

What is size distribution?

Size Distribution is a term used to describe how the suspended particles are distributed over a range of sizes. Size distribution does not have an unambiguous and precise mathematical definition. For example, the size distribution may refer to how the total volume of particles is divided in the size ranges or it may refer to the distribution of total particle areas as well. Often, size distribution refers to number density, i.e. the distribution of numbers of particles in different size ranges. To avoid this confusion, Sequoia uses the terms *volume distribution* and *area distribution*. Even more ambiguity exists in the usage of the term size distribution. Size distribution also refers to the distribution over size ranges of a *unit volume* of particles. This is the *normalized size distribution*, though the use of the word normalized is frequently omitted, which is the origin of this ambiguity.

How do the instruments work?

All LISST instruments are based on the small-angle scattering method that is also known as laser diffraction. Scattering from a laser beam is observed at multiple angles. This multi-parameter equation is then mathematically *inverted* to answer the question: what size distribution would produce the observed multi-angle scattering. Details can be found in Application Note 001.

What wavelength of laser is used? How powerful and how stable is it?

The standard instruments use red diode lasers of 670nm wavelength. The power in the beam entering water is typically 1 milli-watt. Unless reflected from a shiny object into the human eye, the laser beam is harmless. The stability of the laser power output is a few percent over a period of a few years. Because the power may vary with temperature and age, the instruments incorporate a 'reference sensor' that measures the laser output. The PC Windows software reads the reference sensor and corrects for drifts.

Can I buy instruments outside the standard specifications (larger/smaller particle sizes)?

Yes, certain custom specifications can be incorporated into an instrument. Please contact Sequoia.

What are some of the non-standard (custom) configurations made so far?

Sequoia has made custom instruments for high turbidity environments, for deep ocean observation, for green-laser wavelength, and for low-concentration observations. The company is interested in solving your special needs. Please contact us with your requirements.

Can I buy LISST instruments in the green wavelength?

Possibly. Green laser technology is not sufficiently far enough along at the time of this writing (8/99) to incorporate the laser into a reliable instrument. For special applications, Sequoia has developed a green laser instrument. However, the less developed laser technology results in high power consumption and instruments that can be used only for short times unless on external power.

How does the LISST measurement of suspended particles compare with transmissometers and other scattering sensors?

Transmissometers and optical scattering-based sensors respond essentially to the total particle area that is illuminated. Clearly this is not related to the volume in a simple manner when the size distribution includes particles of many sizes. Acoustic scattering sensors also suffer from the absence of a simple relationship between scattering and particle volume. Since the LISST instrument measures particle size distribution it is able to adjust calibration changes in particle size.

Why doesn't the LISST instrument measure mass concentration?

All optical instruments, including ours, observe light scattering which has no simple relationship to mass density. For this reason, Sequoia provides calibration only with volume concentrations. If mass density is of interest, it can be estimated from settling velocity using the LISST-ST.

Can the LISST instruments measure bubbles?

Yes. Bubbles are spherical or near spherical objects. They are ideally suited to the measurement principles of the LISST instruments. However, the LISST sensors can not distinguish bubbles from non-bubble particles.

What is the range of measured sizes?

The LISST instruments can analyze three ranges of particle sizes. The original instruments manufactured by Sequoia covered the range 5-500 microns. This was the Type A instrument, now discontinued. The current models measure over the size range 1.25-250 microns (Type B) and 2.5-500 microns (Type C). Both current instruments cover a 200:1 dynamic range of particle sizes.

Why is the size range limited? Can it be expanded to cover a greater dynamic range?

The corresponding dynamic range of angles over which scattering measurements are made limits the size range. In the current models (Types B and C), the dynamic range of scattering angles covers a 200:1 ratio. These angles are determined by the size of the ring detectors and focal length of the receiving lens (see Application Note 001). Typically, it is difficult to expand the size range without adding more complexity (additional detectors, etc.) or a different geometry; e.g., the Reverse Fourier method. The reverse Fourier method requires high particle concentrations which are rarely encountered in nature. For this reason, Sequoia has used the method that permits observations of weak suspensions.

What are the pros and cons of the LISST method versus single particle counting?

The LISST method is an *ensemble* method. It obtains the size distribution in a single ‘flash’, i.e. a single look. Of course, averaging can be employed to remove natural variability in the suspensions. In contrast, single particle methods build up statistics by counting. In the natural marine environment, single particle counting methods suffer from two disadvantages. The first is the counting of double or multiple particles illuminated by a laser beam as a single particle. This may occur because the counting methods require very weak suspensions. The second disadvantage is the time required to obtain adequate statistics. Particle counting by methods such as the conductivity change across an orifice (made famous by the Coulter Counter) suffer from the disaggregation of natural particles during passage through the orifice. In contrast, laser diffraction need not alter the particles. The absence of moving parts in laser diffraction, in contrast to the pump mechanism needed for the orifice methods, is also an advantage when using field instrumentation.

What is the maximum concentration that the instruments can work in? Why is the useful working range of the instruments specified in terms of optical transmission?

The LISST instruments measure scattering of light by particles. The underlying mathematical model assumes that light is scattered only once from the laser beam, and that scattered light is not scattered a second time by another particle. This is called single scattering. Single scattering is generally prevalent till the optical transmission over the instrument sensing path drops below about 30%. Multiple scattering begins to play an increasing role at lower optical transmission. Although mathematical models for multiple-scattering exist and can be used in situations where optical transmission is lower, we have not implemented them. The result is that the concentration range where the LISST sensors may be used is defined by the optical transmission. Since the relationship between optical transmission and concentration depends on particle size, for practical use the specification sheet for each of the instruments lists concentrations for a defined particle size of 30 microns. One may estimate the concentration limit for a 3 times larger particle to be essentially 3 times larger, and vice versa.

What is the minimum measurable concentration of suspended material? What sets the limit?

The minimum concentration limit is also defined with optical transmission. The reasons are different although similar. The amount of light removed from the laser beam (most of which is detected on the ring detectors) is of course reflected in the measure of optical transmission. Thus, when optical transmission is very high, for example 99.9%, very little light is scattered from the laser beam and hence available for detection on the ring detectors. Under these conditions, the signals are so weak that a smooth estimate of the magnitude of multi-angle scattering is not obtained except by further averaging over many sweeps of the detector rings. This is really a signal-to-noise issue. In our experience, with our hardware, 98% transmission or higher begins to produce noisy estimates of size distribution from single scans. The usual methods of noise reduction are applicable: average, average, average. It is possible to find the number of sweeps to average based on a tolerable noise level and quick estimates of the weighted sum of the normalized standard deviation (std. dev./mean) of the measurements of all rings. Please contact Sequoia if this is an issue for you.

Can I extend the operating limits by shortening or lengthening the optical path?

Yes indeed. The operating limit can be extended in either direction. For example, the 2.5 cm path reducing optical flat is available as an accessory for the LISST-100 increases the operating range of concentrations by a factor of 2. The LISST-‘Long-Red’ instrument, with a 20 cm path extends the operating limit to a value 4 times smaller than the standard 5 cm path LISST-100.

What happens when particles in a natural suspension are outside the measurement range?

Particles too large are reported in the nearest sizes which is at the large particle end. The reverse also applies, i.e. particles too small for the specified range show up as particles in the smallest measurable ranges. In these cases, however, the concentration estimates are erroneous.

Does the concentration estimate include particles bigger or smaller than the specified size range (1.25 – 250 micron)?

No. The concentration of particles outside the measurement range is not faithfully estimated. This is a fundamental limitation that follows from the fact that the needed detail of information about these particles is not available.

How accurate are the LISST instruments?

Accuracy refers to the degradation of a measurement that results from measurement noise. This noise must be distinguished from variability in a sample, e.g. the variability in suspended sediment clouds in the marine or atmospheric boundary layers. Thus, the accuracy of the LISST instrument leads to the question of measurement noise. Through judicious design, the total *measurement* noise in light scattering is reduced to less than one digital count. This makes the primary measurement ‘noise-free’. However, the mathematical inversion of the scattering seldom produces an exact fit of the data to the size distribution that would produce it. This ‘residue’ (difference between observation and fit) is the source of noise in size distribution measurements. We are not aware of a simple, single parameter method for specifying this noise. Based on empirical observations in the laboratory, Sequoia claims a conservative 20% accuracy in the measurement of size distribution. Your measurements should typically produce higher accuracy.

What is the size resolution of the LISST instruments?

The precise answer to this question is not possible without delving into a large amount of mathematical description. In a simple sense, if one employs a single-size sediment sample for testing how well its size is determined, the laser diffraction method will report a size distribution with a near-Gaussian shape, and a half width (FWHM) of roughly 3 bins. This translates to a size resolution (ability to distinguish particles of different sizes) of roughly 36% of the mean size. For example, when observing small particles, say 5 microns, the resolution is about 1.5 microns. In contrast, when observing 100 micron particles, the resolution will be 36 microns.

When the suspension being measured is known a-priori to be extremely narrow, which is often the case, special processing can be employed. Please contact Sequoia if this situation applies to your case.

How does the LISST-ST measure size dependent settling velocity?

The LISST-ST incorporates a Settling Tube on the standard LISST-100 sensor. This permits the measurement of size distribution near the bottom of the settling tube over time. In operation, the settling tube draws and captures a volume of water. Doors on the tube close, and isolate the sample. The initially well-mixed particles begin to settle. The fastest settling particles disappear first from the near-bottom location where the laser measures size distribution. Thus at this point in time, the size distribution observes the absence of particles in the fastest settling particle size bin. At later times, the next slower classes settle out and so on. Therefore, the time at which any size class settles out defines its settling velocity. The actual estimation of the settling velocity for the n th size class, $w_{f,n}$, is done by dividing the settling column length (30cm) by the settling time T_B , as $w_{f,n} = 30 / T_B$.

Why does the LISST-ST report settling velocity in only 8 size classes, not 32?

The reason for the lower resolution in sizes for settling velocity estimates has to do with the inverse of the scattering that determines the size distribution. In order to be sure that the adjacent size class does not contaminate the estimates of settling velocities, it is important to make sure that the size distribution estimates are similarly not contaminated by adjacent size classes. This requirement suggests the use of lower resolution in the inversion of scattering. In other words, we make sure that the size resolution in the size distribution is one size-bin wide, and this requires broader size classes.

Can I convert the LISST-100 to a LISST-ST and vice versa?

This conversion can be done at Sequoia but requires extensive realignment of the optics and testing of mechanical integrity. Additional testing of immunity of alignment to water pressure will also need to be done.

How does the LISST-25 instrument obtain a constant calibration measurement of total suspended volume concentration of particles?

The LISST-25 employs specially shaped detectors in the focal plane of the receiving lens of the optics. The shape of the detectors is mathematically determined. For a detailed explanation, please see [Application Note No. 005](#).

What is the Sauter Mean Diameter (SMD) measured by the LISST-25?

The SMD is defined from the ratio of particle volume V , and particle area A . For spherical particles, it is the ratio $1.5V/A$. The physical significance of the SMD lies in thinking of the surface to volume ratio of a particle dispersion. The term SMD originated from research in aerodynamics and combustion. SMD has significance in marine geology because the ratio of volume to surface area of particles affects the interpretation of light attenuation.

Can the LISST instruments be towed? How fast? Is there an effect of tow speed on the measurement?

Since these instruments are based on the magnitude of light scattering, not Doppler shift, they can be towed at any speed without affecting the measurement. Only the damage-threshold limits tow speed which in most cases is a very high speed. The LISST-ST, of course, cannot be towed as motion of the settling column will cause internal movement of the water column. The internal movement is caused by density differences of the water column, in turn caused by suspended particles or trapped air bubbles.

Can the instruments be used in the profiling mode?

Yes, the LISST-100 and LISST-25 instruments can be used in the profiling mode. In this mode, the instruments may be used to store data on internal memory, or they may send data up a wire, or both. We recommend that whenever possible, the user should employ both internal recording and surface transmission.

Can I store data on the instrument and transmit data up a wire at the same time?

Yes, please see above.

In the profiling mode how long a wire can I use for data communications?

The communications are done over an RS-232C cable, so that the standard restrictions on length apply. In practice, we find the maximum for this length to be around 50m. Please contact Sequoia if you wish to use longer profiling cable.

Can the submersible LISST instruments do “range gating” similar to an acoustic sensor?

No. Range gating with light underwater requires very high-speed electronics. Additionally, the geometry of the measurement is unsuitable for range gating.

What is the effect of particle index of refraction on the measurement?

Small-angle scattering is generally considered insensitive to the refractive index of particles. In an oversimplified manner, forward scattered light can be considered to be the sum of light that is diffracted around the particle and light that entered the particle and exited in the forward direction (‘transmitted light’). The latter is usually weak as it is scattered over a much larger range of angles from the original beam. Thus, diffracted light dominates. Therefore, when the refractive index is close to the surrounding medium (water) that the transmitted light will be stronger. One can expect a dependence on the refractive index. Fortunately, the dependence is weak and it is most significant for the smaller sizes, not for the larger sizes. The reason for the size dependence cannot be explained in simple physical terms. It is merely the consequence of the detailed Mie solution to the problem of light scattering by spheres. In any case, refractive index influences the small size end of the particle size distribution.

When considering the influence of refractive index on the measurements by the LISST-25 instrument, it is found that the estimates of volume concentration of larger particles are similarly relatively unaffected by changes in the refractive index, but the smaller particles may be affected by as much as a factor 2-3. Errors in estimates of the Sauter Mean Diameter may be similarly as much as a factor of 2-3 due to changes in the refractive index over the model used from Sequoia.

Can I specify a certain refractive index for my measurements of size distribution with the LISST-100?

Yes. You may request a special matrix for use in particles of known refractive index. Sequoia will be glad to provide it. It takes a few days to deliver the results.

Can I specify a certain refractive index for my measurements of size distribution with the LISST-25?

No. The detectors are designed for a specified refractive index, chosen as 1.15 (relative to water). The exchange of detectors for different index particles is not practical. However, the fact that volume concentrations of large particles are mostly unaffected by changes in index of refraction is to be noted. Again, it is to be noted that not only are the LISST instruments subject to errors associated with index of refraction, the error is common to all scattering based optical sensors.

Can I use a mix of refractive indices?

Yes, but it may not be practical. In principle, it is possible to specify that the scattering mixture is glass, oil, etc... In this case, one could compute the scattering matrix for these substances and then solve to find what percentage of each is present by a minimization procedure. While this is possible on an individual effort, we can not support such calculations at this time. Please contact the factory if you would like to have us do the calculations.

What is the effect of particle shape on the measurement?

All computations in the LISST-100 are based on the assumption of the particles being spheres. Although there is a wide body of literature in the optical sciences that deals with regular and (recently) irregularly shaped particles, it is of no generalized value. A future Application Note will address this issue in more detail. However, note that the measured scattering, being principally the light diffracted around particles, responds to particle cross-section. Spheres being the lowest cross-section per unit volume whenever non-spherical particles are examined, the volume concentration will be *overestimated*. The fractional overestimate depends on the shape itself; thus, there may be academic interest in estimating this 'overestimation ratio' for selected natural/man-made particles.

What is the result if the scatterers are aggregates?

Please see comments on shape above. Aggregates that are highly porous present problems for all optical measurements. We are unable to offer a definite answer except to state that all optical measurements of aggregates, including photographic suffer from the same uncertainty. For those readers who are familiar with optics theory, a helpful idea in visualizing the scattering by aggregates is to visualize an aggregate as a fibrous material filled with random shape holes. The diffraction then would be the Fourier transform of the 'opacity function' of this composite.

Is there any effect of flow disturbance around the instrument?

The largest and most dense particles may not faithfully follow the flow. This is a very high-order effect and is typically of concern in gaseous suspensions, not in liquids.

What is the maximum depth for a submersible LISST instrument?

The standard maximum depth is 300 meters. Sequoia has developed a version of the LISST-100 instrument for use in the deep ocean, at depths up to 5,000 meters.

What is the best orientation to use the instrument? In laboratory, field?

The instruments are best used with their windows in the vertical plane either in the laboratory or in the field. This is typical of all optical sensors. This keeps particles from settling on the windows. In situations where the natural flow is strong enough, or when towing or profiling, a vertical orientation of the instrument (i.e. windows in the horizontal plane) may be employed.

Does daylight affect the measurement? How should I deal with it?

Strong daylight affects the measurement of small particles. When operating in bright sun or daylight, shielding is recommended. At shallow depths underwater on a sunny day, it is recommended that the instrument be pointed with sensing end down.

What type of mounting should I use?

The mounting depends on the instrument. LISST-ST instrument should be mounted on a stable platform that is bottom mounted (see photo on right). Mooring use has not been attempted but it may succeed in calmer currents. The LISST-100 and LISST-25 can be clamped in the necked narrow mid-section, or if needed, just 'inside' of the end-caps. Clamps should never be attached to the end-caps or the protective rings at the ends.



How do we deal with bio-fouling of optical windows?

Although the usual range of poisons may be used to suppress bio-fouling (but none directly on the instrument windows!) it is our experience, backed up by US Navy documents, that highly polished glass resists bio-fouling. Biology, quite simply finds it hard to get a foothold on a smooth glass surface. The LISST windows are polished to the highest commercial specifications and have been known in our own research to be clean when the rest of the housing is massively covered with growth. This observation is from an experiment in bottom boundary layers fielded at the LEO-15 experiment site of the Rutgers University, New Jersey. When left in the photic zone, barnacle growth on windows can occur in less than a week. We are not able to advise a cure for this, other than the usual poisons. Barnacles can be readily removed by soaking the instrument in a vinegar solution!

What type of batteries do the instruments use? Where can I get these batteries? How long can the batteries last?

All instruments use custom made Alkaline batteries, except the LISST-Portable that uses rechargeable Nickel Metal-Hydride (NiMH) batteries with a 3-hour continuous use life. The main batteries used in the LISST-100 and LISST-ST are identical, with a +/- 15V-output and 14A-hr capacity. This battery can power the instruments for well over 6 months. The -ST uses an additional rechargeable Lead-acid battery to power the door motors. The batteries can be purchased only from Sequoia. If other batteries are employed, the warranty may become void.

The LISST-25 uses 4 standard 9V alkaline batteries.

How can I get more than standard life out of the battery?

For very extended deployments, the battery drain of the LISST-100 and -ST can be reduced to a few micro-amps. The Tattletale software used in the instruments needs modification to drop the instrument into the 'DONE' mode between samples. In this mode, the instruments shut down the main computer, keeping only the memory energized.

When using the 'DONE' mode, date and time information is lost. Alternate methods for keeping track of time can be devised in this case. Typically, a variable keeps track of the number of times the instrument 'wakes' from the DONE mode. This variable is stored and later interpreted as time.

How long can the back-up battery preserve my data?

The data back-up battery of the LISST-100 and LISST-ST instruments has an estimated life of about 5 years. Nonetheless, we recommend that they be replaced every year.

What is the data capacity of each instrument? What happens if I try to write more data when the memory is full?

The standard data capacity of the instruments is as follows:

LISST-100: 512K, expandable to 2M. Each data record uses 80 bytes.

LISST-ST : 512K, expandable to 2M. Each data record uses 80 bytes.

LISST-25 : 512K, each data record uses 18 bytes.

LISST-PORTABLE: 512K, each data record uses 160 bytes.

All instruments will not overwrite the data when memory is full. They will simply quit operation and shut down.

Are the instruments Y2K compliant?

The instruments and PC Windows software are all Y2K compliant.