Abstract of ASME-JSME-KSME Joint Fluids Engineering Conference 2011
AJK2011-FED
July 24-29, 2011, Hamamatsu, Shizuoka, JAPAN

AJK2011-PL003

TOWARD SECOND-ERA OF COMPUTATIONAL FLUID DYNAMICS -FROM THE OBSERVATION FROM THE STUDIES IN AEROSPACE-

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ABSTRACT

1. Introduction

Computational Fluid Dynamics became one of the primary tools for fluid dynamic analysis and design. Numbers of researchers and engineers in academia and industries now use CFD as a tool[1]. CFD obviously replaced certain part of fluid dynamics analysis and design, which had relied only on theories, empirical methods and experiments. This trend will continue and grow as evolutionary effort by the CFD researchers. When practical CFD was initiated in late 70' in aerospace, there was a strong statement that supported CFD activity. The statement not only emphasized replacement of theories and experiments by CFD, but also emphasized that CFD could do more than experiments. When we trace the history of CFD and remember the time of establishment of the CFD basis, we recognize that we still have much to do to make use of the inherent power of CFD[2]. With the aid of strong HPCI (High Performance Computing Infrastructures) having order of 100 TFLOPS to 10 PFLOPS performance, now may be the time to consider new era of CFD as revolutionary effort.

2. Glancing back 30 Years of CFD

In 1977, a workshop named "Computer Requirements for Computational Aerodynamics" was held at NASA Ames Research Center. This workshop aimed for promoting activity of computational fluid dynamics (CFD) in aerospace and supporting large-scale computer facility. Prof. Dean Chapman at Stanford University said, "There are two major motivations behind CFD and that would not change in coming decades" in his keynote speech. The two motivations were, (1) providing an important new technology capability and (2) economics. We may consider both issues have been realized by the fact that CFD in general has become an important analysis and design tool and reduces both cost and time for the product developments. There is, however, some CFD activities hidden under his words that still remained not to be realized. In other words, benefit of CFD has not been well used. For example, we can easily try many types of ideas under virtual computer environment but we do not seem to use CFD as "an innovative design tool". Such is required even though the two motivations given by Prof. Chapman are realized as shown in the research examples to be presented in this plenary lecture. The examples will include, dynamic instability analysis of the reentry capsule of spacecraft "Hayabusa", high-speed Shinkansen and Maglev train developments, design of rocket launching site for the reduction of acoustic waves[3].

Fig. 1 Dynamic instability Analysis of the Hayabusa caplsule

3. Recent Trend –Significance of LES simulations

Prof. Chapman added one more message in his talk; There are many restrictions in the wind-tunnel experiment such as scale effects, wall and support interference, aerodynamic distortion, and else. In Ref. 1, the author emphasized that (1) RANS simulations are useful but those do not capture essential part of physics and therefore do not evaluate "scale effects", and (2) We have to move to LES/RANS hybrid, LES or DNS simulations except limited applications. Even for the discussion of time-averaged flows, it is necessary to conduct unsteady flow simulations with certain space and time resolutions. Prof. Chapman might have considered that CFD could evaluate scale effects by simply changing Reynolds number in the simulation but RANS simulations are not the ones to achieve it. LES type of simulations are necessary not because computer capability has made progress but because those are inevitable for the discussion of physical phenomena and evaluation of aerodynamic performance. Only with such simulations, the speaker believes that CFD can become a tool for an innovative aerodynamic design.

It is true that CFD made remarkable progress and became an important tool for analysis and design. Some people say CFD for basic flows are established and nothing interesting remains. The message here is that CFD has come up to the certain stage but now is the time to move to the second era where CFD plays much more important role.

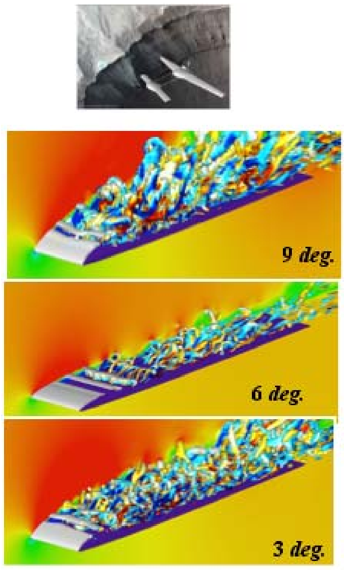
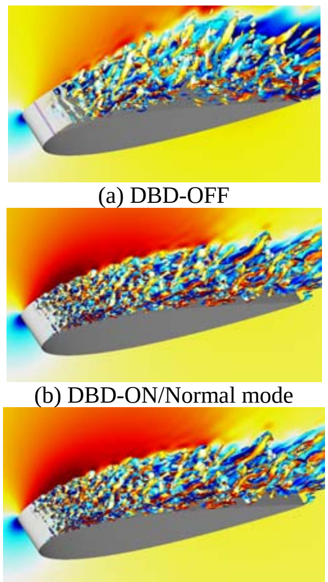


Fig. 2 Mars aircraft: airfoil flow analysis at a low Reynolds number.

As an example, the author's group has been engaged in the development of Mars aircraft surveyor, hoping to propose a small one in the MELOS Mars mission in 2020 or so. In the presentation, some of the CFD effort by the author's group for the Mars aircraft wing/airfoil design which required LES simulations will be presented as an example.

As another example, study for the mechanism of flow separation control by the DBD plasma actuator is presented. It is now well known that DBD plasma actuator is an effective tool that avoids flow separation over a wing surface[4,5] and it works at least in the laboratory level through numbers of experiments. There are also numbers of CFD study, but how the induced flow influences and avoids flow separation is not well understood. The study, with the Grant in Aid financial support 20246122, using LES simulations begins to reveal the flow structures. As suggested in Ref. 6, laminar-to-turbulent flow transition turned out to be the key issue from a series of LES simulations for unsteady flow field over an airfoil. The process of separated flows to attached flows is deeply examined and how two-dimensional spanwise vortices are formed and break up to three-dimensional flow structure is revealed[7].


(a) DBD-OFF

(b) DBD-ON/Normal mode

(c) DBD-ON/Burst mode

Fig. 3 Computed Instantaneous Flow Fields

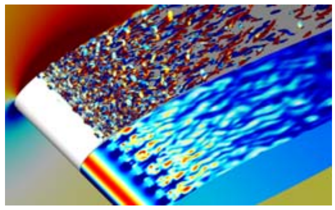


Fig. 4 Effective 3-D DBD plasma actuator layout

Comparison of unsteady flows both for an effective pulsated (burst) mode and an ineffective normal mode showed why burst mode is effective (Fig. 3) for avoiding flow separation.

Based on the observation, the author's group proposed three-dimensional DBD plasma actuator layout virtually in Ref. 8. The results will be included in the presentation.

4. Bridge from Analysis to Conceptual Design

How can we bridge fluid dynamic analysis to conceptual product design using benefits of CFD under the virtual environment? Idea is, of course, necessary, but useful tools for helping the idea may be important. The author's group recently focuses their effort on MOEC (multi-objective evolutionary computation) and MODE (multi-objective design exploration) technique[9-11]. If time allows, the presentation also addresses importance of such approach with the examples of jet acoustics analysis for rocket plumes, wings and others.

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