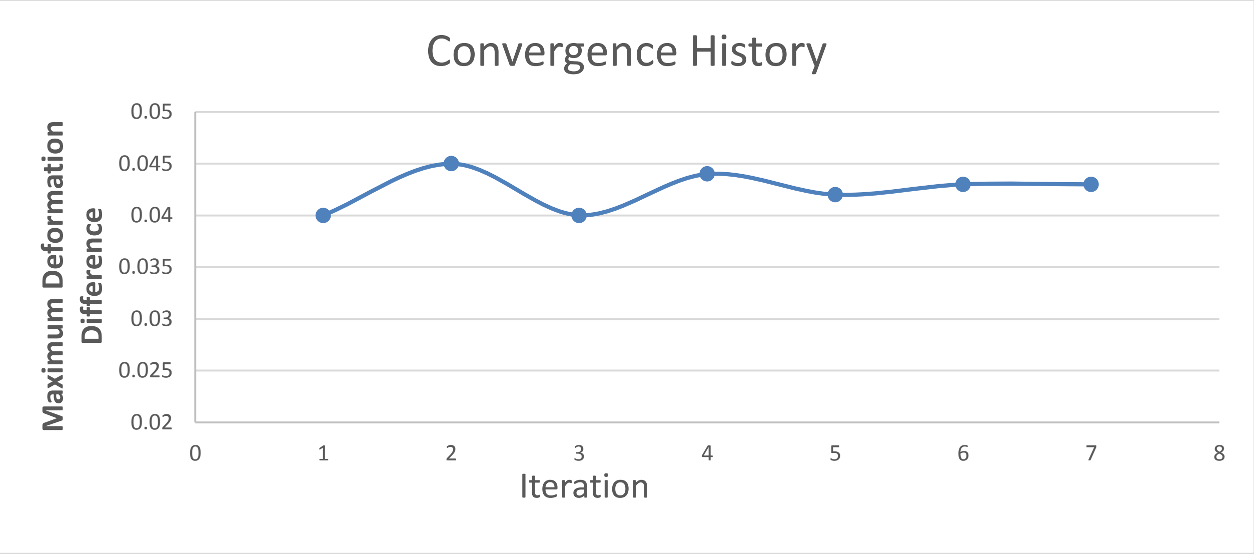

Figure 4 - Maximum deformation difference in each iteration

4. Conclusion

Fluid-Structure Interaction analysis has been performed on the wing of KLA-100 aircraft. Artificial Neural Network is used to model and interpolate the pressure from CFD nodes into FEM nodes on PATRAN.

FSI process in this thesis was performed in seven iterations. It can be seen that the difference of maximum displacement was decreased in every iteration. This result showed a good trend of the structural displacement. The convergence of FSI analysis process was reached at 0.3044 m maximum displacement.

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