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Review

Progress of Visualization

Nakayama, Y.*1 and Aoki, K.*2

*1 Future Technology Research Institute, 3-56-2 Higashi-Oizumi, Nerima-ku, Tokyo 178-0063, Japan.
e-mail: y-naka@mug.biglobe.ne.jp

*2 Department of Mechanical Engineering, School of Engineering, Tokai University, 1117 Kitakaname, Hiratsuka, Kanagawa 259-1292, Japan.
e-mail: katumi@keyaki.cc.u-tokai.ac.jp

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***Abstract*:** Visualization is an interdisciplinary imaging technique devoted to make the invisible visible by the techniques of experimental and computer-aided visualizations. It is applicable to various phenomena such as flow, heat, sound, electromagnetism, chemical kinetics and any of their combinations. This review describes the process of development, the present state and fruit of application, and the expectation of future development of visualization using examples. These examples expand to a wide range of fields including engineering, physics, medical science, agriculture, oceanography, meteorology and sports science.

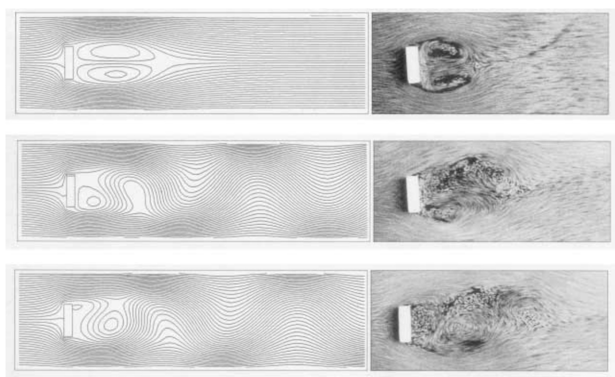
***Keywords*:** visualization, visualization history, visualization technique, utilization of visualization, future of visualization.

1. Beginning of Visualization

Since very early times, man has attempted to visualize the flow of water, which the naked eye could not perceive. One example is the earthen vessel "Joumondoki", excavated in Japan and it was made 4,500 years ago (Fig.1, Nakayama et al., 1987). On this vessel we can see patterns resembling a twin vortex and Kármán vortex created behind a pile and a stone in a river. Perhaps they watched flow patterns in the movement of fallen leaves, petals and pollens as tracers. We can obtain the same patterns by numerical simulation and experiments (Fig.2).

Umataka remains Sasayama remains

Fig. 1. Earthenware patterned flames and water crests.



Numerical simulation Experiments

Fig. 2. Vortex behind a square pillar.

2. Heart of Visualization

Figure 3 shows the famous paintings by a Spanish painter, Goya. It is quite natural to fantasize a naked body of a fully dressed beautiful lady. Goya expressed this desire by these paintings. Figure 4 shows two persons who received a grand prix at an international magic show. It is very exciting to find out what hidden tricks of the magic are. These feelings are commonly shared with visualization.

Clothed Maja

Naked Maja

Fig. 3. Famous paintings by Goya (Prado museum).

Fig. 4. Fling out pigeon (magic show).

3. Persons Fostered Visualization (Nakayama and Boucher, 2000)

The first man to take a scientific approach to visualization was probably the multi-talented Leonardo da Vinci (Fig.5). More than three centuries later Osborne Reynolds, an English scientist and engineer (Fig.6), made a great discovery by clarifying the transition phenomena from laminar to turbulent flow. Subsequently, most of the principal discoveries on fluid phenomena were made through visualization, such as the study of high-velocity air flow by Ernst Mach, an Austrian physicist and philosopher (Fig.7), the advocacy of boundary layer by Ludwig Prandtl, a German physicist (Fig.8), the elucidation of Kármán vortex by Theodor von Kármán, a Hungarian-born engineer (Fig. 9) and the discovery of bursting phenomena in the generating mechanism of turbulence by Stephen Kline, an American engineer (Fig.10).

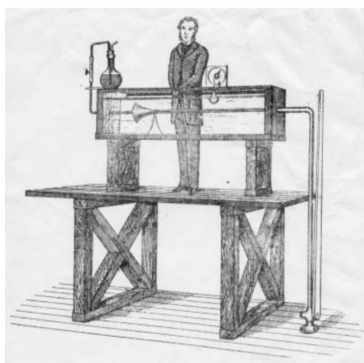
Flow around an obstacle

Vortices of divergent flow and behind body

Streamline shape

Leonardo da Vinci (1452-1519)

Fig. 5. Many kinds of flow (Leonardo da Vinci's notes).



Osborne Reynolds (1842-1912)

Fig. 6. Famous pipe flow experiments of Reynolds.

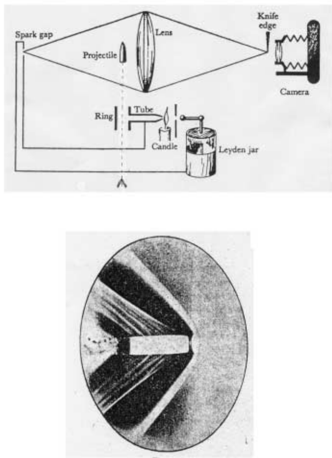
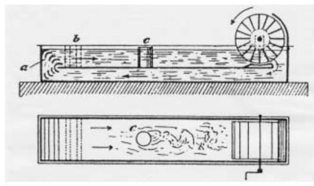
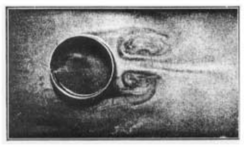


Fig. 7. Schlieren apparatus using a delay circuit and a Schlieren photograph using this apparatus.

Ernst Mach
(1838-1916)



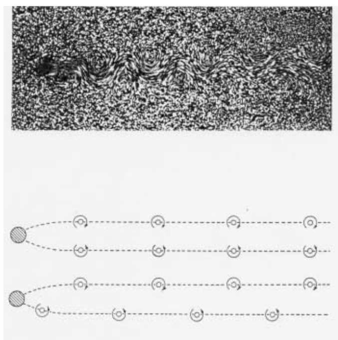
Ludwig Prandtl
(1875-1953)



Wake of a cylinder

Boundary layer movement by suction from a slot

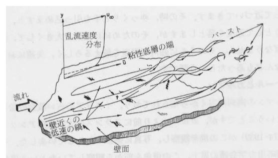
Fig. 8. Water channel having a water stroked wheel.



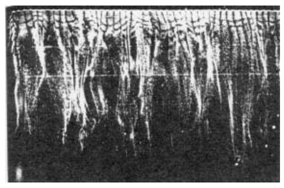
Upper: Symmetry   Lower: Asymmetry

Theodor von Kármán
(1881-1963)

Fig. 9. Two vortex streets.

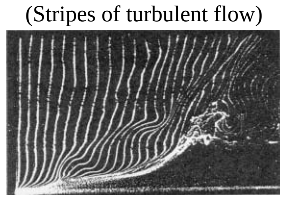


Bursting phenomenon



Horizontal direction
(Stripes of turbulent flow)

Stephen Jay Kline
(1922-1997)



Vertical direction

Fig. 10. Boundary layer on a flat plate.

4. International Symposia on Visualization

(1) International Symposium on Flow Visualization (ISFV) (Since 1977, every 2 years)
(2) Symposium on Fluid Control Measurement and Visualization (FLUCOME) (Since 1985, every 3 years)
(3) Asian Symposium on Visualization (ASV) (Since 1988, every 2 years)
(4) International Workshop on PIV (PIV) (Since 1995, every 2 years)
(5) International Conference on Optical Technology and Image Processing in Fluid, Thermal and Combustion Flow (VSJ-SPIE) (1998)
(6) Pacific Symposium of Flow Visualization and Image Processing (PSFVIP) (Since 1997, every 2 years)
(7) International Symposium on Visualization and Imaging in Transport Phenomena (VIM) (2001)

5. Classification of Visualization Techniques

5.1 Experimental Visualization Methods

(1) Wall surface tracing method
The wall tracing method is required to observe the flow on a surface. Material attached on the body surface varies its shape or state according to the flow (Fig.11, Murai, 1977).
(2) Tuft method
The flow state can be seen by observing the direction and motion of the tufts made of thread of an appropriate length (Fig.12, Tagori et al., 1980).

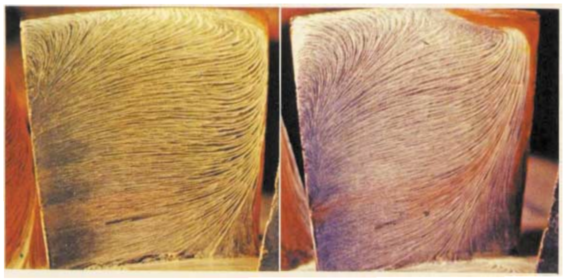


Fig. 11. Oil film pattern on an impeller surface of an axial flow pump (oil film method).

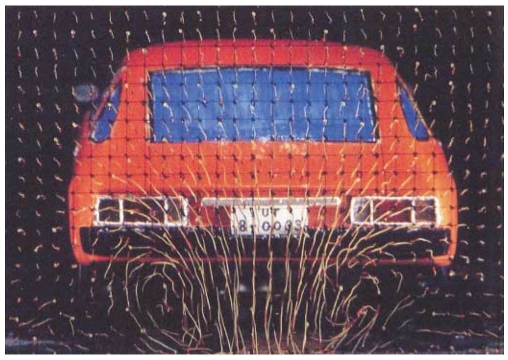


Fig. 12. Wake behind an automobile (tuft grid method).

(3) Injected tracer method
A substance called a tracer which consists of particles, smoke or dye, can be used as marks in the flow. The state of the flow is shown by the resulting stream of the tracer (Fig.13, Taneda, 1977).

(4) Chemical reaction tracer method
The flow is visualized using a chemical reaction between the fluid and the surface substance of the test model (Fig.14, Ukegichi et al., 1967) or between the fluid and another injected fluid.

(5) Electric controlled method
Tracers are generated by the controlled electric current in the flow. There are three kinds of methods, hydrogen bubble method, spark tracing method (Fig.15, Nakayama et al., 1976) and smoke wire method.

(6) Optical method
Changes in the density and refractive index of fluid, interference of light (Fig.16, Fujii, 1995), (Fig.17, Nagayama and Adachi, 1977) and unevenness of the fluid surface in the flow are visulized optically.

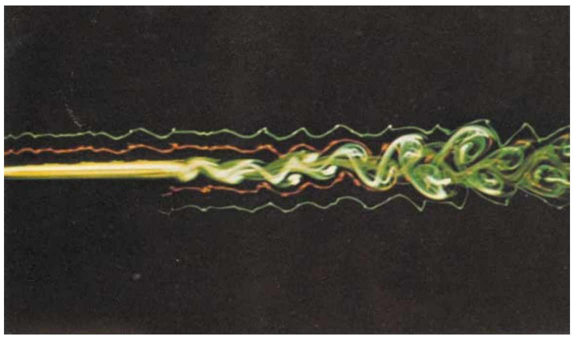


Fig. 13. Kármán vortex street behind a flat plate (pigment streak line method + condense milk method).

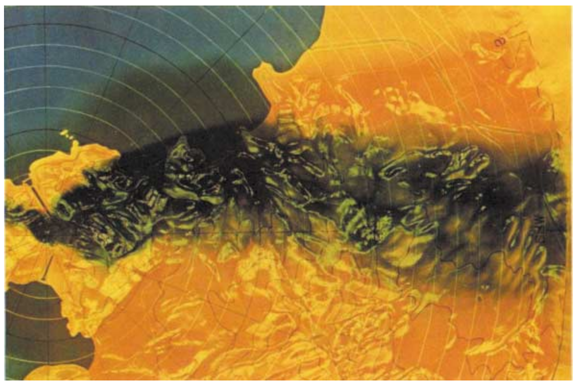


Fig. 14. Scattering of exhaust gas from a chimney (body surface painting film's coloring method).

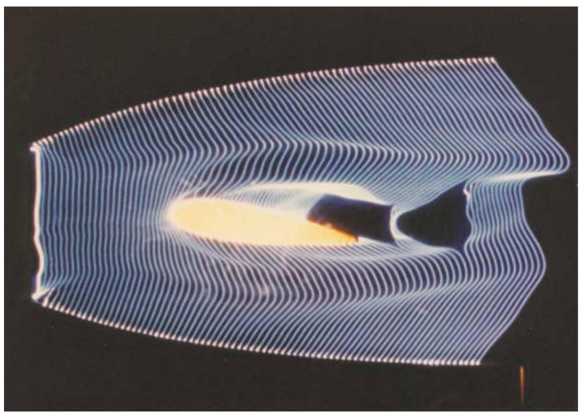


Fig. 15. Flow around a wing (Spark tracing method).

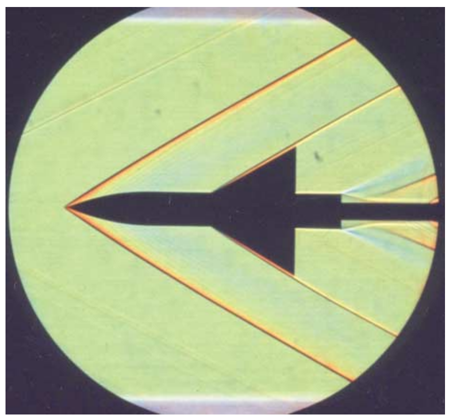


Fig. 16. Supersonic flow around a simplified supersonic aircraft (Color Schlieren method) M=2.2.

Fig. 17. Flow around driven blade on low-pressure stage in stream turbine (Mach-Zehnder interferometer method).

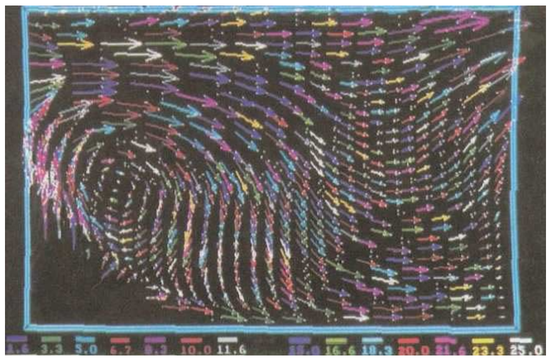


Fig. 18. Velocity vectors of flow over a circular cylinder [Particle Tracking Velocimetry (PTV)].

5.2 Computer-aided Visualization Method

(1) Visualised image analysing method [PIV (Particle Imaging Velocimetry)]

There are four methods, PTV (Particle Tracking Velocimetry)(Fig.18, Boucher and Kamala, 1992), Correlation Method (Fig.19, Kobayashi, et al., 1997), (Fig.20, Aoki et al., 2001), LSV (Laser Speckle Method) and HPIV(Holographic PIV).

(2) Numerical data visualization method

There are many methods such as contour manifestation method, area colouring manifestation method, volume rendering method, etc. (Fig.21, Kobayashi, 1997).

(3) Measured data visualization method

Utilising flow velocimeters, pressure gauges and acoustic intensity method, velocity distribution, pressure distribution and the size and direction of sound waves are manifested in an image (Fig.22, Fujikawa, 1993) or in terms of vectors.

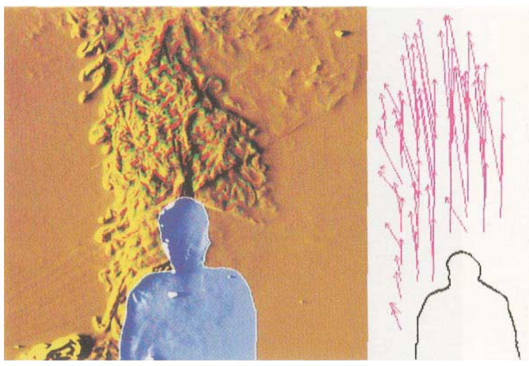


Fig. 19. Natural convection around a human body (correlation method).

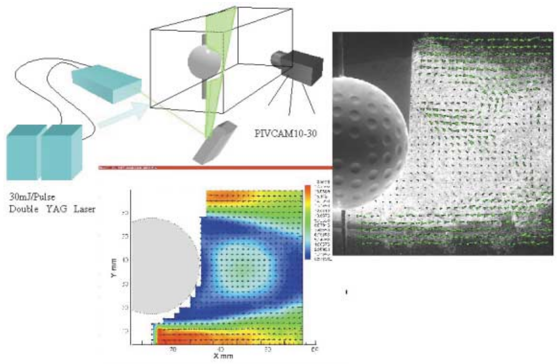


Fig. 20. Flow around a golf ball (correlation method).

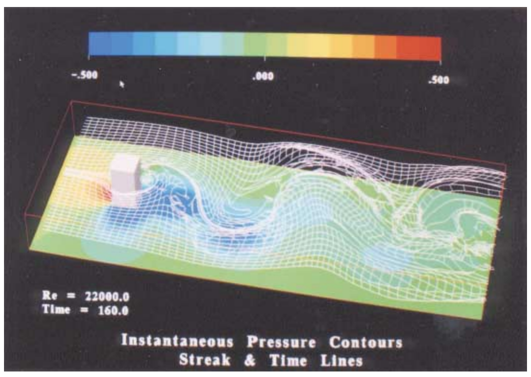


Fig. 21. Turbulent flow around rectangular column [Large Eddy Simulation (LES)].

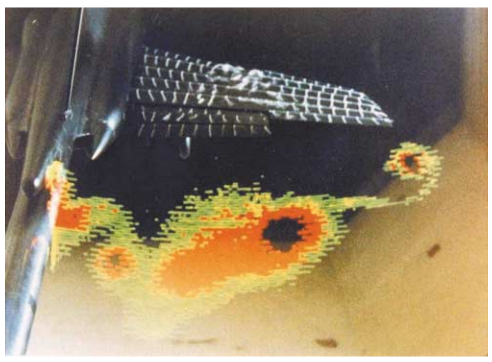


Fig. 22. Total head pattern behind horizontal tail (pressure sensors and light-emitting diodes combination method).

6. Utilization of Visualization

Visualizations are used for many kinds of fields. Let us now consider the close relationship between visualization and the present world in which we live. Typical examples are as follows.

(1) Vehicles

Visualization is used to assist designing automobiles. Air flow over the body can be visualized by means of smoke lines in a wind tunnel (Fig. 23 (a), Takagi, 1993) and by computer simulation (Fig. 23 (b), Miwada, 1990). Figure 24 shows isobar lines diagram of a super express train (500 km/h) rushing into a tunnel (Ogawa et al., 1992). Streamlines around an orbiting plane at its re-entry stage (Mach number 15) are shown using the rarefied gas flow analysis taking into account of finite-rate chemistry in Fig.25 (Wada et al., 1993).

The same visualization techniques can be used for designing fluid machines and engines, etc. Figure 26 shows an internal flow of a blower (Nakayama et al., 1985) and Fig. 27 shows numerical simulation of a flow inside a cylinder (Yamada, 1993).

(2) Nature and daily life

The meteorology has strong relation with visualization. Figure 28 shows the erupting smoke from a volcano (Kinoshita, 1997). We can also use visualization to improve our living environment. We can, for example, observe the wind around buildings (Fig.29, Miyachi, 1996), diffusion of the smoke from chimneys (Fig.14) and ventilation within a room.

(3) Medical science

Another important contribution of visualization is to the field of medical science. The velocity distribution and stream lines of blood flow in a heart can be visualized (Fig.30, Tanaka et al., 1993), which can be important data for a surgical operation. The cross section of head can be visualized using X-ray CT and MRI as shown in Fig.31 (Komaki, 1996). It is essential for diagnosing the brain.

(4) Sports

Visualization is also used actively in the field of sports, particularly in the quest for new records for example in ski jumping and swimming. Visualization is also used to improve the performance of golf balls (Fig.32, Nakayama et al., 1990), tennis balls, soccer balls, etc.

(5) Sound

In Fig.33 an acoustic power flow from a cello is visualized by the acoustic intensity method (Tachibana et al., 1996). The size and direction of the energy flow at each point are obtained through a computational process from the cross-vector of the sonic pressure signal on a microphone.

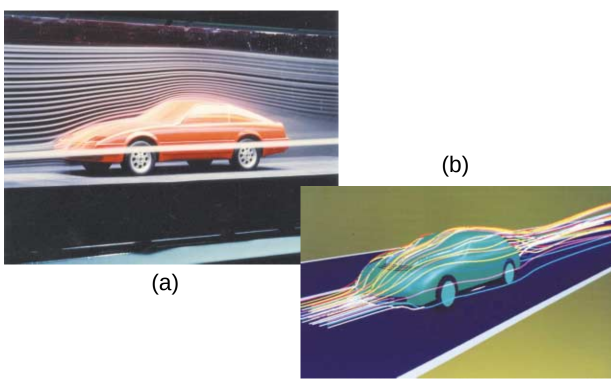


Fig. 23. Flow around an automobile: (a) Experimental result (smoke method), (b) Result of 3D unsteady flow analysis (finite volume method)

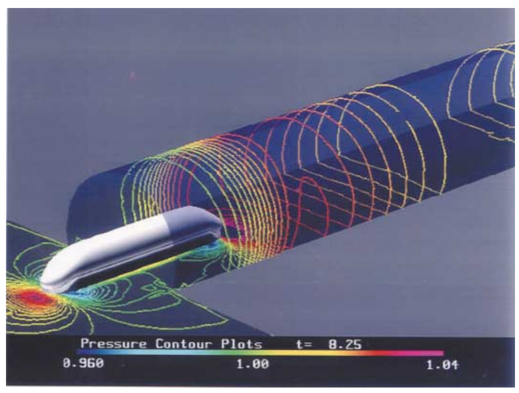


Fig. 24. Isobar lines diagram of a super express train (500 km/h) rushing into a tunnel (finite difference method).

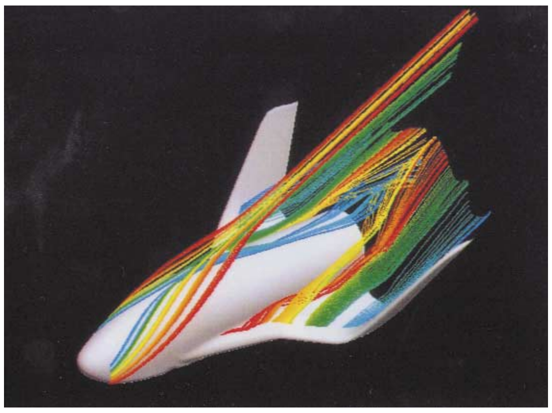


Fig. 25. Flow around a space plane by computer simulation.

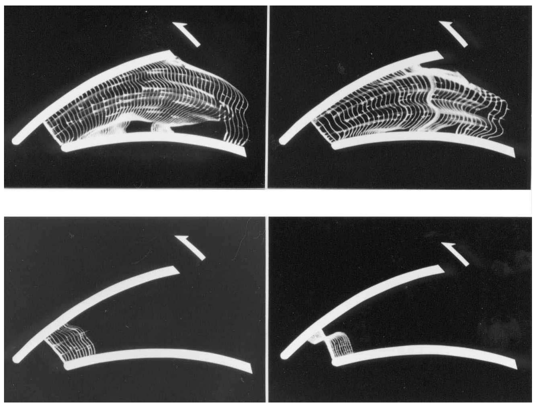


Fig. 26. Relative flow velocity distributions in a centrifugal blower impeller (spark tracing method).

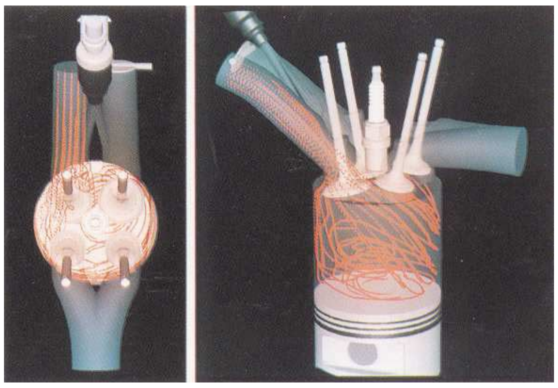


Fig. 27. Numerical simulation of flow inside a cylinder (finite difference method).

Fig. 28. Erupting smoke of Sakura-jima taken by remote sensing.

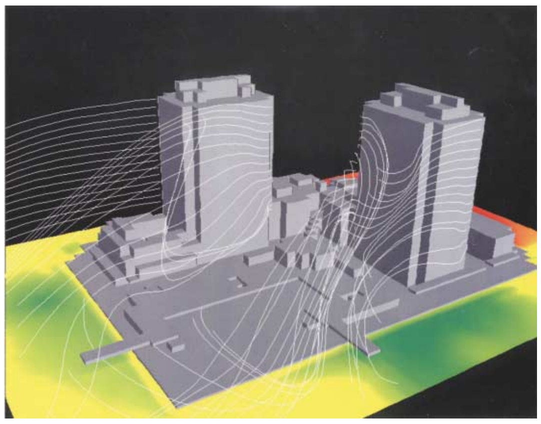
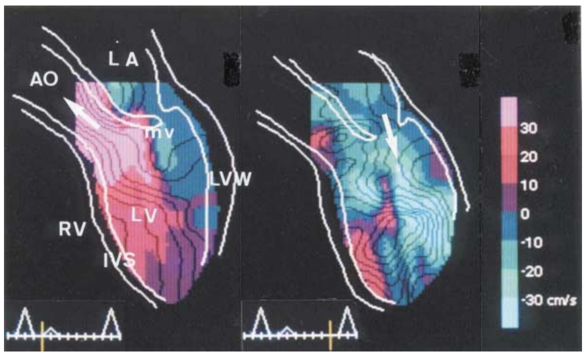
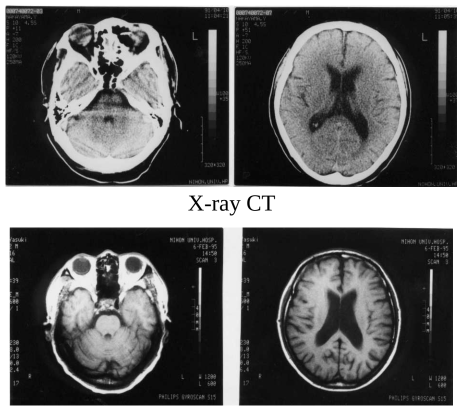


Fig. 29. Simulation of a locally strong wind blowing along a street of tall buildings (finite difference method).



Contraction (flow out) Expansion (flow in)

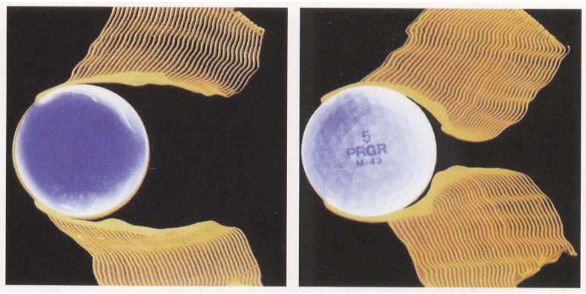
Fig. 30. Blood flow in a heart (super sonic pulse doppler method).



X-ray CT

MRI

Fig. 31. Cross section of head.



Sphere Golf ball

Fig. 32. Flow around a ball (spark tracing method).

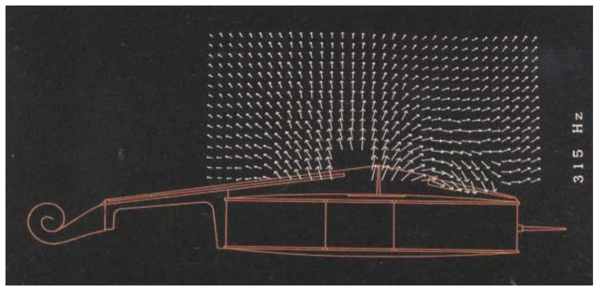


Fig. 33. Radiated power flow of a cello (acoustic intensity method).

7. Future View of Visualization

(1) Expansion of visualization field
Visualization will become more and more important not only in engineering and physical science but also in medical science, agriculture, oceanography, meteorology and sports science.

(2) Application of electromagnetic waves in various spectra
Now the visible ray is generally used, but in future laser beams, infrared, gamma rays, X rays, electromagnetism and supersonic waves will be used successfully.

(3) Development of new experimental visualization method
New visualization methods like the laser light sheet method, laser holographic interferometer method, speckle method, etc. will be developed successfully with usual visualization methods especially injected tracer method and optical method.

(4) Progress of image analysing method
Progress will be made in New methods such as PIV (Particle Imaging Velocimetry), computer tomography, remote sensing, thermographical method, etc.

(5) Development of computer simulation techniques
The computational time will be 10~100 times faster in 10 years, where fairly practical computation will be performed using 1 TFLOPS super computer.

(6) Progress of metrology
The measuring techniques are expected to develop from point measurement to two-dimensional and three-dimensional measurements and much information will be acquired simultaneously.

(7) Advancement of computer graphic techniques
The enormous data obtained by the image analysing method, computer simulation and multi-point simultaneous measurements will be presented using ultra-high speed computers.

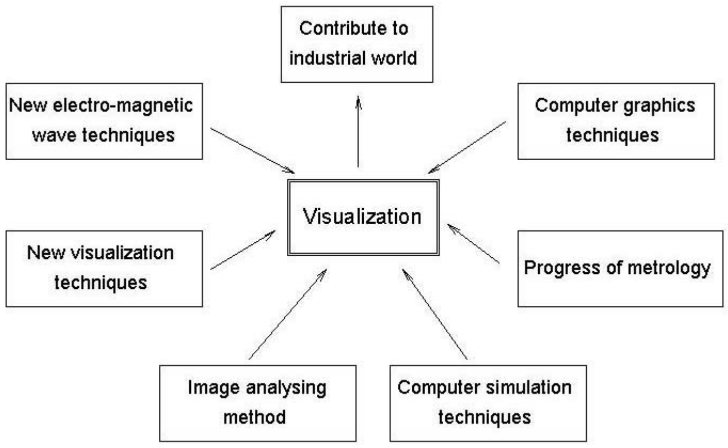


Fig. 34. Future prospect of visualization.

The above-mentioned items are summarized as shown in Fig.34.
We hope to achieve the ideal of visualization from two dimensional to three dimensional observation, from steady to unsteady phenomena and from qualitative to quantitative observation.

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Author Profile

Yasuki Nakayama: He received his Ph.D. in Mechanical Engineering from Waseda University in 1963. He joined the National Railway Research Institute and conducted many research investigations in the area of fluid mechanics. He then became a Professor of Tokai University, where he taught and researched fluid mechanics and visualization. He later became President of the Future Technology Research Institute.
He has received many distinctions and awards for his outstanding research. He has been a visiting Professor of Southampton University, UK, President of The Visualization Society of Japan, and Director of The Japan Society of Mechanical Engineers. He has published 10 books and more than 160 research papers.

Katsumi Aoki: He received his M.Sc.(Eng.) degree in Mechanical Engineering in 1967 from Tokai University and his Ph.D. in Mechanical Engineering in 1986 from the same university.
After obtaining M.Sc. he worked as a research assistant, a lecturer, and an associate professor at Tokai University before taking up his current position as a professor of Tokai University. His current research interest covers flow around a rotating circular cylinder with and without grooves, flow around a rotating sphere, possibility of drag reduction using triangle-type cavity and flow visualization by spark tracing method of complicated flow field like in centrifugal blower.