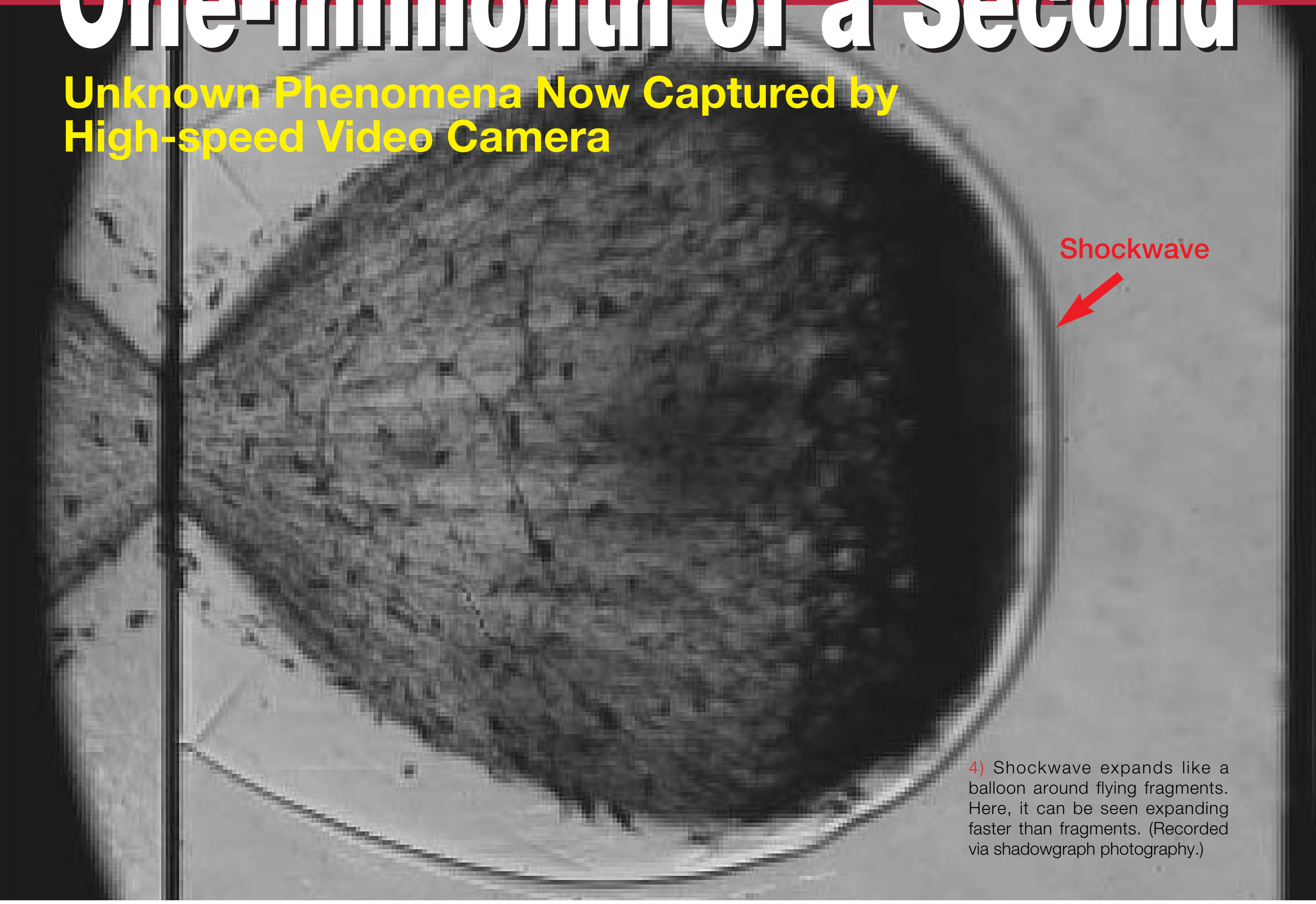
Shockwave Recorded in One-millionth of a Second

Unknown Phenomena Now Captured by High-speed Video Camera



4) Shockwave expands like a balloon around flying fragments. Here, it can be seen expanding faster than fragments. (Recorded via shadowgraph photography.)

Explosions generate shockwaves. Shimadzu's high-speed video camera captured pressure waves propagating at supersonic speed. This video camera is expected to contribute significantly to Japan's scientific and technological development.

The Instant a Bullet Penetrates an Aluminum Plate

Boom!!! Opening the large stainless-steel chamber revealed aluminum plates with holes blasted clean through them by the high-speed projectile.

This is the Shock Wave Research Laboratory, Transdisciplinary Fluid Integration Research Center, in Japan's Tohoku University, one of the world's leading research institutions for shockwave and high-speed collision phenomena.

The boom came from the university's world-class two-stage "light-gas gun". In this gun, a gunpowder explosion drives a piston that compresses a light gas, such as hydrogen or helium, to a high temperature and pressure. This energy is then converted to accelerate a projectile to ultra-high speeds. This gas gun is a large piece of equipment, measuring almost 20 m. The "bullet", an aluminum projectile sealed in a polycarbonate tube, exits the gun at a speed of 3.25 km/s _ approximately ten times the speed of sound. At this speed, it could fly 3000 km, or the length of Japan, in just 15 minutes.

When the projectile collided with the two vertical aluminum plates, it penetrated the first plate with a tremendous shock before pulverizing as it impacted the second, 5 mm-thick plate.

The time elapsed from recording the first frame up to the 100th frame is only about one ten-thousandth of a second. Shimadzu's HPV-1 High-Speed Video Camera was able to resolve distinct time intervals over this brief instant.

"The ability to record dynamic images

over short intervals is extremely significant. Moreover, now high-speed phenomena can be easily photographed without any specialized knowledge of high-speed photography." Prof. Kazuyoshi Takayama enthusiastically claims that Shimadzu's HPV-1 should be able to contribute significantly to the scientific and technological development of Japan.

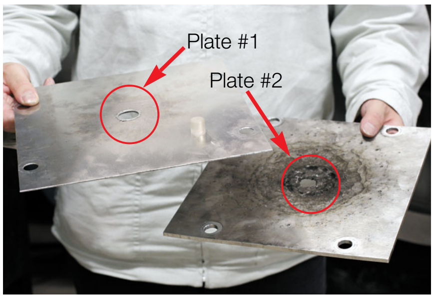
Photographing a Projectile Flying at Ten Times the Speed of Sound

Such high-speed phenomena are commonplace in space. Space debris _ meteorites, used satellites and fragments dislodged from satellites _ orbits the Earth at speeds ranging from seven to 14 kilometers per second.

Such fragments colliding head-on with a space structure could easily penetrate the outer skin. Currently, the International Space Station is under construction and the Japanese Experiment Module is due to be launched. The construction, material, and thickness of the external skin are being carefully calculated and verified to ensure safety.

Such calculations demand high-speed collision testing and the urgent development of measurement techniques. A normal video camera, which takes a mere 30 frames per second, is not fast enough to capture instantaneous events and supersonic phenomena becomes a mere blur. Such phenomena requires a high-speed video camera, however, conventional high-speed video cameras can only take up to approximately 10,000 frames per second. That is to say, they could capture only the first frame and the last frame of the gas gun's projectile.

The photographs shown here were taken with the Shimadzu HyperVision HPV-1. They were selected from a 100-frame sequence recorded at approximately 1/100,000th second intervals. Even though the HPV-1 is not significantly different in size from a commercial video camera, it can capture images at up to one million frames per second. In the example described above, the camera was able to photograph a projectile



Images of the removed aluminum plates. The first has a neat hole. The second is deformed and discolored by the violent impact.

moving faster than a jet fighter in approximately 3 mm increments. At this speed, the HPV-1 can record truly ephemeral phenomena.

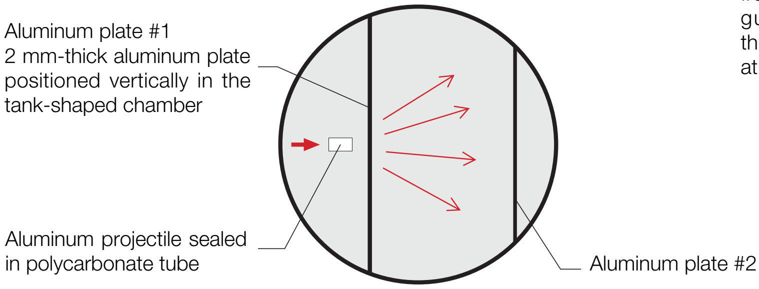
Shockwave Phenomena Around Us

Prof. Takayama was waiting for a high-speed camera like the HPV-1 to arrive.

Prof. Takayama's field of research is shockwaves, which are waves that propagate faster than the speed of sound, causing an instantaneous increase in pressure. They are generated by an instantaneous release of energy, such as an explosion.

Shockwaves are also generated by

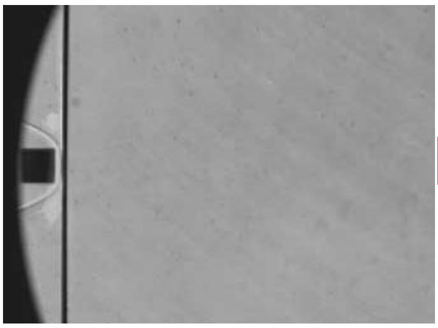
A window into the Two-Stage Light-Gas Gun

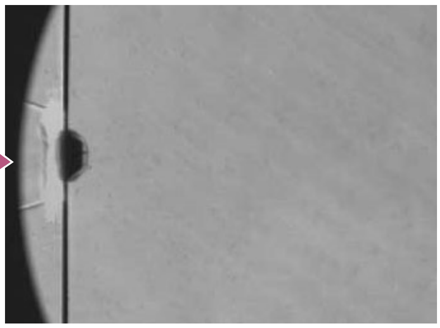


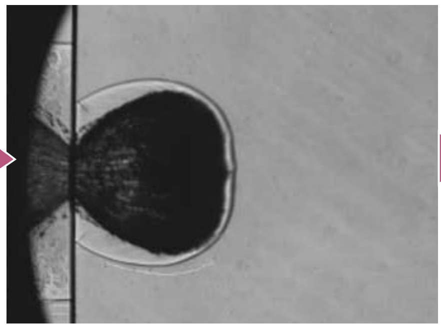
The projectile explodes out from the left side of the gas gun. The projectile flies through the gas-gun barrel at 3.25 km/s.

HPV-1 High-speed Video Camera

Continuous High-speed Video Camera Images of the Projectile (Recorded via shadowgraph photography) Images supplied by: Prof. Takayama


1) Left-side projectile is flying at 10 times the speed of sound. Instant before impact with the first aluminum plate.


2) Instant the projectile penetrates through the aluminum plate. A small explosion can be seen.


3) About 1/100,000th of a second after penetrating the plate. A strong shockwave is apparent.

4)

the impact of a high-speed projectile. However, not all shockwaves are caused by artificial factors; they occur also in nature.

For example, explosive volcanic eruptions, thunder, and supernovae in space all generate shockwaves.

Other "shock-like" phenomena can also be seen in our daily lives, such as the flow of pedestrians or automobiles, the spreading of rumors, and the spread of panic. While no mathematical models have yet been established for these phenomena, they exhibit similar properties to shockwaves. The clarification of shockwave phenomena is the pinnacle of dynamics. By promoting basic shockwave research and interdisciplinary applied research, Prof. Takayama has become a world-renown leader in this field.

Prof. Takayama explained, "It wasn't easy to capture supersonic waves.

"Previously, we had taken static photographs using instantaneous light sources to record shockwave phenomena. We then used supercomputer simulations to determine the shockwave dynamics. We also developed double-exposure holographic interferometry to precisely measure high-speed phenomena resulting from shockwaves at high resolutions. However, we were unable to take dynamic images at a high temporal resolution below one-millionth of a second.

"The Shimadzu HPV-1's ability to capture continuous images at one

million frames per second allows us to meet these demands for the first time. This kind of performance is truly revolutionary for shockwave research."

Shockwaves Revolutionize Medicine

Shockwave research is sometimes applied in unexpected places. In medicine, extracorporeal shockwaves in water are focused on kidney stones in a patient's body to pulverize and eliminate them. Such extracorporeal shockwave treatment is commonly used for pain treatment and is now being tested as a cancer therapy.

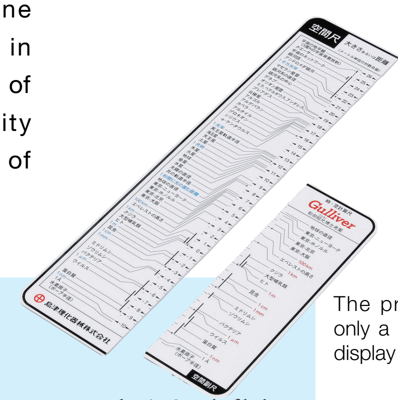
More advanced medical applications of shockwaves are being promoted by the Tohoku University Biomedical Engineering Research Organization (TUBERO).

For example, an extremely fine "scalpel" is being developed in collaboration with the Department of Neurosurgery, Tohoku University School of Medicine. The interior of capillaries is illuminated with pulsed laser light to generate bubbles. The movement of these bubbles generates minute intermittent water jets that cut body tissue without breaking blood vessels exceeding 0.2 mm diameter. Clinical applications are currently under investigation.

Also, a treatment method is being developed that applies water jets generated in blood vessels to cerebral thrombosis to rapidly re-establish blood flow.

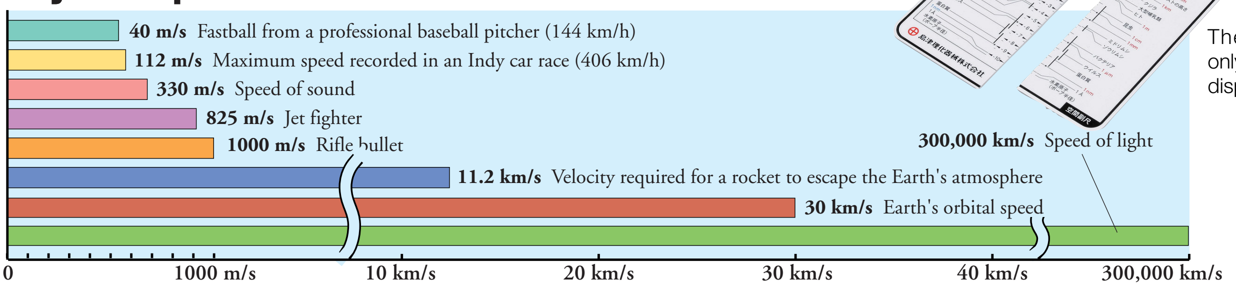
Currently, when cerebral thrombosis leads to cerebral infarction, treatment involves giving a thrombolytic agent to dissolve the thrombosis. However, if the thrombosis is hard or difficult to dissolve, the high dose of thrombolytic agent required often results in the post-treatment side effect of internal organ hemorrhaging.

In tests being conducted by Prof. Takayama et al, shockwaves create water jets that penetrate a thrombosis and break it into smaller particles, which are then absorbed. This procedure virtually eliminates the need for a thrombolytic agent. This research was assisted by the Ministry of Education, Culture, Sports, Science and Technology 21st Century COE (Center of Excellence) Program (2000 to 2004) to promote the establishment of a research organization of a high



The product is only a Japanese display

Physical Speeds

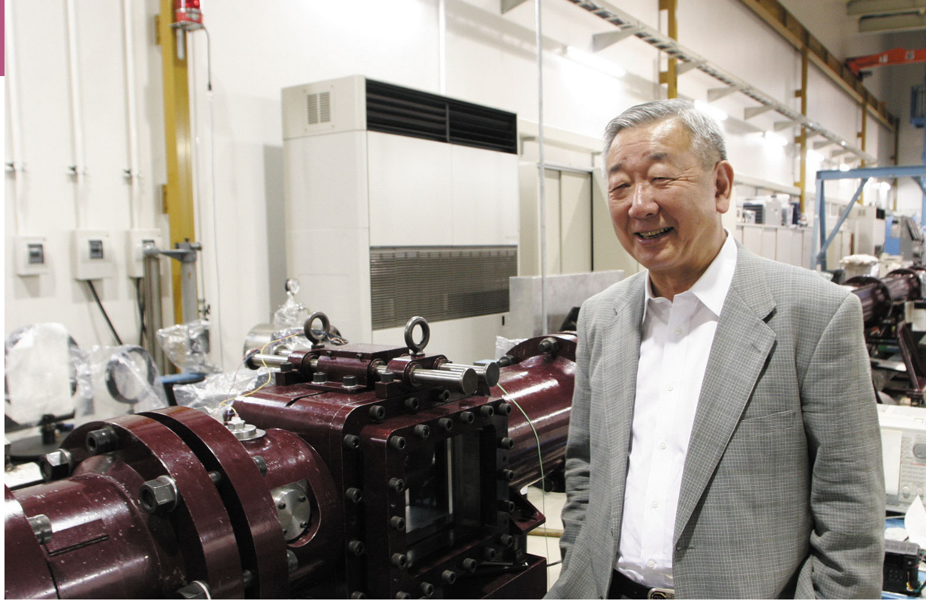


Gulliver space-time slide rule: Shimadzu Rika Instruments Co., Ltd. (www.shimadzu-rika.co.jp)

The Gulliver space-time slide rule converts the vastness of space and the eons since the birth of the universe into familiar distances and times. If the time since the birth of our solar system is taken as one year, the Gulliver space-time slide rule shows that only a few hours have elapsed since our first human ancestors appeared. Similarly, one hour on this scale is equivalent to the world of millionths of a second studied by Prof. Takayama. (designed by Dr. A. Wada)

Prof. Kazuyoshi Takayama
Professor Emeritus, Tohoku University

Born in Hokkaido in Japan in 1940, he became an assistant professor at the Institute of High-speed Mechanics (currently: Institute of Fluid Science) at Tohoku University. Became a full professor in the Institute of High-speed Mechanics in 1986 and then the Director of the Shockwave Research Center (currently: Transdisciplinary Fluid Integration Research Center), Institute of Fluid Science, in 1988. Employed in the Shockwave Interdisciplinary Research Program in 2000 as part of the Ministry of Education, Culture, Sports, Science and Technology 21st Century COE Program. Resigned on his retirement in 2003. Currently a professor at Japan's Tohoku University Biomedical Engineering Research Organization (TUBERO). He is a world-renown leader in shockwave research and his achievements over many years were rewarded with the German Ernst Mach Medal in 2000. He became editor of the International Shockwave Journal in 2003 and became Chairman of the International Shockwave Research Association in 2005.



international standard. Practical applications are being encouraged in order to rapidly return the results of this research to society.

To Further Develop Japan as a Technologically Advanced Nation

Prof. Takayama explained, "For medical applications, in particular, a high-speed video camera with a recording speed of one million frames per second is a necessity for high-magnification photography in a micro viewing-field, even of slow-moving phenomena. The Shimadzu HPV-1 can record under extremely poor or dark illumination conditions, with either bright or dark exposures, and uses a computer to perform image contrast reconstruction after recording. The high-speed video camera plays an extremely important role in shockwave medicine basic research.

Currently, in the field of nanotechnology static photography is the mainstream method for recording high-magnification images. However, there is now a trend towards measuring the movements of nanotech phenomena. High-magnification measurements of micro-scale phenomena at high temporal resolution requires ever-higher recording speeds."

Prof. Takayama concludes, "Clarifying unknown phenomena that previously lay in the realm of the imagination will result in dramatic developments in dynamics research, such as fluid mechanics or material mechanics.

"This should not only open up new development concepts and support the fundamentals of various design disciplines, but also stimulate Japanese science and technology overall. This will, in turn, lead to revolutionary new products by opening the door to developing devices and equipment with high-level performance and a strong emphasis on creativity.

"The Shimadzu HPV-1 is valuable not only because Japan was the first to create this device, but also because it will play an important role as an invaluable measurement instrument that will further develop Japan's status as a technologically advanced nation.

"Of course, similar products from all over the globe will probably begin to reach the market, resulting in strong competition in equipment performance. As a researcher, I hope the Shimadzu Corporation will remain a key player in the development of products in this field, and thus transmit Japanese technology to people and organizations all over the world."

HPV-1 High-speed Video Camera Captures Dynamic Images at One Million FPS

The Shimadzu HPV-1 can perform ultra-high speed recording of phenomena at up to one million frames per second. It uses a unique CCD image sensor that was jointly developed in collaboration with Prof. Takeharu Etoh of Japan's Kinki University and uses electronic control to record 100 continuous frames. Also, conventional processing-related time-lag problems are eliminated via image post-processing. The resulting video recordings reveal a previously unknown realm seen only for one-millionth of a second.

The need to capture high-speed phenomena comes not only from academic institutions but also from various manufacturing industries. Applications include photographing fuel injection in internal-combustion engines and the dispersing of ink drops by inkjet printers. Many phenomena, such as how a golf club distorts at the instant of impact with a golf ball, can only be captured at one-millionth of a second.

"We are always being asked for faster speeds and clearer images. I want to continue to develop even better performance in the future."

Y. Kondo, Manager, Research & Development Group, Analytical & Measuring Instruments Division, Shimadzu C