ABS

Acoustic Bubble Spectrometer®

Measurement of Bubble Size, Bubble Number & Void Fraction

DYNAFLOW, INC.®

Research & Development in Applied Sciences

DYNAFLOW, INC.

The ABS Advantage

- Very sensitive to bubbles
- Optically transparent liquid or containers are not required
- Distinguishes bubbles from particles
- Built on a PC Windows platform with a user-friendly graphical interface
- Measurements are easily and rapidly conducted
- Validated by comparison with microphotography
- Near real-time measurement
- Cost effective
- User-friendly system

Applications

Maritime – hydrodynamics, propulsor performance, cavitation, power plants, turbomachinery, pumps

Biomedical – blood transfusions, artificial heart valve, bubbles in tissue and blood, decompression sickness

Space – effects of microgravity on multiphase fluids, reduced pressure effects

Oceanography – atmosphere / ocean interface studies, air entrainment, oxygenation, sound transmission, background noise

Multiphase Flow – valves, pumps, propellers, fluid machinery, industrial & chemical processes, specialty fluids, measurement of aeration bubbles, boiling

Education / Research – fluid dynamic & cavitation studies, bubble nuclei in water tunnels

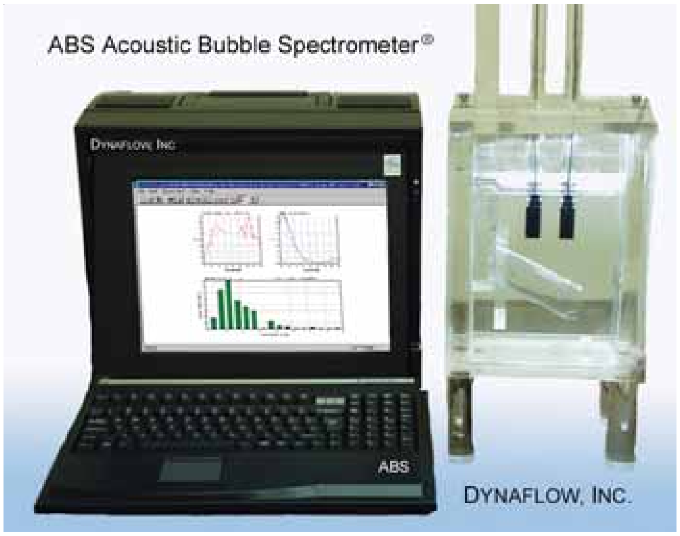
Environmental – categorizing fish by size, monitoring sewage treatment, mixing

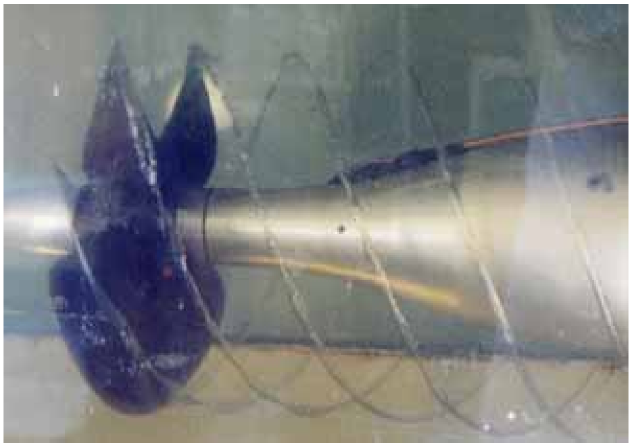
Acoustic Bubble Spectrometer®©

Background

The **ABS Acoustic Bubble Spectrometer**®© is an instrument developed by DYNAFLOW, INC. to measure bubble size distributions and void fraction in gas/liquid mixtures and flows. Not only does the ABS measure the total "void fraction" (volume fraction of the gas phase in the liquid), it also measures the distribution of the sizes of the bubbles. This difficult-to-measure characteristic proves invaluable in numerous areas. For example the top ten meters of the sea contain many bubbles that greatly affect acoustic properties by scattering signals and creating noise. Knowledge of the bubble size distributionis also important when modeling chemical or biological processes. The ABS is also useful in the development of processes that mix a gas in a liquid such as waste treatment and the design of aeration systems.

Another application area where the ABS proves invaluable is engineered systems that might experience cavitation.

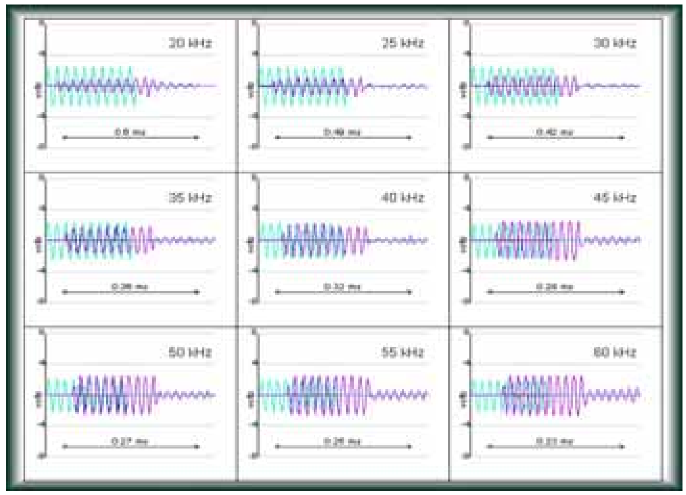




Cavitation is the formation of vaporous and gaseous filled bubbles or "cavities" in a liquid, typically due to a sudden change in pressure. This occurs, for example, along the flow path through a pump or over a propeller blade. Cavitation can have a dramatic effect on both the performance and life of such devices. In particular, cavitation significantly affects the performance and operation of propellers, hydrofoils and pumps. The collapse of cavitation bubbles cause both substantial physical damage and considerable noise. The distribution of bubble nuclei strongly influences the propensity for cavitation. This is particularly important if one wants to experimentally scale a device subject to cavitation since it is necessary to properly control and account for the existing bubble nuclei distribution in the liquid.

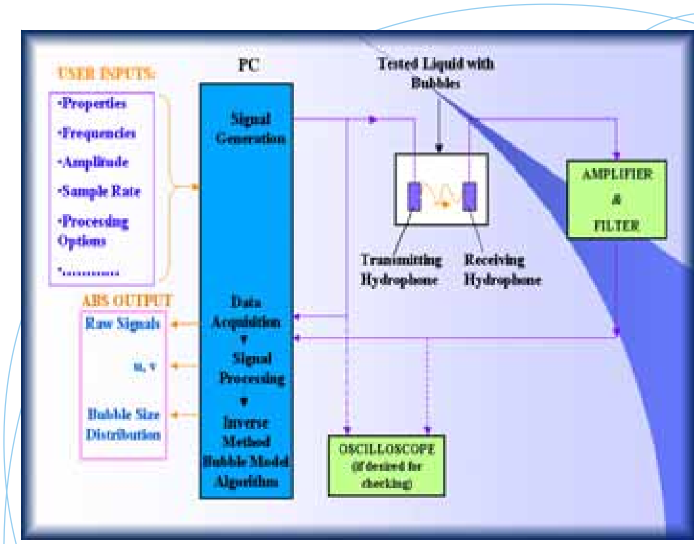
Measuring bubble distribution, visually or optically, is painstaking or impossible when dealing with a large system and a non transparent medium. Moreover, it becomes increasingly difficult to distinguish small particulates from small bubbles. Bubbles, however, are more sensitive to acoustic waves than particulates, hence the ABS can readily pick out small bubbles in a liquid. The ABS also does not require optically transparent liquids or containing structures.

How the ABS System Works



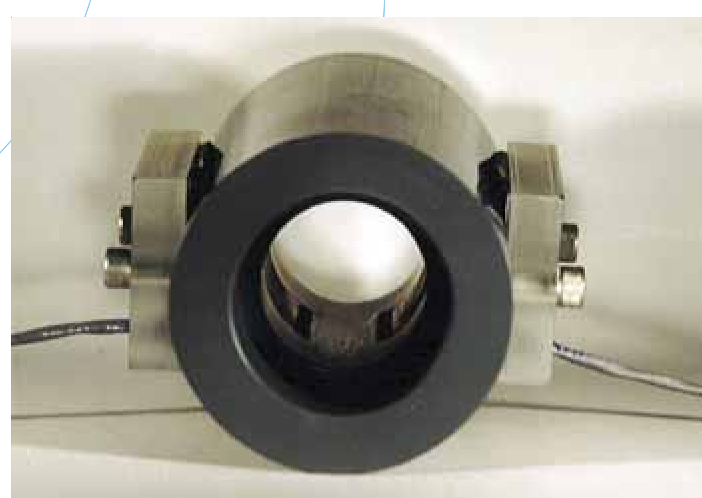
The Raw Signals Display which shows the transmitted and received data.

The ABS is built around a PC Windows platform and includes high-speed cards for signal generation and data acquisition. This high speed operation is required because the signal bursts are very short in order to detect very small bubbles. Additionally, since the system determines any changes in the speed of sound due to the presence of bubbles, true simultaneous sampling is mandatory, especially when the distance between the two hydrophones is small.



Sketch of the ABS Acoustic Bubble Spectrometer®© Operational System

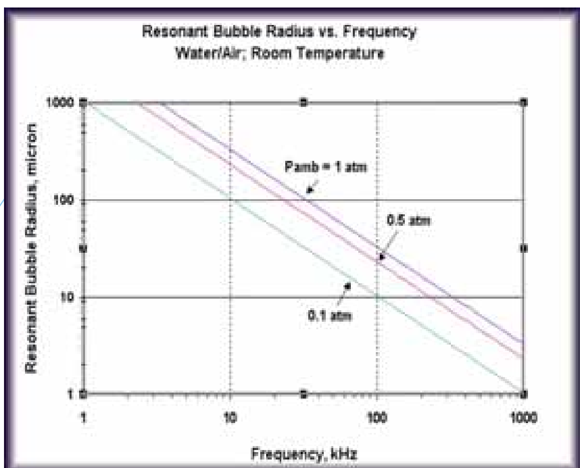
Two hydrophones or transducers are used, one to transmit and the other to receive a series of short monochromatic bursts of varying frequencies. From these readings, the attenuation and phase speed in the bubbly liquid are determined as a function of the frequency. The data from these signals are processed and analyzed with the copyrighted software algorithms developed by DYNAFLOW. These algorithms employ specialized techniques to solve the mathematically ill-posed inverse problems, and thus obtain the bubble size distribution and void fraction.



In-line ABS Measurements

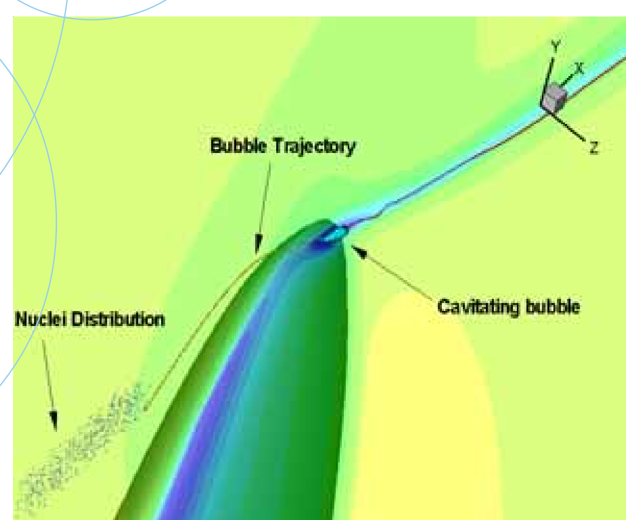
The Principle of Operation

The ABS Acoustic Bubble Spectrometer®© exploits the fact that bubbles strongly affect acoustic wave propagation. Bubble size distribution measurements are based on a dispersion relation for sound wave propagation through a bubbly liquid. Bubbles in the liquid have an effect on the strength of the signal that reaches the receiver, as well as on the speed at which the signal travels between the emitter and receiver. Bubbles of a given size have a resonant frequency where effects are the strongest, but will affect signals of all frequencies. For each burst, the system measures the changes in the speed of sound and the signal amplitude. With more bubbles, the speed of sound and the signal's amplitude decrease further.



A multiphase fluid model for sound propagation through bubbly liquids is combined with a model for the bubble oscillations, including various damping modes. The combined model relates the attenuation and phase velocity of a sound wave to the bubble population or size distribution. These relations produce two ill-posed Fredholm integral equations that require special treatment for their solution, particularly in the presence of noise. Novel algorithms developed by DYNAFLOW are used to accurately solve these equations using a constrained optimization technique that imposes a number of physical constraints on the solution.

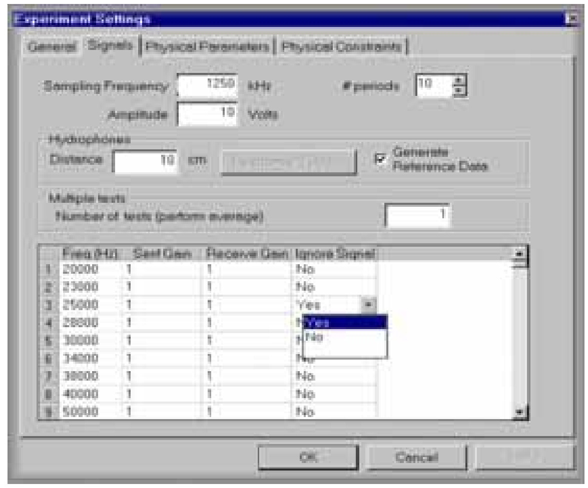
http://www.dynaflow-inc.com/Products/ABS/ABS.htm



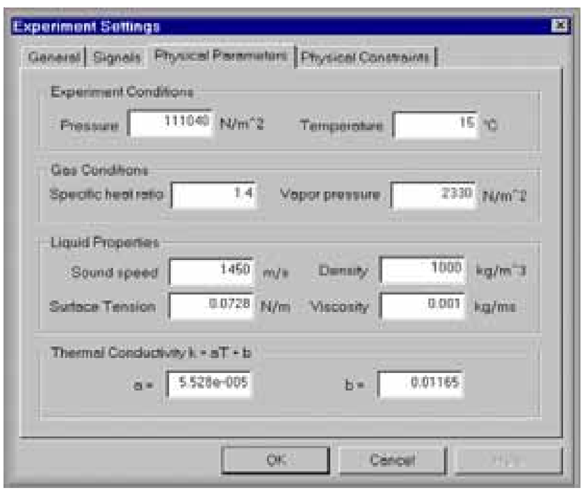
Operation of the ABS

User Input

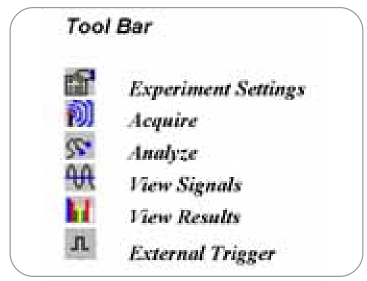
Measurements are easily and rapidly conducted with the aid of a user-friendly Graphical User Interface. All physical, experimental, and analytical parameters are input by the user via dialog boxes initially loaded with default values. Both raw and processed experimental data can be saved to disk for future use. The signals and results are displayed graphically by the interface in real time and can also be stored or printed. The measurement can be started either by clicking on an icon displayed on the screen or through use of an external trigger signal to synchronize with a desired event.



The Dialog Box to enter Signal Parameters



The Dialog Box to Enter Physical Parameters



A "pure liquid" provides a background reference state. This "no bubble" reference state is used in calculating the bubble size distribution from data "with bubbles". This reference state data set is obtained by conducting an experiment in the absence of bubbles under conditions and settings otherwise identical to those which will be employed in determining the desired bubble size distribution.

Displayed Results

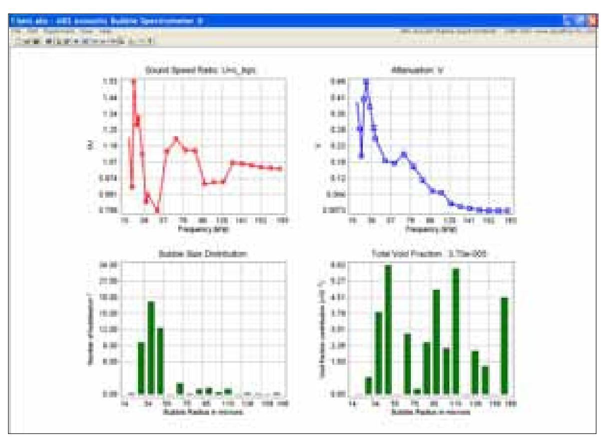
Results from the analysis of the experimental data appear on the screen in easy to read displays in the form of plots.

Sound Speed Ratio (u=c/co) versus frequency

Attenuation Ratio (v) versus frequency

Bubble Size Distribution as the number of bubbles per cubic centimeter versus bubble radius in microns

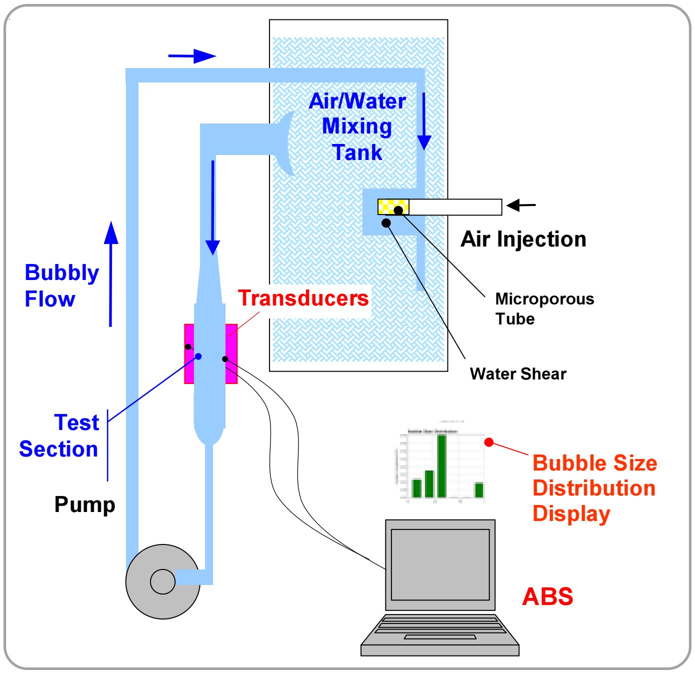
Void fraction contributions vs bubble size

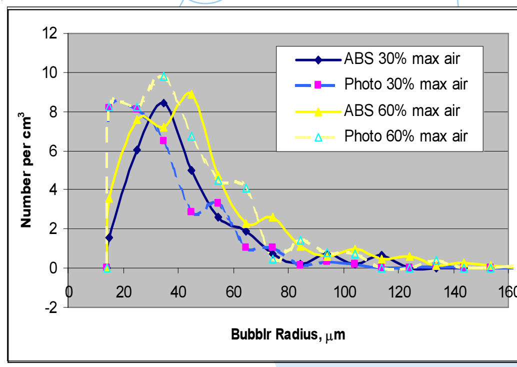


Screen shot of the ABS output graphical user interface showing the sound speed ratio u, the attenuation ratio v and the resulting bubble size distribution.

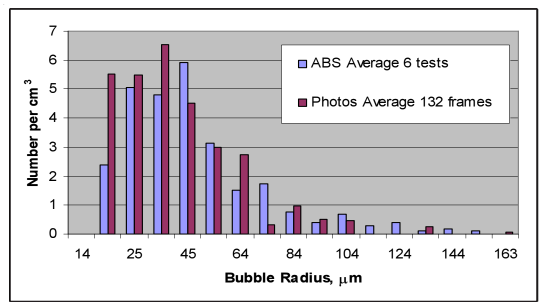
Validation

The bubble distributions obtained from the ABS Acoustic Bubble Spectrometer® have been validated by comparison with microphotography. Bubble populations were generated using electrolysis and air injection through porous tubes. The bubble population obtained using the ABS compared very favorably with the results of the microphotography.





Sensitivity of the bubble size distribution measurements to the amount of injected air



Comparison between ABS measurements and micro video photography

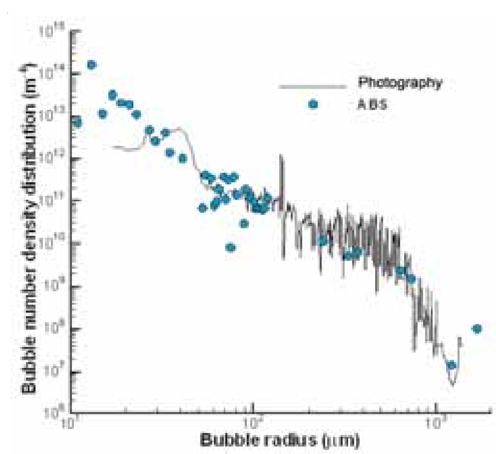
Main Characteristics

Data Acquisition 5 MS/s. , 10 MS/s.

Transducers used :

Size range	1cm	⟶	10 cm
Frequency range	2 khz	⟶	300 khz
Typical Bubble sizes	2µm	⟶	500 µm

Note that the software and the principle of operation are not dependent on the ranges of instrument operation, which are controlled by the data acquisition card and the hydrophones used. These can be upgraded without needing to modify the basic bubble size determination software.



Total Void fraction of 2x10⁻³

Comparison of the bubble density distribution between high speed video measurements and ABS Acoustic Bubble Spectrometer®©

Generation II

ABS Acoustic Bubble Spectrometer®©

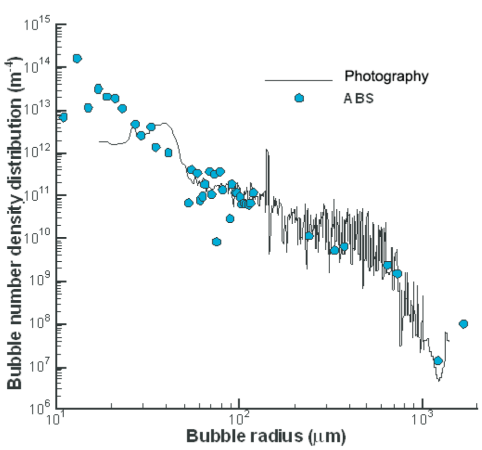
Generation II ABS Acoustic Bubble Spectrometer®© exploits new aquisition cards and PC hardware developments and significantly improves the ABS performance. It is built on a Windows XP based PC (either a desktop or a laptop) with high-speed cards for signal generation and data acquisition. It now boasts a data acquisition speed up to 10 MS/s for each channel, provides stable signal output over a wide frequency range, and is being developed to support more than one set of hydrophones to improve bubble size measurement range.

Base System Includes the following:

- High-speed data aqusition card for signal generation and data acquisition (data sampling rate 5 MS/s per channel).
- A desktop computer, cables and adapters.
- First year support and upgrades of the DYNAFLOW proprietary ABS Software to drive the transducers/hydrophones, and to analyze the data.
- Two 1/2in square transducers with 15 ft. cables

Upgrades for the system are as follows:

- Laptop PC
- Higher Data acquisition speed - 10 MS/s per channel
- Different size transducers
- Amplifier
- Multi-set hydrophones support



Total Void fraction of $2x10^{-3}$

Comparison of the bubble density distribution between high speed video measurements and ABS Acoustic Bubble Spectrometer®©

Generation II Specs

Base System

- Desktop Pentium IV (CPU Only), Windows XP
- 5 MHz Data Acquisition Card
- 1/2 inch Transducers (2)
- First Year Software Support and Upgrades

Upgrade

- 10 MHz Data Acquisition Card
- Notebook PC w/Extension unit for PCI
- 64 Bit Dual Core Processor

Side by Side Comparison of the Generation I and Generation II systems

Requirements	Generation II	Generation I	Generation II Advantages
Sampling rate	5 MS/s or 10 MS/s for each channel	Up to 2.2 MS/s shared by two channels	More accurate results especially for high frequency signals
Resolution	12-bit	12-bit	N/A
Signal Generation-Voltage output	20V peak-peak. Almost constant voltage output over the frequency range	16V peak-peak, voltage output decreases with frequency	Better and almost constant signal output
Signal Generation-Frequency limit	Capable of emitting and receiving signals up to 450 kHz	Capable of emitting and receiving signals up to 200 kHz	Higher frequency signals Enable detection of smaller bubbles

Requirements	Generation II	Generation I	Generation II Advantages
Computer	Any computer with one spare PCI slots	Computer must have 2 spare ISA and 1 spare PCI slots	Can use virtually any Computer
Operating System	Windows NT/XP compatible	Windows NT	Compatible with updated Windows XP
Portable System	Any laptop computer with a PCMCIA slot	Special order lunch box PC is required	Portable system can use virtually any laptop

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DYNAFLOW's capabilities include :

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Multiphase Flows

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Flow Visualization

Underwater Explosions

Computational Fluid Dynamics

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Computed Tomography

Fluid-Structure Interaction

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Materials Erosion

Oxidation

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