R & D of CFD Code for Compressible Interdisciplinary Flows (from gas turbine to phase-change technology)

Satoru Yamamoto
Tohoku University

1. Introduction

CFD codes for simulating compressible interdisciplinary flows are being developed in our laboratory. Especially, numerical methods for calculating steady and unsteady flows with complicated physics have been proposed which could not be solved by the existing commercial codes. Unsteady hypersonic flows with thermo-chemical nonequilibrium effects, unsteady condensate flows with homogeneous and heterogeneous nucleations, and magneto-plasma dynamics(MPD) flows have been numerically investigated by each fundamental equations, models, and numerical methods developed by our group. Our CFD group in the department of aeronautics and space engineering has a small-scale super-computer NEC SX-4/2C and our university has a large-scale one SX-4/128C(replaced by SX-7/232C in 2003). Both computers are available for our research.

Here, our recent research works related to flows through gas-turbine cascade and condensate flows are introduced.

2. Gas turbine analysis

One of the main studies in our laboratory originated from my supervisor, Prof. Daiguji, for last two decades has been the simulation of unsteady transonic flows through gas-turbine cascade. We proposed a higher-order and high-resolution finite-difference method based on the fourth-order compact MUSCL TVD scheme(Compact MUSCL)[(1)] and a maximum second-order implicit time-marching method[(2)] for capturing unsteady shock/vortex interactions observed in the gas turbine. As a typical numerical example, we calculated unsteady transonic flows through a 3-D gas-turbine cascade using the high-resolution method[(3)]. Fig.1(a)(b) show the calculated instantaneous Mach number contours at 50% span in the cascade channel. The Compact MUSCL is used for space difference in both cases. The time accuracy is first-order in the case of Fig.1(a), while it is high-order in the case of Fig.1(b) calculated by our method. Normal shocks are sharply captured in both cases because of using the Compact MUSCL. But, the wake behavior is quite different. As shown in Fig.1(b), our method can capture unsteady periodical vortices from the trailing edge of the blade generated by shock/boundary-layer interactions. On the other hand, the wake looks like a stick in Fig.1(a) due to a lack of time accuracy. These results suggest that higher-order accuracy both in space and time may be necessary to calculate unsteady shock/vortex interactions. Another study was conducted as a collaborative research with Toshiba cooperation[(4)]. An optimization of cooling ejection from trailing edge of gas-turbine blade was assisted by our code. Fig.2(a)(b) show the calculated instantaneous Mach number contours with and without the cooling ejection. These figures indicate that a proper mass in the ejection from the trailing edge can weaken the shock/vortex interactions around the blade.

Dept.of Aeronautics and Space Engineering.
Aobayama01, Aoba-ku, Sendai 980-8579, JAPAN
Phone: +81-22-217-6988 Fax: +81-22-217-6988

3. Wet-steam turbine analysis

Recently, the gas-turbine code has been extended to a code for simulating unsteady transonic wet-steam flows through steam-turbine cascade. Additional fundamental equations and condensation models were introduced in the code for taking condensation in account. As one of typical examples, unsteady wet-steam flows through a 2-D steam-turbine stator-rotor cascade were calculated by using the steam-turbine code[(5)]. Fig.3(a)(b) show the calculated instantaneous Mach number and condensate mass-fraction contours, respectively. Unsteady condensation due to nonequilibrium condensation influenced by unsteady wakes from the trailing edge of stator blade is captured in the rotor channel.

4. Current additioinal works

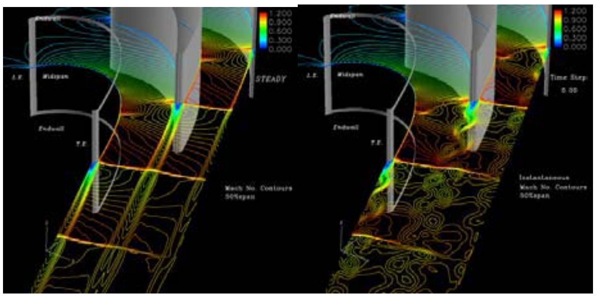
The numerical algorithm for solving condensate flows applied to the wet-steam turbine is further extended to the calculation of vapor trail over aircraft wing. For examples, condensate flows in moist air over 3-D delta wing have been calculated[6]. Fig.4 shows the calculated condensate mass-fraction contours over the delta wing at 0.5 in uniform Mach number. Condensation occurs in a large-scale vortex generated over the delta wing due to the saturation of vapor in it.

Currently, the code for condensate flows is being extended to a code for condensate flows at very low Mach number[7]. The preconditioning approach is employed. Many practical problems related to condensation are known, for, example, chemical vapor deposits, crystal growth, aerosol, meteorology, and so on. Therefore, it is expected that our present work will play an important role in future researches and developments not only for the gas turbine but also for future technologies and sciences related to condensate flows.

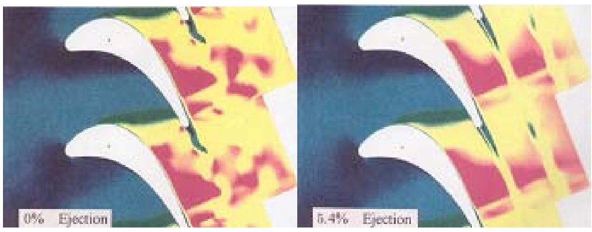
Our research works are introduced in our web site, http://www.caero.mech.tohoku.ac.jp/.

References

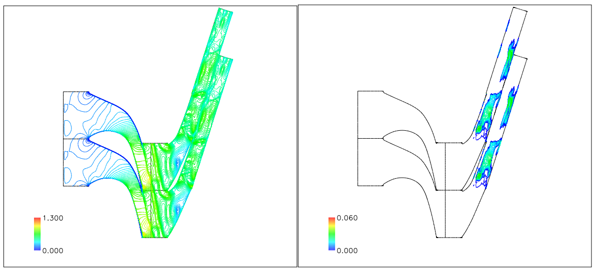
1. Yamamoto, S. and Daiguji, H., Computers and Fluids, 22-2/3(1993), 259-270.
2. Yamamoto, S, Kano, S. and Daiguji, H., Computers and Fluids, 27-5/6(1998), 571-580.
3. Yamamoto, S. and Shiraishi, T., Trans of JSME, Series B, 64-624(1998), 2424-2430, in Japanese.
4. Tanuma, T., Shibukawa, N. and Yamamoto, S., ASME Paper 97-GT-479, (1997).
5. Yamamoto, S. and Tanuma, T., Proc. IGTC 1999 Kobe, I(1999), 489-496.
6. Yamamoto, S., AIAA Paper 2001-2651, (2001).
7. Yamamoto, S., Proc. 2nd ICCFD Sydney, (2002), Springer, in press.



(a) First-order in time (b) Present method
Fig.1 Calculated instantaneous Mach number contours



(a) Without ejection (b) With ejection
Fig.2 Calculated instantaneous Mach number contours



(a) Mach number (b) Condensate mass fraction
Fig.3 Calculated instantaneous contours

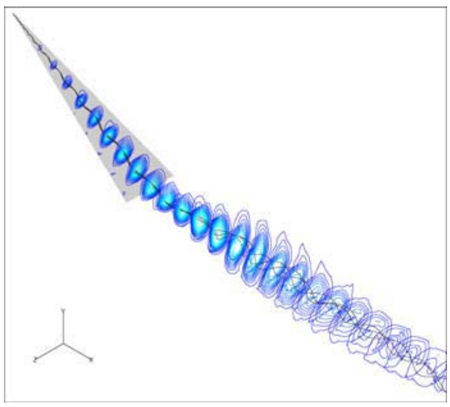


Fig.4 Calculated condensate mass- fraction contours