MULTI-DISCIPLINARY OPTIMIZATION FOR WING FLAP CONSIDERING NOISE AND LIFT BASED ON GRID TECHNOLOGY

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Abstract

Bilateral Research and Industrial Development Enhancing and Integrating GRID Enabled Technologies（BRIDGE） project has been developed and put into operation under the EU project. The goal for aerospace application is to optimize an airplane wing flap position for low noise and high lift during aircraft landing situation.

In this project, several simulation optimizers have been developed as Grid services deployed in different locations form Europe to China. EADS provides the Acoustic Simulation Service, executing on an EADS cluster. AVIC provides three services including Unsteady-aerodynamic, aero-elastic, simulation, and genetic algorithm optimization in China. A Meta Modeling service from FhG-SCAI is running in Germany. A workflow management OPTIMUS, provided by LMS, is adopted to establish the workflow. The Grid platforms are created by integrated European Grid middleware GRIA and Chinese Grid middleware CNGrid GOS by Southampton University and BUAA.

BRIDGE project has fulfilled its objectives. The EU final review report gives the following conclusion: "The project was very successful and achieved all its goals."

1 General Introduction

In commercial field, the environment is become a issue in recent years. One target is to reducing the airfield noise. The airframes noise during landing procedure has become the main noise source more than engines noise in commercial airplane. A CFD simulation is showing the results.

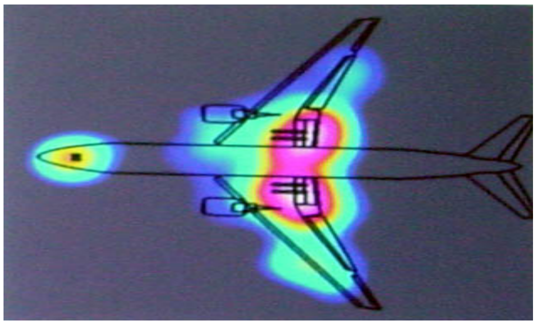

Fig.1. Noise Distribution during Aircraft Landing Procedure

The BRIDGE project aims at demonstrating the benefit of Grid Technology for international co-operation, especially between Europe and China. The goal of these Grid research activities is focused on developing the technology and infrastructure which can enable effective sharing of distributed resources and cooperative work on the scope of Internet.

The aims of the Work Package(WP)2 Aerospace Applications work package is to set-up and demonstrate in operation a distributed workflow for optimization that includes at least two simulation modules. A total of five GRID Service will be located and computed in different sites, three of the Services being located in the EU, while two Services being located in China.

1.1 Structure Noise for Landing Procedure

The airframes noise is caused by landing gear, flap and the interference between wing and fuselage. This research concentrates on optimization of the flap position to reduce the noise and to keep the wing lift.

1.2 The Application Scenario

In this application scenario, the two group flap axis positions and flap deflection angles are defined as design variables. The optimization is in two disciplines : aero-elastic influenced wing lift and unsteady aerodynamic influenced the ground aero-noise. The optimization is based on the services oriented architecture (SOA) provided by all partners from EU and China [3].

Fig. 2. WP2 Application Scenario

1.3 The Challenge for Optimization

It is the first time for us to face the complicated optimization objective which concerns both aerodynamic and structure characteristics. The wing with flaps aerodynamic models related to each flap position and angles are needed for the unsteady aerodynamic CFD simulation and used for acoustic simulation; the wing with flaps structure models are needed to support the aero elastic simulation for wing lift analysis. Auto-modeling tool is developed to establish the mesh.

All application services are provided by deferent partners; all services only need providing I/O data format to partners. The system will be running in EU and China's Grid Platforms to complete the optimization. The optimization running time will be around two weeks for each procedure; there is strong robust and stable requirement for the system as well as the grid platform.

2. Optimization System

2.1 Optimization Process

Acoustic simulation needs to import data from unsteady aerodynamic CFD simulations; which need 30 thousand step CFD simulations and takes 5 days in a 16-CPU cluster. The acoustic simulation time is also need 3 days for each case. To create and to use an acoustic Meta Model related with flap position/angle for optimization is necessary.

A Genetic Algorithm Optimization system (GAO) has been improved for this project. The optimization process workflow consists of two parts: creating an acoustic Meta model and running the two discipline optimization process.

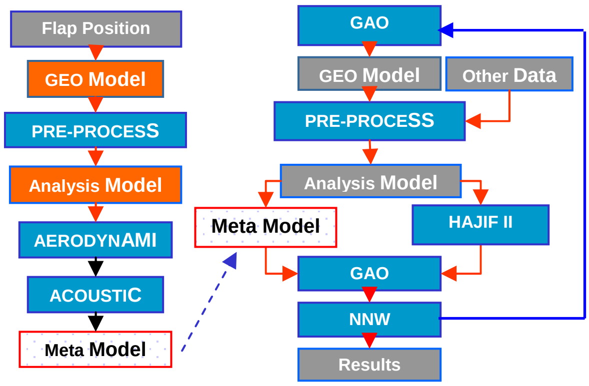

Fig. 3. Processes workflow for Creating Acoustic Meta Model and for Optimization

2.2 Auto Modeling Tools

Two Auto-modeling tools have been developed for aerodynamic modeling and structure modeling with different flap positions/angles. This tool could create FEM simulation model automatically and CFD mesh model semi-automatically from CATIA model with given flap axis positions/angles. The FEM simulation models can quickly be created from GAO population data. The CFD simulation models are built semi-automatically when the acoustic Meta Model is set up.

2.3 Unsteady Aerodynamic Simulation

The project uses unsteady aerodynamic CFD (Navier-Stokes Equation) software developed by China partner. Unsteady aerodynamic CFD simulation is step-by-step following the time domain for creating the wing flow field pressure fluctuation. The fluctuation pressure is transformed to dipole and monopole items by Ffowcs Williams-Hawkings (FW-H) equation and the results are sent to acoustic simulation. The simulation is running in 360-CPU cluster supported by Grid platform. It has been continuously running for 4 months to create the 100 flap positions/angles with pressure distribution in this project, which will be provided to EADS for acoustic simulation and acoustic simulation results are delivered to FhG-SCAI for creating Meta model.

2.4 Acoustic Simulation

The acoustic simulation system is derived from air noise simulation software developed by EADS in France. The simulation input data is the flow field pressure distribution dipole monopole items from the unsteady aerodynamic simulations. A flow field mesh for acoustic simulation will also be created. The simulation is running in EADS cluster supported by the grid platform. The simulation has taken 2 months to get the acoustic results for FhG-SCAI to create the Meta Model in Germany.

2.5 Meta Model for Acoustic Simulation

FhG-SCAI has created the acoustic Meta Model using EADS acoustic results and flap positions/angles. The software tool developed by FhG-SCAI called DesParO, which can create high accuracy response surface for simulation. The Meta Model running in Germany cluster provides the acoustic simulation service for GAO.

2.6 Genetic Algorithm Optimization

GAO was developed by AVIC in 1990's and improved in this project. It is very useful for complex variable optimization and multi-disciplinary optimization. It also can be running in SOA and Grid Platform to using distributed application services around EU and China. In BRIDGE project, GAO is integrated into a work flow management system OPTIMUS to receive the right data, to invoke corresponding services, and to deliver the Genetic Algorism Population (200 flap positions) to its destination service running in EU and China though Grid Platform, than to get the results back to GAO for next loop (15 loops for one step). One complete optimization needs 140 thousands executions of the services across the platform.

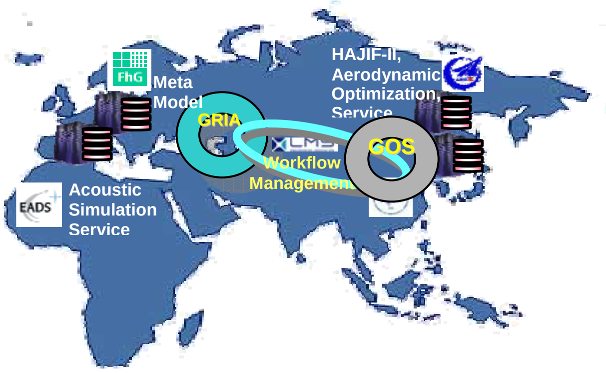

Fig. 4. GAO Optimization Is Running All Services in EU-CHINA Grid Platform

2.7 OPTIMUS Workflow Management

The OPTIMUS software is an efficient workflow management tool developed by LMS for integrating optimization and the workflow engine is operating all services through the Application Program Interface (API) in Grid platform. It has developed a double-loop workflow function application for GAO optimization in BRIDGE project, as shown in Fig 5.

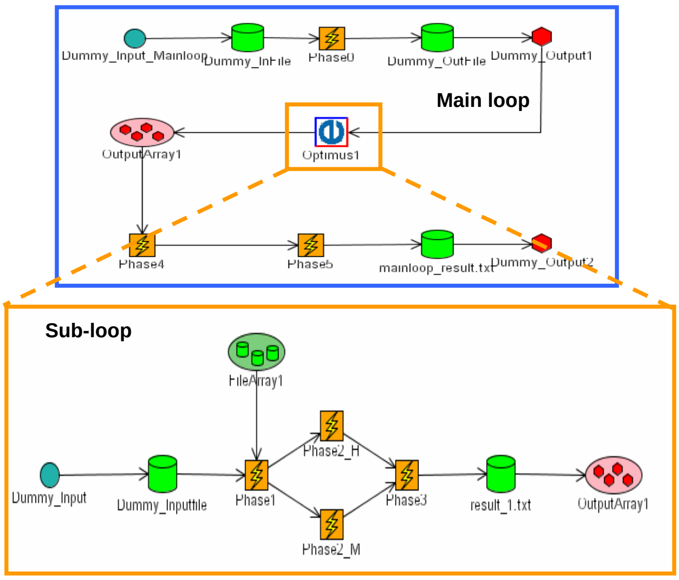

Fig. 5. Double Loop Workflow for Acoustic Optimization in BRIDGE Project

2.8 Grid Platform

The BRIDGE developed an interoperable intercontinental Grid infrastructure enabled by GOS and GRIA. Here GRIA is a European gird middleware and GOS is a grid middleware developed in China. This joint platform supports sharing of resources in both EU and China effectively and provides secure and manageable distributed workflow for optimization applications.

GOS and GRIA are grid middleware which provide access to data and services in the grid environment. There are some differences in their design principles and implementation strategies. Works on interoperability are needed to make these two software systems interoperable. A gateway-based scheme, together with the workf low-level service invocation between two systems using standard interface, is adopted, which enables GOS and GRIA to work jointly. The interoperability efforts include

- An adaptor between GRIA and GOS services is developed and added to GRIA and GOS, respectively. Standardization at the service level is defined. A gateway between GRIA and GOS services is developed to achieve interoperation between these two grid middleware.
- Interoperability issues on data storage, data access, process state management, resource and capacity management, resource discovery, and meta-scheduling are addressed and solutions are developed according to the application requirements.

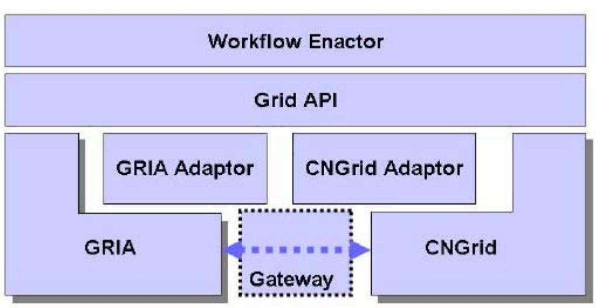

Fig. 6. General Approach to Achieve Interoperable Grid Infrastructures

2.9 System Architecture

The architecture of our optimization system consists of five layers including Interface, Optimization, Platform, Service Resources, and Heterogeneous OS. The grid platform layer includes the joint grid platform and APIs for invoking the lower level services. The optimization layer is the main body of the system which consists of the workflow-enabled GAO program and the workflow engine. The interface layer is provided by OPTIMUS integrated user interface.

The system is built upon heterogeneous operating systems such as Linux and Windows which host different services provided by different partners of BRIDGE.

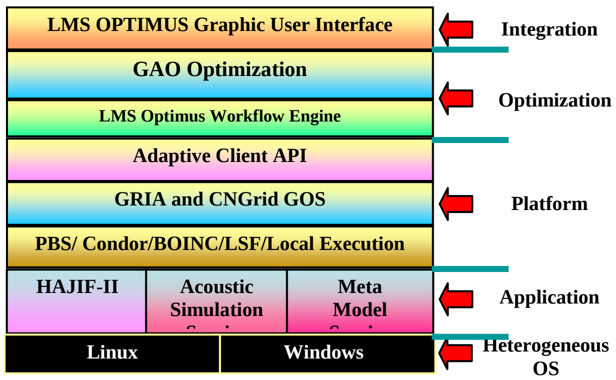

Fig. 7. BRIDGE System Architecture for Simulation and Optimization

3. Optimization Results

3. 1 System Operation

The flap positions/angles optimization for acoustic and lift has been performed on the platform for 3 times and got very close results. Each optimization consumes 140 thousands loops inner loops and takes about 14 days (350hours). The experiments show that both the system and Grid Platform are quite robust and exhibit good performance. The system has never encountered reliability problems during the operation.

3.2 Simulation Process

The simulation consists of two steps: creating a Meta Model and performing optimization on flap positions/angles for reducing the noise.

3.2.1 Create the Meta Model

AVIC, EADS and FhG-SCAI have jointly developed the acoustic Meta Model related flap positions/angles, which has taken 6 months hard work based on large number simulation cases in flap position feasible field.

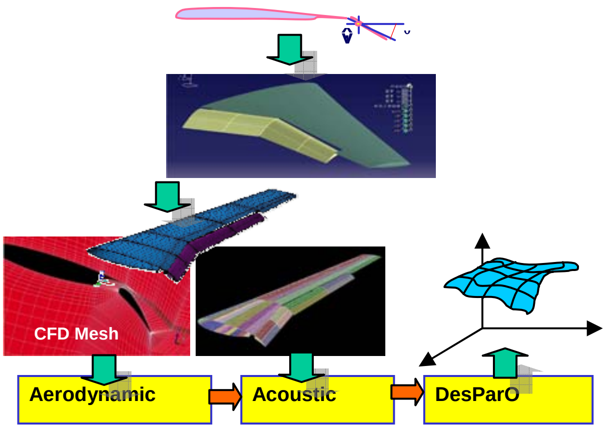

Fig.8. Create Acoustic Meta Model

3.2.2 Optimization

The GAO is Genetic Algorithm Optimization software [6] with Neuron-network function developed by AVIC, which is running with Meta Model and aero-elastic service together to get lower noise and keeps lift increasing, as shown in Fig 9.

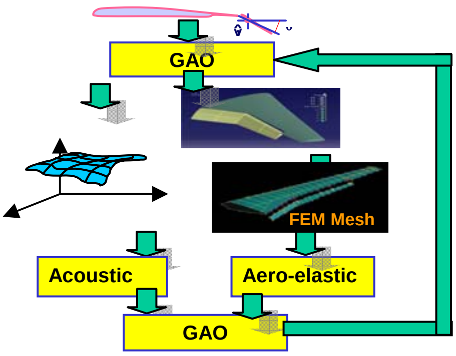

Fig.9. GAO Optimization Process

3.3 Simulation Results

The final optimized results reveal that reducing noise 2.37db and increasing lift(Δ Cy) about 0.0056 in comparison to original flap positions/angles, as shown in Fig 10. The optimization results generated by the outer loop steps of the optimization are shown in Fig 10 as the noise reducing curve and the lift increase curve.

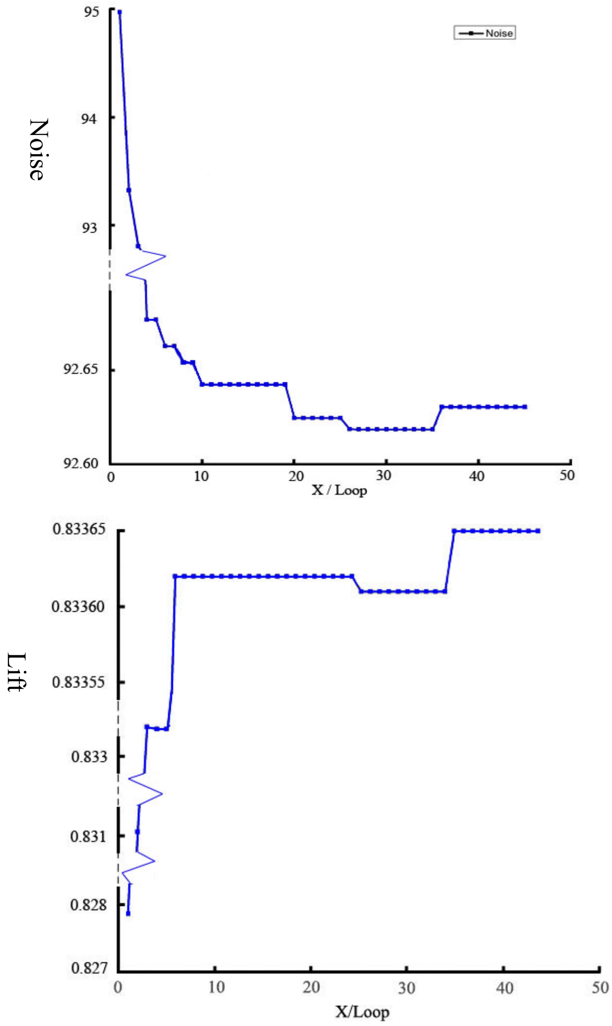

Fig.10. Optimization Results of Noise Reduction and Lift Increasing

4. Conclusion

Under the support of the BRIDGE project, our aircraft noise optimization system has been successfully developed. Access to optimization services distributed in different locations of Europe and China has been enabled by the joint EU-China grid platform. The main optimization program GAO is implemented under the support of the workflow system OPTIMUS. The results from the optimization runs prove the robustness and effectiveness of the optimization system. The BRIDGE project has achieved its goal and successfully passed the final review held at ECM WF in Reading, UK. The final review report gives BRIDGE the following remark: "The project has fully achieved its objectives and technical goals for the period and has even exceeded expectations" [3]. "The project was very successful and achieved all its goals" [4].

We are going to work on large design variables optimization for wing aero-elastic tailoring based on the technique foundation of BRIDGE.

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