Specialized techniques based on high-speed digital imaging allow analysis of instantaneous impacts.

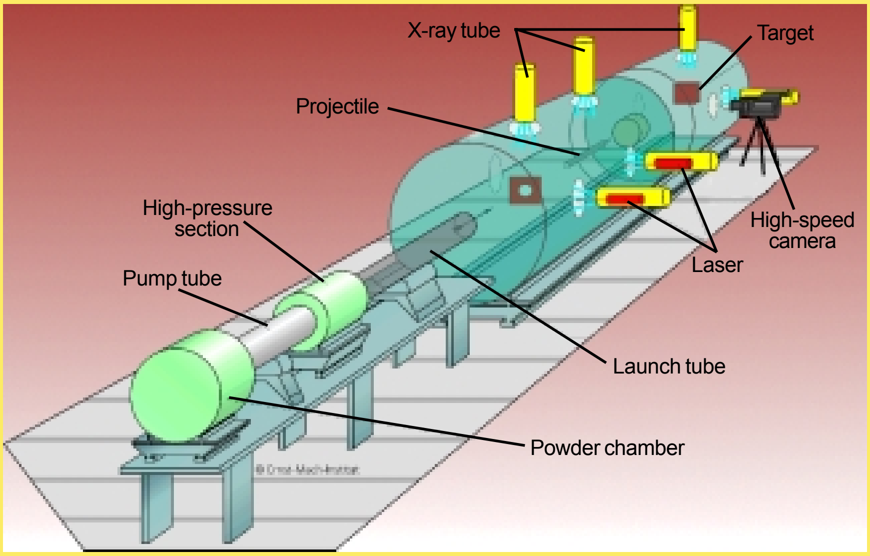

FIGURE 1. Typical Ernst-Mach-Institut launch facility is designed to send a projectile into a chamber in which the projectile's impact on a target can be characterized, often with high-speed imaging equipment.

High-speed imaging is used widely To characterize fast events or processes in the military and civilian sciences. Specific applications include ballistics, hypervelocity impact, aeronautical design, and power generation. Spanning these applications is the field of impact physics, which covers a range of related disciplines such as acceleration technology, chemistry, shock-wave physics, fluid dynamics, dynamic material behavior, observation techniques, and numerical and analytical analysis. Its uses include testing modern ammunition and armor (ceramics, fiber-reinforced plastics, and reactive armor) and crash-testing of automotive components, as well as investigation of meteoroid and space-debris protection shields for satellites and space stations. Non-nuclear kill of re-entry vehicles, rockets, spacecraft, and warheads are other examples, together with simulation of cometary impact on earth and planets.

Experimental investigations can be performed in the impact velocity range from a few meters per second (car crash) to more than 10,000 m/s (meteoroid/space debris impact) corresponding to masses from 500 kg to a few micrograms, respectively. Various types of accelerators are used to produce such high kinetic energies, including light-gas guns, which are favored because of their ability to accelerate projectiles with complex shapes, different materials, and masses to high-impact velocities. A typical Ernst-Mach-Institut (Freiburg, Germany) launch facility includes blast tank, velocity-measurement station, and impact chamber with instrumentation for the diagnostics necessary to study terminal ballistics, hypervelocity impact, and planar impact (see Fig. 1).

Traditional high-speed observation techniques such as flash radiography and high-speed photography have been and still are used for impact physics testing. However, ultra high-speed digital-imaging technology offers benefits and greater scope for applications where traditional methods cannot achieve extremely short exposure times of a few nanoseconds. Flash x-ray photography is often used for observation of processes in opaque solid, fluid, or gaseous materials, such as metals and ceramics, or of events that are accompanied by formation of dust, debris, or strong light. Flash x-ray tubes are commercially available for voltages in the 150- to 1200-kV range with pulsewidths of 35 or 20 ns, respectively. The thicker the material to penetrate, the higher the voltage of the x-ray tube must be. Because the discharge repetition rate of single x-ray tubes is restricted to 10,000 pictures per second, multiple-tube systems are required. For flash x-ray cinematography, multiple x-ray tubes are triggered in sequence on the same film. The number of x-ray tubes applicable for observation of a certain process is often limited to three or four tubes in sequence because of the relatively large tube-casing diameter (see Fig. 2). There are two categories of high-speed photography: high-speed video and high-speed cinematography. High-speed video cameras are an option for relatively slow-impact processes that occur at several tens of meters per second over a time range of several milliseconds. There are typically trade-offs between the number of frames captured and the resolution per frame—the more frames the lower the resolution. An example of an application is looking at the deformation of car components in crash tests.

High-speed cinematography uses image-dissection techniques, either optical or mechanical, to capture sequences of images on film. The technique can produce images with framing rates on the order of 2 million frames/s, with a minimum exposure time of 0.25 µs. Sources such as high-power lasers (copper-vapor or ruby) usually complement high-speed photography to provide the requisite high illumination level with short shutter speeds.

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Ultra high-speed digital imaging

Ultra high-speed digital cameras use gated image intensifiers delivering a very fast-acting shutter system based on the photo effect, by which the photons of the object induce emission of electrons from a photocathode. The emitted electrons are intensified by microchannel plates (intensification factors of 100,000 are possible) and transmitted to a phosphor screen, where the resulting light-intensified image of the object is displayed and photographed by a charge-coupled-device (CCD) camera. In modern ultra high-speed cameras, the images can be transferred to a computer system via a fiberoptic link, and digital image processing can significantly enhance the image quality. The digital images can be archived on a computer or transmitted electronically via a network or the Internet. An example of a commercially available system is the HSFC-PRO camera from The Cooke Corporation/PCO Computer Optics. The four-channel camera allows up to 500 million frames/s, with a maximum pixel resolution of 1280 x 1024 and up to eight full frames. With a dynamic range of 12 bits, exposure time from 1.5 ns to 1000 s, and an interframe time of 2 ns, the HSFC-PRO is reportedly the fastest commercially available CCD camera in the world. Hence, it is possible to image the formation and expansion of the impact flash and debris cloud of an aluminum sphere projectile striking a thin aluminum shield at 5.2 km/s recorded with a framing sequence of 5 µs and an exposure time of 20 ns for each picture (see Fig. 3). A xenon flashlamp source with a flash duration of approximately 80 µs was used in the backlight mode. In contrast to the flash x-ray photograph of Fig. 2, the formation and expansion of the impact flash and the oxidation of the front part of the debris cloud due to the high temperatures from shock-wave heating during the impact process can be made visible. Combining conventional systems with ultrahighspeed digital cameras offers the possibility of a digital high-speed multipleframe radiography system with framing rates of up to 500 million frames/s.

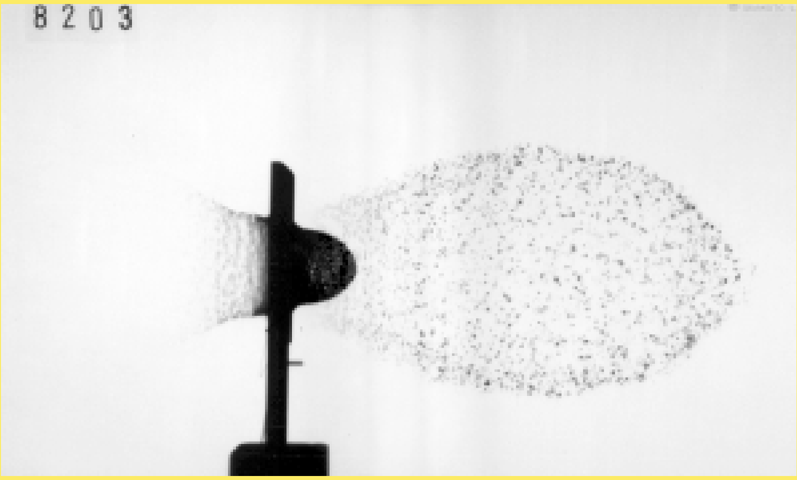

FIGURE 2. Double-exposure flash radiography (with a framing sequence of 60 µs) images the debris-cloud expansion after impact of an aluminum sphere on a titanium/tungsten shield at 5.7 km/s.

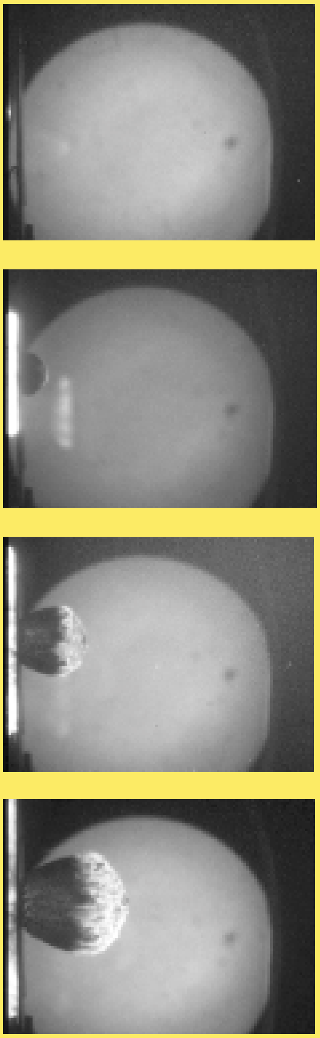

FIGURE 3. Ultra high-speed digital imaging captures the impact flash and debris-cloud expansion behind a thin aluminum shield after it is impacted by an aluminum sphere at a striking velocity of 5.2 km/s (framing sequence 5µs, exposure time 20 ns).

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