The Laboratory of Fluid Mechanics

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Professor Yoshinobu Tsujimoto retires at the end of next March due to retirement rule which is at the end of scholar year (April to March in Japan) after reaching 64 years old. He joined the laboratory of fluid mechanics of the department of Mechanical Engineering in the division of Engineering of Osaka University, to write his bachelor theses in 1970 and spent several years until accomplishment of doctor thesis. The time he worked with us was not long but it is vitally useful both for him and for ourselves. This short note is to commemorate his retirement, mentioning briefly about the Laboratory, the background of his 'early days'.

The Laboratory was constructed in 1932 principally to support power generation engineering by water turbines, under the direction of Prof. Jiro Tanide and shortly after, succeeded by Prof. Tokio Uematsu. The latter served as the director until 1963 and gradually extended the scope of research works to a variety of problems in fluid mechanics, such as multi-phase flows, turbo-machinery, noise in fluid machineries, etc. Basically, one-dimensional and empirical fluid mechanics were the major tool for research works, since it was expected to give answers comprehensively and quickly to problems raised from practical engineers. First two decades were a time of serious difficulty due to war, and bombardment by US air force in the last stage of World War II caused serious damage on the Laboratory. In addition, elimination of aircraft industry decelerated largely the progress of fluid engineering in Japan. But what is surprising for me is that I find the historically important paper of hydraulic loss in rough pipes by Moody which appeared in Transaction of ASME in 1944, in the library of Osaka University. Despite the war, U.S. did not cease to supply academic products to Japan, fighting enemy.

Pioneering launching of man-made-moon by USSR in 1957 urged acceleration of development in science and technology, and consequently, needs of educated engineers greatly in the western world and in Japan as well. So, Prof. Uematsu was involved in building a new division of engineering under the concept different from the existing ones. Science division aims to understand the nature as possible as exactly and correctly, irrespective of whether the understanding is useful straightforwardly for human's life or not. Meanwhile, the research works in the engineering division must have anything to do with benefit to human's life or to industrial activity. Newly prospected division was fusion of both. Prof. Tsujimoto spent there for 36 years and made excellent job, manifesting the spirit of the division, as observed in his 'opportunities'.

Prof. Uematsu left the laboratory in 1963 and Prof. Susumu Murata was invited as the succeeding leader of the Laboratory in the same year. Although aeronautical industry and relevant research activity were totally eliminated in Japan after the end of World war II, talented people in fluid mechanics in mechanical engineering community in Japan gathered to start studies of gas turbines several years thereafter. Prof. Murata was among them and worked hard with his staffs and students to make the Laboratory one of the most active research center of turbo-machinery in Japan. Along with experimental studies on stability, rotating stall in particular, theoretical works were also conducted on flows through impellers of various kinds. Since he was very good in mathematics, sophisticated hydrodynamics based on mathematical analysis, in place of one-dimensional flow analysis, was widely applied.

High speed computer which became available shortly after the World war II opened new fluid mechanics, CFD(Computational Fluid Dynamics). In the Laboratory, it was in early 1960's when we started making use of it. In Osaka University, the first high-speed computer was NEAC2203 which was the first generation computer in Japan and was installed in 1963. Computer was indeed a serious impact, despite that computational speed was slower than a pocket calculator of today. Before computer, the laborious work of hand-made computation on mechanical calculator took about one week in order to determine mapping constants which were necessary to make flow analysis through impeller cascade by conformal mapping. A couple of seconds was enough to complete it by the computer, though careful work of programming was needed, since at the time of start of NEAC, an assembly language was used for programming. Today, computational science covers most of fields but users of the first computer in entire Osaka university were only five laboratories, including us. As is well known, calculation speed has grown about 10 times every 8 years and operation software was rapidly improved to make it more user-friendly. The performance of Japanese hardware reached that of US in mid 1990's. In Japanese universities, computers of most powerful performance have been installed in prior to all others and were consistently available for researchers. Fluid mechanics have benefitted the environment greatly.

Our first flow analysis on computer was an invscid flow through circular wing cascade. It is the extension of straight wing cascade based on two-dimensional boundary element method which requires lengthy calculation to solve a large set of multi-dimensional algebraic equations. The early works on the flow was combination of two-dimensional flows in several axi-symmetric surfaces which are obtained by meridional flow analysis. Computer simulation was stepped up steadily to fully three dimensional inviscid flow of compressible fluid without shock wave.

Our novel extension of the cascade flow analysis is to a flow in a thin liquid film, or fluid bearing. In a thin film of viscous fluid, pressure plays a role of flow potential in inviscid flow and the pressure distribution is reduced to Raileigh's equation. Most useful application of the idea is to a thrust grooved bearing in which land and groove surfaces are separated by sharp step of different film thickness. The plan form of the geometry is similar to that of a centrifugal impeller and hence inviscid flow theory can be applied straightforwardly by representing the step boundaries by line sources and outer periphery by a line vortex. The work was initiated to give answer to the question raised from nuclear power engineering, to manufacture uranium 238. Reliable supply of electricity by nuclear power station to cover the shortage caused by oil-shock in early 1970's was a vitally important issue in Japan. The work on the film bearing was further extended to that of externally pressurized gas bearing and finally resulted in a patent of supersonic bearing which allows us to enhance load capacity as high as requested.

Research works in the laboratory until 1980 were devoted to various kinds of fluid machineries, including ones other than turbo-machineries, such as friction pump, cross-flow fans and turbines, etc. As for wing cascade, Prof.Tsujimoto conducted theoretical works under the supervision of Prof.Murata and made a prominent contribution. Instead of making use of high power of computer, they preferred to work on mathematics. But it is needless to say that computer helped greatly their task, since it had become an indispensable tool in research activity in his 'early days'. Thereafter, they consistently had exchange with each other until today, but the time he worked in the Laboratory as a pupil of Prtof.Murata's school, though short, formed the framework of his whole career.

After Prof.Murata retired from the Laboratory in 1982, the present writer succeeded the chair and started computer simulation of turbulent shear flow. We intended to simulate a channel flow resolving the region closest to solid walls which is the most important layer to understand the mechanism of turbulent flow. At that time only LES(Large Eddy Simulation) which assumes slip flow on the wall was available. But it was only a couple of months after our start of the work that a first paper of the same purpose appeared in a journal. The paper by Moin and Kim is appreciated today as an historical paper of DNS(Direct Numerical Simulation) of any kind of turbulent shear flows.

In 1987, CFD was selected by ministry of education as a particularly important area of science to be promoted by an organized national team under the support of Grant-in-aid. Our laboratory participated in the team and accelerated our simulation of turbulent flows, to get ideas of the mechanism of turbulent shear flows. Since CFD was a serious impact for both academic research and engineering application, particular support by Grant-in-Aide was given to CFD community through one decade.

Today, CFD has become an indispensable tool in engineering and in science but simulated results are still caotic, in the sense that each run gives just a case. Substantial understanding must be extracted otherwise from many runs and experiments, if available. Prof. Tsujimoto extracts the substance of the flow by appropriate modeling based on good insight, not relying on simulations. The writer chattered frequently with him in his office and was stimulated greatly by his way of thinking.

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