A PRIMER

OF

SELECTED VISIBILITY MEASUREMENT ISSUES

FOR

LARGE OBJECTS

July 1986

CONTENTS

I. INTRODUCTION

This short note summarizes several issues related to making detailed optical measurements of large-scale objects. The issues involved are set within the context of selected assumptions and constraints developed to scope a very large and complex technical area. In the following section, the equivalency between the visibility of an object and selected measurement protocols is discussed. An evaluation of different approaches to developing a large scale measurement facility is provided in Section 3 to provide an intuitive feel for the differences between scanning and flood illumination. A summary of issues outstanding is presented in Section 4.

1. This note focuses uniquely on issues associated with developing a large-scale, ground-based, indoor measurement facility. Other approaches, e.g. outdoor ranges, table-top, small scale laboratory ranges, or in-situ space and field-testing approaches are excluded;
2. The analysis assumes a specific viewing geometry;
3. Only measurements of visible optical signatures have been addressed herein. No consideration has been given to thermal or infrared signatures or other signatures outside the visible frequency band;
4. This analysis was done to scope the range of problems that relate to measurements that validate an optical signature requirement. As such, this work does not address the precise optical requirement to be validated not the correctness or relevance of such a requirement. It is intended to identify problems that should be addressed in the future; finally,
5. This note does not address important issues related to an operational detectability assessment.

Figure 1. Issues to be Addressed

2. VISIBILITY AND MEASUREMENT EQUIVALENCY

Suppose we have a surface being illuminated by sunlight and we wish to know its brightness (image irradiance) for imaging purposes. The usual approach is to assume that the surface is a Lambert reflector. This means that its brightness is constant for any viewing angle. Clouds and white bond paper are common examples of surfaces that closely approximate Lambert surfaces across the visible spectrum. We will first review this case and then examine the situation where brightness varies as a function of both the illumination and observation angles. In addition to specular, (i.e., mirror-like), many surfaces exhibit such directional reflectance properties. For example, a full moon is seven times brighter than a half moon because the lunar surface scatters preferentially in the direction of the incident light.

2.1 LAMBERT SURFACE

The simplest geometry is that shown in Figure 2. The target consists of a flat surface that is illuminated at some angle of incidence, θ_i, as shown.

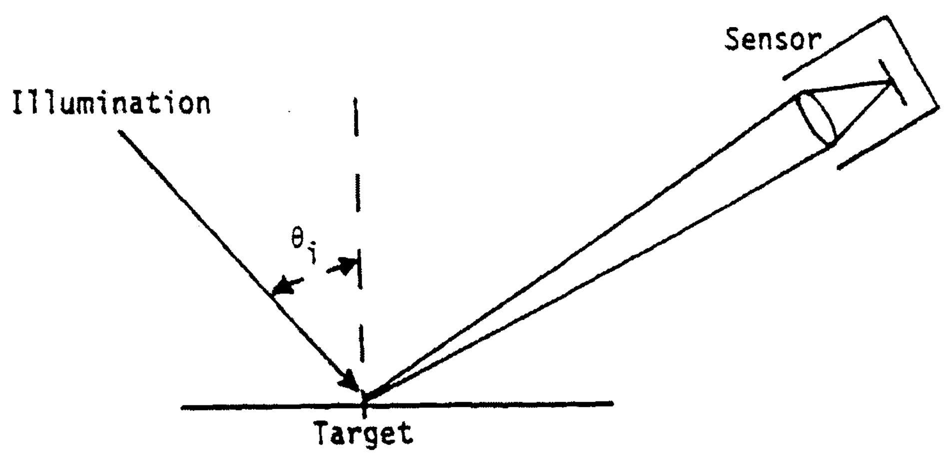

Figure 2. Illumination and Viewing Geometry.

The first thing to note is that the irradiance (the number of watts per unit area incident on the surface) depends on the illumination angle. If the solar constant is E_s, then the actual irradiance is $E_s \cos \theta_i$. Thus, the irradiance peaks at about "noon" and then continually diminishes until the sun sets. (For complicated shapes, θ_i varies over the surface so that irradiance is also complicated.)

An alternative way is to think about this in terms of the total power (radiant flux), Φ, incident on the surface. This can be expressed as

$$\Phi = E_s A_p ,$$

where A_p is the projected area of the surface as viewed from the direction of the incident radiation. If the area has a specific shape (square, for instance), then the projected area depends on the orientation of the surface as well as the angle of the incident radiation. Thus, two angles are involved in determining the total incident power.

For a Lambert surface with a reflectance , , the radiance, L, (watts per unit area per steradian) is obtained by dividing the irradiance by π. Thus

$$L = \rho E_s \cos {}_i / \pi .$$

If we assume that an imaging sensor utilizes a solid-state area detector to image the target, then the relevant area depends on the projected dimension of a pixel as shown in Figure 3. If R is the distance to the object and F the focal length of the collection lens, then the projected area of the pixel, A, is

$$\Delta A = d'^2/\cos\theta_v = (Rd)^2/(F^2\cos\theta_v) .$$

$$\text{where } d' = \frac{R}{F} d$$

$$\theta_v = \text{zenith angle}$$

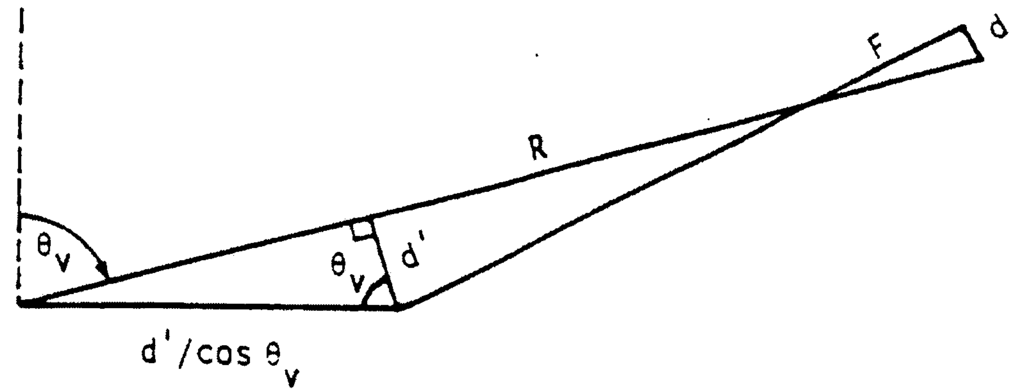

Figure 3. Projected Pixel Geometry.

The number of watts collected by the lens is obtained by multiplying the radiance by the projected area and the solid angle subtended by the lens. The solid angle defined by the lens, $\Delta\omega$, can be written

$$\Delta\omega = \pi D^2/4R^2 \quad ,$$

where D is the lens diameter. The watts collected by the lens, Φ_C, can therefore be expressed as

$$\Phi_C = L\, \Delta A\, \Delta\omega$$

$$= \rho \frac{E_s d^2 \cos\theta_i}{4(F/D)^2 \cos\theta_v} \quad ,$$

where the ratio F/D is called the F-number of the lens. Note that as long as the target is larger than the projected pixel area, the number of watts collected is independent of range.

If the target is smaller than the projected area, then the collected power will decrease with range. In this case, it is more convenient to work with the radiant intensity, I, of the target. For a Lambert surface with reflectance, ρ, I is Φ divided by the solid angle, π. The power collected by, Φ_c, will then be

$$\Phi_c = I\Delta\omega = \frac{\rho E_s A_p D^2}{4R^2} .$$

Thus, larger lenses are required to collect some minimum power as the distance increases. This is the reason large telescopes are needed to see distant stars.

2.2 SPECULAR REFLECTOR

Now suppose we have a flat plate that is not a Lambert surface and is specifically a specular reflector. By definition, nearly all the incident energy will be reflected at an angle equal to the angle of incidence (see Figure 4).

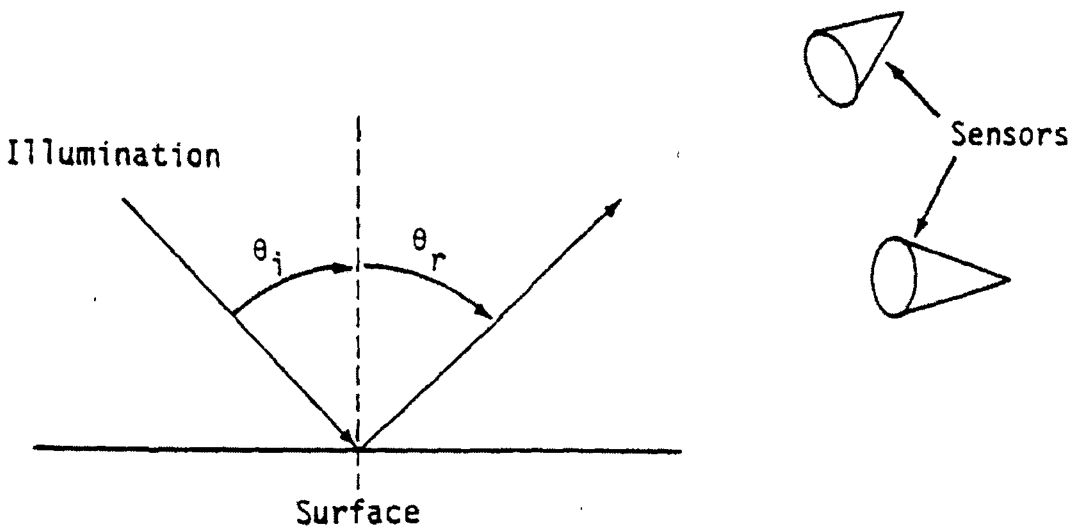

Figure 4. Illumination and Viewing Geometry

If a sensor is looking in the direction of the reflected energy, the plate will appear very bright. Sensors looking in other directions, however, will see only some minute fraction of the reflected energy. If the plate is uniformly irradiated and is uniform and isotropic, then the fraction of the radiation that is reflected in a particular direction is called the bidirectional reflectance-distribution function (BRDF). Its value is a function of the radiation wavelength as well as two angles of incidence and two angles of reflectance. The BRDF itself is a ratio of infinitesimals and therefore is never measured directly. Instead, measurements are averaged because of the spread in the incident and reflected angles. The BRDF is useful for characterizing the reflectance properties of a simple surface such as a mirror, but misleading and not useful for complicated surfaces.

2.3 COMPLICATED SURFACES

If surfaces are not simple, then it can be quite difficult to characterize the "scattering" properties of the surface. For example, suppose we have a complicated arrangement of surfaces such as that shown in Figure 5.

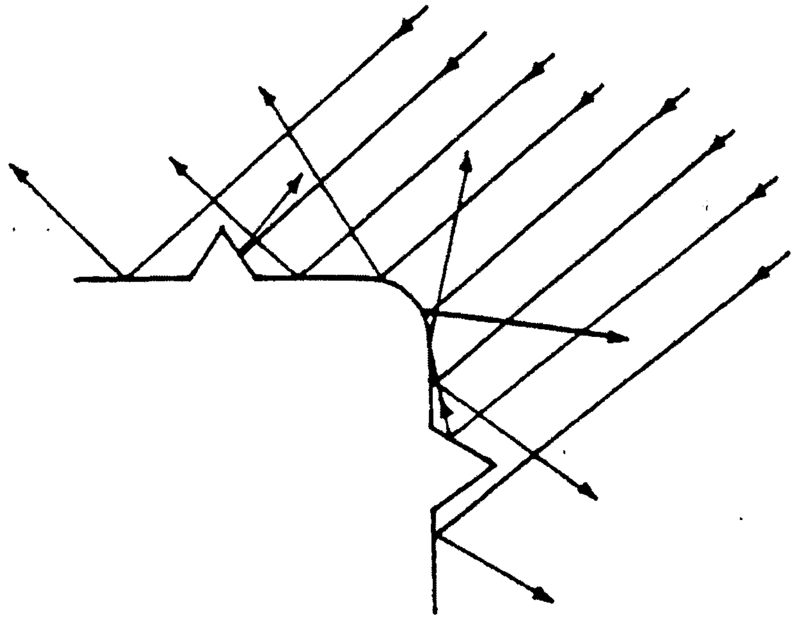

Figure 5. Irradiation of a Complicated Specular Surface.

Because the radiation strikes each surface at a different angle, the irradiance of each surface is different. Thus, even if all the surfaces were Lambertian, their radiant intensities would vary in a complicated way. For specular surfaces, the situation is much worse because the BRDFs (or their equivalents) do not vary in a known way. Moreover, some surfaces may be irradiated by secondary reflections from one or more other surfaces.

Because the dimensions of the surfaces could be quite small and there could be numerous surfaces in a small area (1 cm^2, for instance), trying to estimate scattering in a particular direction from the BRDF property of each surface would be hopeless. The complicated surface will, of course, still have directional scattering properties--but they should not be called BRDFs. There are some questions, however, on how to measure these properties, and, more importantly, how to synthesize them.

2.4 THE MEASUREMENT OF SCATTERING PROPERTIES

If we wish to estimate the directional scattering properties of a surface or combination of surfaces from laboratory measurements, there are several considerations. First, there are serious questions concerning the characteristics of laboratory illumination versus the real stuff. Lack of uniformity in beam intensity could lead to significant measurement errors. Variations in power as a function of wavelength will also have an effect. Even actual sunlight will be altered by the earth's atmosphere and will therefore vary during the day. Solar simulators differ from sunlight in spectral power as well as angular spread. Some light sources are polarized and this significantly affects reflectance measurements.

Assuming we can compensate for these potential illumination errors, there is, however, perhaps a more fundamental issue. How does one utilize measurements from a relatively small area to characterize the properties of a larger surface or combination of surfaces? If the surface is flat and uniform (i.e., a measurement for one portion of the surface is statistically valid for the remainder of the surface), the answer is straightforward. The scattering is proportional to the projected area of the surface, A_p, divided by the cross-sectional area of the test beam, A_s. Of course, it must also be modified to account for variations from a "true" solar spectrum. Thus the estimated radiant intensity, I, in a particular direction could be written

$$I = K_m(A_p/A_s)I_m(\theta_i, \phi_i, \theta_v, \phi_v) \quad ,$$

where K_m accounts for variations with the solar spectrum (and varies with wavelength), and $I_m(\theta_i, \phi_i, \theta_v, \phi_v)$ is the measured intensity for a set of illumination and viewing angles. In practice, the "measured" values would probably be extrapolated from a relatively small set of measurements at selected illumination and viewing angles. The measurements would also probably be normalized to compensate for variations in illumination source power. For a simple, flat surface, these normalized intensity measurements are equivalent to BRDF measurements.

Suppose, however, that a surface is curved like a cylinder or sphere. The illumination and viewing angles will vary over the test area because they are measured with respect to surface normals. The smaller the test area, the less the variation, but the required number of measurements is increased. Because it is not feasible to make measurements for all possible combinations of angles, extrapolations would be mandatory. Increasing the size of the test area reduces the extrapolation requirements, but, even when the entire surface is illuminated, extrapolations are required for the viewing angles.

If a surface is curved but not complex, then we could estimate total intensity from the surface somewhat similarly to a flat surface. For instance, a series of test measurements on a cylindrical surface could be treated as a series of N "flat" surface measurements. The total intensity, I, would then be

$$I = K_m \sum_{j=1}^{N} \left(\frac{A_{pj}}{A_s}\right) I_{mj}\left(\theta_i, \phi_i, \theta_v, \phi_v\right),$$

where A_{pj} are the projected areas of the surface in the direction of the incident beam and I_{mj} are the corresponding measurements for the associated test areas in the direction θ_v, ϕ_v. This is certainly not precise because there will be gaps or overfills of the test areas. Also, the normalized measurements, I_{mj}, are, in general, not equivalent to BRDFs because there is no one normal to a curved surface and therefore no single set of associated angles. Again, the larger the test areas, the better the estimates should be because there are fewer problems with gaps and overfills (see Figure 6).

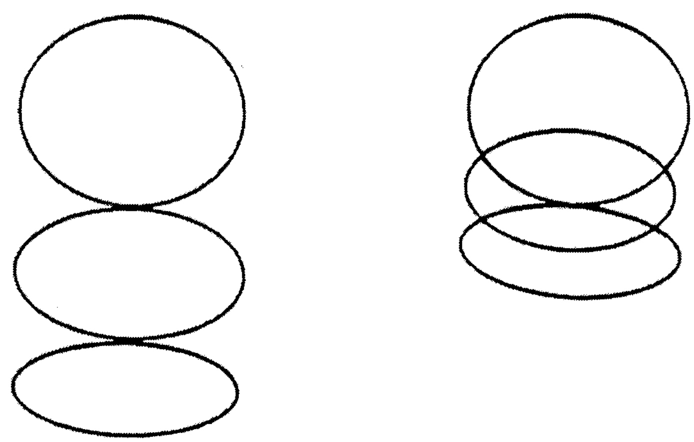

Figure 6. Test Area Gaps and Overfills for a Curved Surface

For complex objects, there are potential problems with secondary reflections as well as the possibility that extrapolations are less accurate because variations in angular intensity are more pronounced. For example, assume that a single defect, or feature, is the predominant scatterer in a test area. Angular intensity measurements, I_m, will depend on the location and orientation of the defect as shown in Figure 7. If the beam intensity is not uniform, it will also affect the measurements. Because of these effects, it is probably necessary to scan completely all complex areas. Scanning gaps would permit potentially important scattering sources to be missed. On the other hand, overscannning not only takes time, but there are questions concerning the equivalency of such measurements to that of a fully illuminated area. If we recognize the possibility of secondary reflections, analysis and synthesis become even more complicated. Again, these potential problems are ameliorated as the size of the test area (scan spot) is increased.

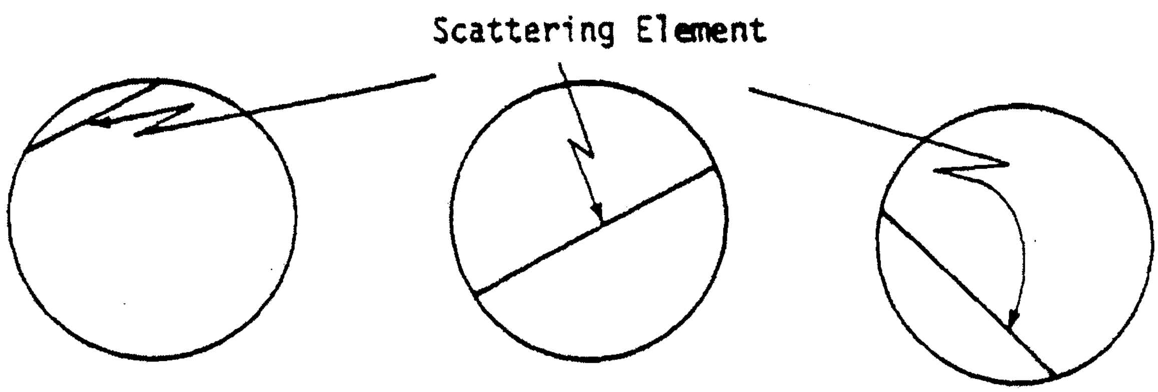

Figure 7. Angular Intensity Measurements Depend on the Location and Orientation of the Dominant Scattering Sources as Well as on Beam Uniformity.

2.4.1 Detector Field-of View

The actual value of an angular intensity measurement depends on the field-of-view (FOV) of the detector or a detector element. The FOV, in turn, depends on the distance between the collection lens and the illuminated surface. Except for the simplest type of surface, i.e., a flat plate, distances will vary because of changes in object shape and illumination angles. In theory, distances could be calculated and their effect compensated. However, a more effective and more accurate approach is to directly compensate for changes in FOV by placing a Lambert reflector at the irradiated spot.

One way to make the measurements is to match the detector FOV to the spot area. This gives a measurement that is averaged over the solid angle. Therefore, the smaller the FOV, the more precise the angular intensity measurements. A small FOV might be desirable then if intensity is changing rapidly with angle. Another, and perhaps more important, reason for wanting a small FOV is to locate "bad" spots within the illuminated area. In other words, a surface may, in general, be a low scatterer except for a few features, and we would like to know which features are the culprits.

One way to do this is to use an imaging array such as a CCD. The individual pixels have a small instantaneous FOV while the total FOV can be matched to the spot. Individual pixel measurements would indicate bad spots, or the measurements could be statistically analyzed to determine variability of the measurements.

2.4.2 Calibration Techniques

In addition to the above mentioned compensation for FOV changes, variations in source power must be compensated. All the contemplated light sources have power outputs that vary with time. Solar power, for instance, varies because of clouds, time of day, and season. The calibration technique is to normalize all measurements by the instantaneous power output of the source. If a chopper is used, this is easily done by reflecting some fraction of the total available power onto a detector. In the case of a very large heliostat, this would not be feasible, but a light-meter or a pick-off measurement would suffice.

2.5 ERROR ESTIMATES AS A FUNCTION OF SPOT SIZE

We previously stated that measurement errors are reduced by using larger test areas. Since this may not be obvious, we will examine in more detail how the errors might occur. As a first step, consider how the length of a board is measured.

Suppose the board is about 8 feet long, and we have a ten-foot tape measure. We would obviously hook the tape over one end of the board and then read the length from the tape measure. Assuming the tape measure is accurate and is not cocked there are several sources of error. First, there is uncertainty in lining up and reading the edge of the board with respect to the scale marks. Second, the length may actually vary depending on where the tape is "hooked." These errors are random and can be reduced by averaging a number of measurements. In general, the uncertainty in the measurement varies inversely as $1/\sqrt{N}$, where N is the number of measurements.

Now suppose that a tape measure is not available and that, instead, measurements are to be made with a 6-inch ruler. If there is any error in the length of the ruler, this systematic error increase <u>linearly</u> with the number of measurements. In addition there will be a random reading error with each measurement. This sort of error is known as a random walk error, and its estimated magnitude is $\sqrt{N}\, M_{rms}$ where M_{rms} is the root-mean-square value of the reading errors. (This is also called the standard deviation of the measurements.) The net error, ε, can be written

$$\varepsilon = N \Delta L + \sqrt{N}\, M_{rms}$$

where ΔL is the systematic error in the length of the ruler. Since N decreases with the length of the ruler, the net error clearly decreases as the length of the ruler is increased.

The situation is similar, though slightly different, when making angular intensity measurements of a surface. Consider a surface illuminated by a beam having a "known" cross-sectional area. (This is the equivalent of the ruler.) Any errors in the determination of the angle of incidence or in the beam area, power, or uniformity will introduce systematic errors. These errors may add or offset but their effect will increase linearly with the "number" of measurements made. In other words, if an area is fully illuminated, only one measurement is made and the effect is slight. If small beams are used, however, the effects add linearly and could be significant.

It should be pointed out that the lack of parallelism in both solar and solar simulator light sources is a potential source of serious error. Because of the lack of parallelism, beam area will increase with distance and therefore, in general, with angle. The effect is approximately ten times worse for a solar simulator because of the approximate ±3 degrees normal divergence of the beam.

In addition to these potential systematic errors, there will be random errors common to any measurement. Beam non-uniformity will generate some of the randomness because scattering will depend on the specific location of micro-defects within the beam. Power fluctuations and normalizations will also introduce random errors. The net error, ε, could be expressed as

$$\varepsilon = N(\pm A_e \pm P_e \pm \theta_e) + \sqrt{N}\, M_{rms}$$

where A_e, P_e, and θ_e represent uncertainties in beam area, beam power, and the angle of incidence, respectively. The M_{rms} represents the rms value of the random errors in the measurements. Thus, just as in the case of measuring the length of a board, it is generally better to minimize the number of measurements if the objective is to minimize error.

3. MEASUREMENT FACILITY ISSUES -- SCANNING VERSUS FLOOD ILLUMINATION TECHNIQUES

3.1 ASSUMPTIONS MADE

As will become apparent in subsequent parts of this section, an important parameter in evaluating trade-offs between scanning and flooding viability is the time required to make measurements corresponding to a whole body signature. Accordingly, this evaluation will be predicated on two assumptions -- more properly observations -- that mitigate the impact of unacceptably long scan-times. These assumptions include:

1. All test objects of interest will exhibit a preferential direction or orientation bias that will control the overall optical signatures in the viewing geometry of interest in this problem; and,

2. An initial, coarse grained preliminary scan may be done of the preferential surface -- by either (human) visual or electro-optical viewing techniques -- to identify physical areas that warrant fine-grained, detailed measurement (i.e. edges, corners, cracks, etc.).

The first assumption is based on the fact that many objects of interest will be protected with a large-shield. Moreover, many unshielded objects are deployed such that they orient themselves in a specific direction to accomplish their mission. The second assumption, acknowledges that certain easily observed regions of a space object are likely to dominate the optical signatures of the whole object whereas other regions will contribute little or nothing to the total optical cross-section.

3.2 REQUIREMENTS

Figure 8 shows three classes of objects in low and high altitude deployment modes. At high altitudes the objects appear as either points or barely imaged objects. At low altitudes the viewing aspect depends on the type of object--specifically on whether it is a "pointer" or "setter" and whether it is shielded.

DEPLOYMENT \ TYPE	UNSHIELDED "POINTER"	UNSHIELDED "SETTER"	SHIELDED OBJECT
LOW ALTITUDE	CHANGING ASPECT	RELATIVELY CONSTANT ASPECT	"CONSTANT" ASPECT
HIGH ALTITUDE	POINT OBJECT	N/A	POINT OBJECT

Figure 8. Object Deployment by Type.

3.3 MEASUREMENT TECHNIQUES -- EXAMPLES TO SCOPE SELECTED PROBLEMS

Two concepts for making measurements have been postulated for further discussion. The basic elements of these concepts are listed in Table 1. The concepts differ in how or whether the test object is moved and in how it is illuminated. All of the concepts include light-trapping walls as the preferred means for absorbing specular reflections. (It is felt that movable absorbers are too difficult to implement --especially if there are secondary reflections.) All the concepts also include large numbers of wall- or dome-mounted detectors in order to reduce measurement times.

A. TRANSLATING AND ROTATING OBJECT/MOVABLE OPTICS • TRANSLATING TURNTABLE • VERTICAL MOTION OPTICS/TILTING MIRRORS • DETECTOR DOME • LIGHT-TRAPPING WALLS B. MOVABLE OBJECT/STATIONARY ILLUMINATION • FLOOD-LOADING HELIOSTAT • TRACKED CEILING CRANES FOR LIFT, TILT, TRANSLATION AND ROTATION OF OBJECT • WALL-MOUNTED DETECTORS • LIGHT-TRAPPING WALLS NOTE: ALL CONCEPTS HAVE STATIONARY OR FIXED-ANGLE DETECTORS

Table 1. Test Facility Concepts

Concept A uses a relatively simple rotating/translating turntable to move the object. Heliostat and/or solar simulator light sources provide the illumination by means of movable optics.

Concept B uses a large heliostat to completely illuminate at least the full width of the object. Other than the heliostat, the optics are stationary and the angles of illumination are varied by moving the object with ceiling cranes. This approach should minimize measurement errors and synthesis problems.

3.3.1 Facility A Description

Figure 9 illustrates the Concept A Facility. The test object is moved by a translating, rotating turntable. A solar simulator or heliostat provides the illumination. Movable mirrors direct the illumination to a mirror assembly that illuminates the object. A small number of detectors are attached to the mirror assembly to monitor "backscattered" irradiation. The majority of the detectors are mounted on a dome enclosing the test area and their pointing would have to change as the illuminating spot moved.

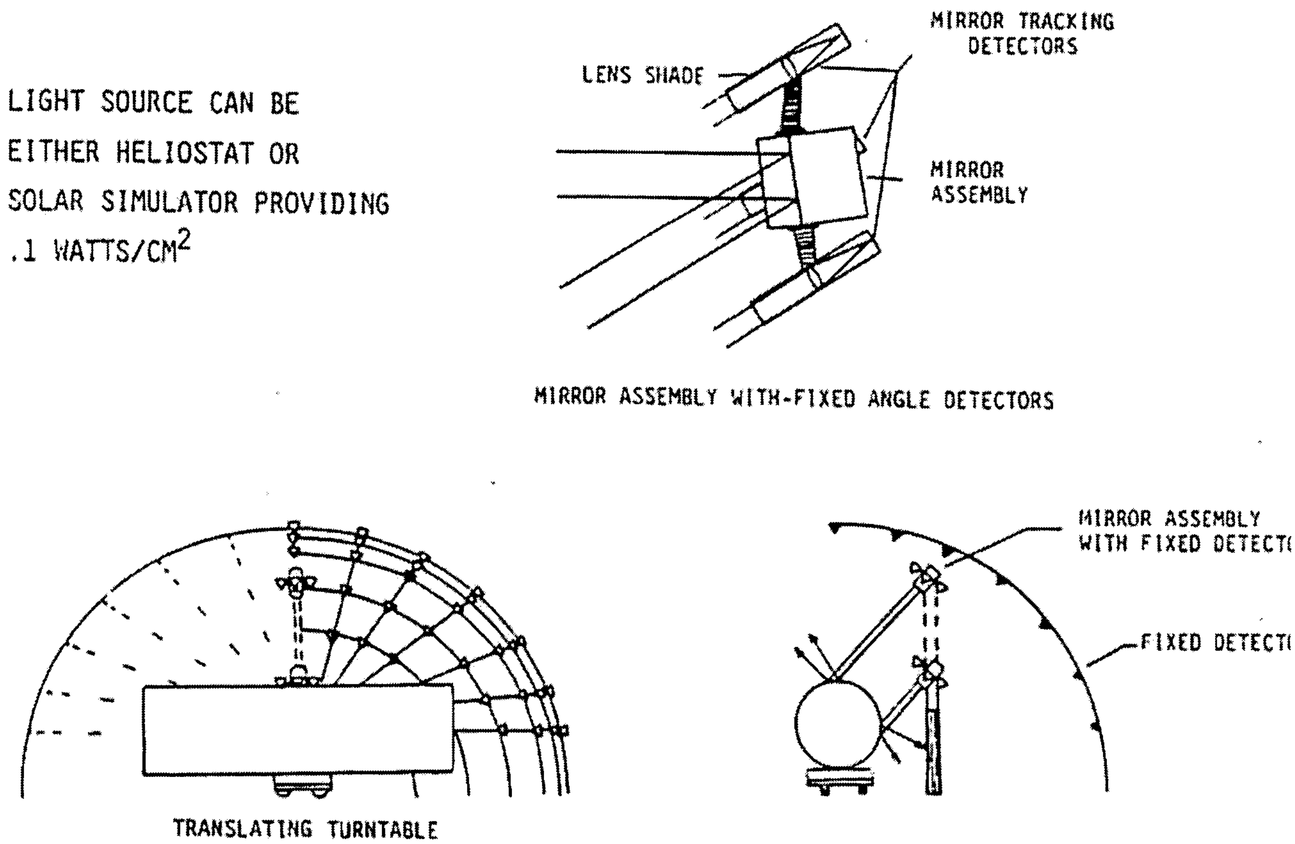

Figure 9. Concept A
(Translating and Rotating Object/Movable Optics)

In Concept A the illumination source is chopped and the detectors are operated in a phase-locked loop mode. This eliminates problems with unchopped stray light and increases the sensitivity of the detector measurements.

3.3.2 Facility B Description

Figure 10 illustrates a possible configuration for the Concept B Facility. The key feature is a very large heliostat to provide illumination. The heliostat directs the illumination to a fixed mirror that, in turn, illuminates the object. The beam is large enough to completely illuminate the width of the object so that synthesis problems are largely eliminated. This might require the largest heliostat ever built, but optical quality requirements are minimal.

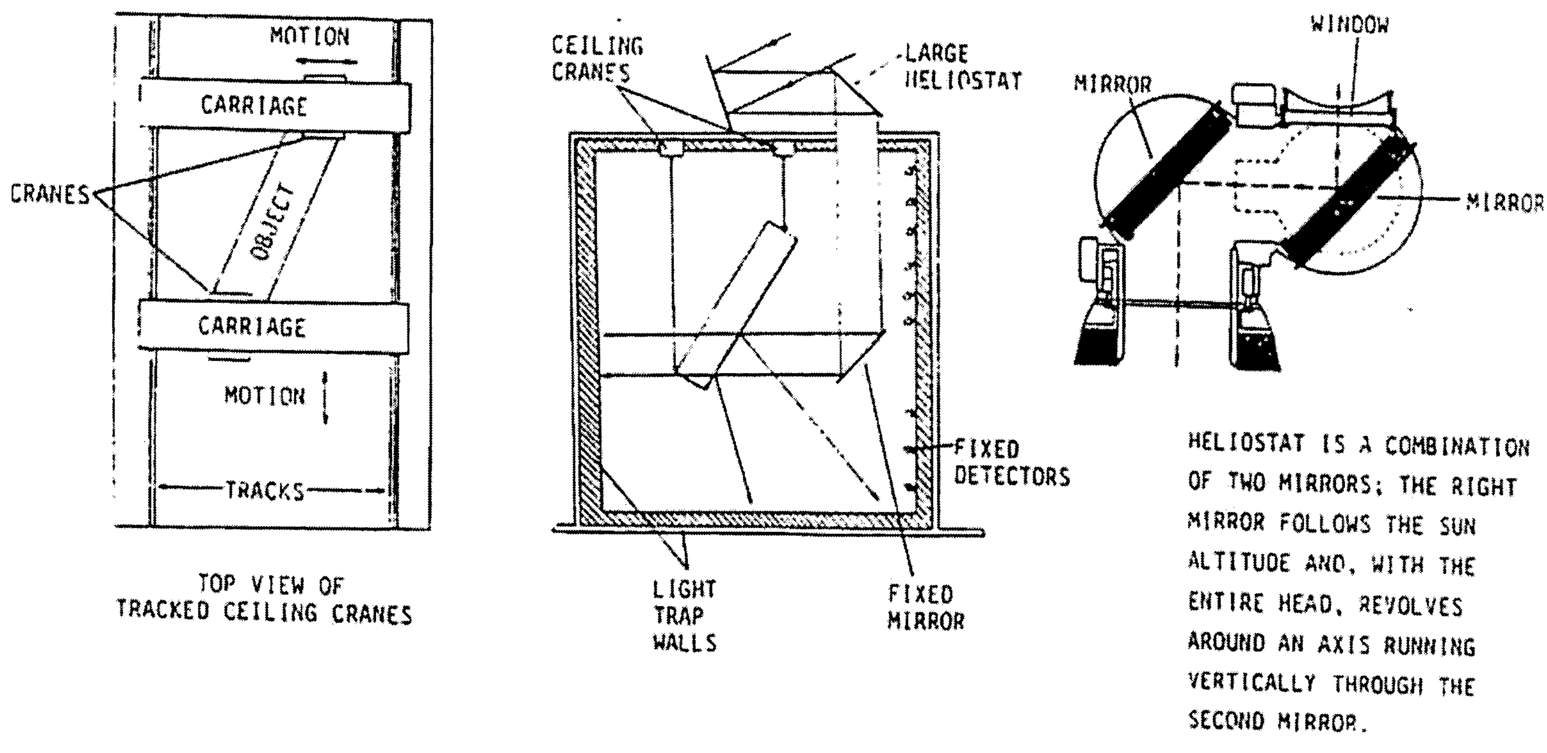

Figure 10. Concept B
(Movable Object/Stationary Illumination).

The angle of incidence and position of the beam on the object are altered by moving the object with ceiling cranes. The cranes lift or tilt the object with respect to the fixed beam. One possible advantage of this arrangement is that the fixed detectors have a constant angular relationship to the incident beam. This should simplify computations compared to Concepts A. Because of the size and total power in the beam, however, chopping is not feasible and measurement sensitivity will be inferior to the other concepts. This, however, may be offset by greatly increased power levels.

3.3.3 Technical Factors Common to All Facility Concepts

Several features have been postulated that are common to both concepts. This directly simplifies comparison. One is the use of light-trapping walls to absorb reflected radiation. The main reason for this is that curved surfaces and secondary reflections can direct energy over a wide range of angles and movable absorbers would be difficult to implement and would probably interfere with some angular measurements.

All concepts have fixed detectors mounted on domes or walls to measure radiant intensity at various angles. The basic purpose is to eliminate the time that would be required to move a single detector or small set of detectors around.

3.3.3.1 Light-Trapping Walls

There are undoubtedly numerous ways to build light-trapping walls that are far superior to "flat black" paint in their ability to absorb radiation. The basic idea is to cause the light to undergo a large number of reflections before being ultimately reflected away from the wall. This implies that outer edges should be sharp so that energy is not reflected back after a single reflection. Surfaces should also be smooth or mirror-like so that energy is not excessively scattered at each reflection. A stack of razor blades is excellent for this purpose but probably impractical for large areas. The equivalent of either the razor blades or a Rayleigh horn might be constructed of a variety of materials. (The Rayleigh horn is shaped like a cornucopia, but similarly curved surfaces like those shown in Figure 11 might also be effective.)

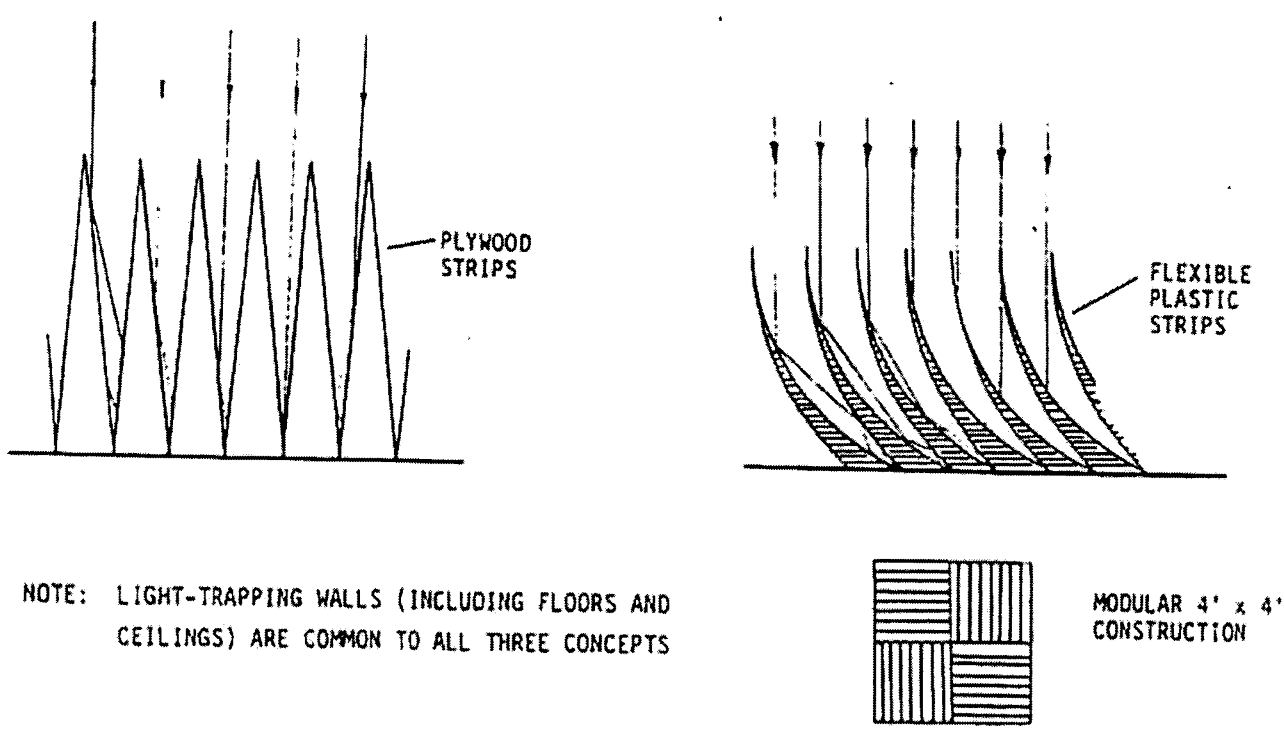

Figure 11. Light-Trapping Wall Designs.

On the other hand, it may be that the light-trapping walls will not have to be as efficient as we have assumed. A combination of paints, velvet curtains, and relatively small, movable absorbers might suffice. The answer will depend on geometric factors as well as on specific designs for the illumination and detection systems, and on experimental verification.

3.3.3.2 Detector Domes

In the preliminary analyses, it has been assumed that measurement times should be minimized by making all detector measurements simultaneously. This means large numbers of fixed detectors mounted on domes or walls. In Concept A, however, the location of the illuminated spot changes so that the "fixed detectors must be pointable to the various locations. The calculation of the angle relative to the incident beam could be tricky in the sense that it might require considerable data processing.

In the case of Concept B, where the illuminating beam is fixed, the detector pointing angles can also be fixed. This eliminates the data processing, but it is not clear how the angle would be measured because of the large spot size. The field-of-view and detector selection would probably be quite different from the other concepts. Imaging sensors, for instance, would indicate "true" object visibility with little need for synthesis.

If the object was stationary then a full dome (see Figure 12) is required to cover all possible observation angles. If, however, there are preferred observation angles, as in Concept A, then a half dome might be adequate.

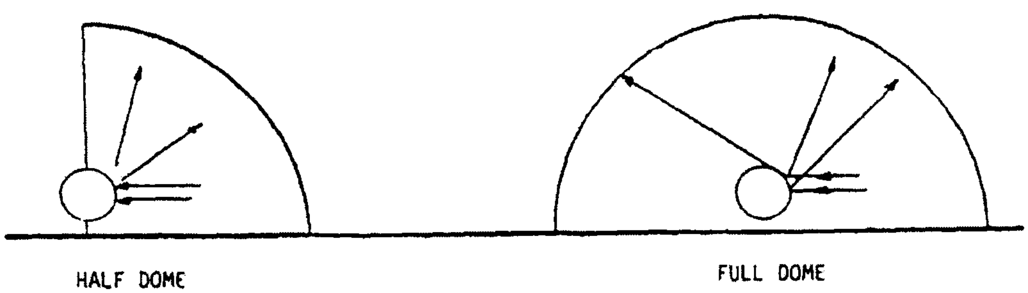

Figure 12. Full and Half Dome Designs.

3.4 REQUIREMENTS COMPLIANCE

There are only two basic requirements for making the measurements of interest:

1. An "accurate" estimate of the visibility of large objects must be available from the measurements.

2. The measurements must be completed in a reasonable time, i.e., days or weeks are preferable to months.

The factors affecting the accuracy of the visibility estimates have been reviewed in Section 2. One conclusion is that accuracy improves with increased spot size. Of course, a large scan spot size is also desirable from the standpoint of reducing total scan time. These points are critical.

The total scan time is a function of the ratio of total object area, A_t, to scan spot area, ΔA. If there was a complete scan of the total area, then the time to scan for a <u>single</u> illumination angle, T_1, would be proportional to this ratio times the scan period, τ_s. (The scan period is the time required to make one set of measurements and move to the next scan area.) In this case, for a single illumination angle, the total time to scan, $T_\emptyset$, would be

$$T_0 = \tau_s \left(\frac{A_T}{\Delta A} \right) \quad .$$

If, however, a relatively few statistical measurements of simple surfaces are adequate for estimating visibility, then the total scan time can be reduced. Suppose a fraction, f, of the total area is complex and the remainder is simple. Then, if 100 percent of the complex area is scanned, but only 10 percent of the simple area, the scan time for a single illumination angle, T_1, can be written as

$$T_1 = T_0(.9f + .1) \quad .$$

The relative reduction in scan time as a function of the complex fraction, f, is shown in Figure 13.

- ASSUMPTIONS
  - SCAN 100% OF COMPLEX AREAS
  - SCAN 10% OF NON-COMPLEX AREAS
  - SIMULTANEOUS MEASUREMENTS AT ALL OBSERVATION ANGLES
  - SOME FRACTION, f, OF TOTAL PROJECTED OBJECT AREA, A_T, IS COMPLEX $(0 \le f \le 1)$

$$T_1 = \frac{\tau_s A_T}{\Delta A}(.9f + .1) = \text{TIME TO SCAN FOR ONE ILLUMINATION ANGLE AND OBJECT ORIENTATION}$$

τ_s = SCAN PERIOD

ΔA = SCAN SPOT AREA

$$\tau_s\left(\frac{A_T}{\Delta A}\right) = T_0 = \text{TIME TO SCAN WHOLE AREA}$$

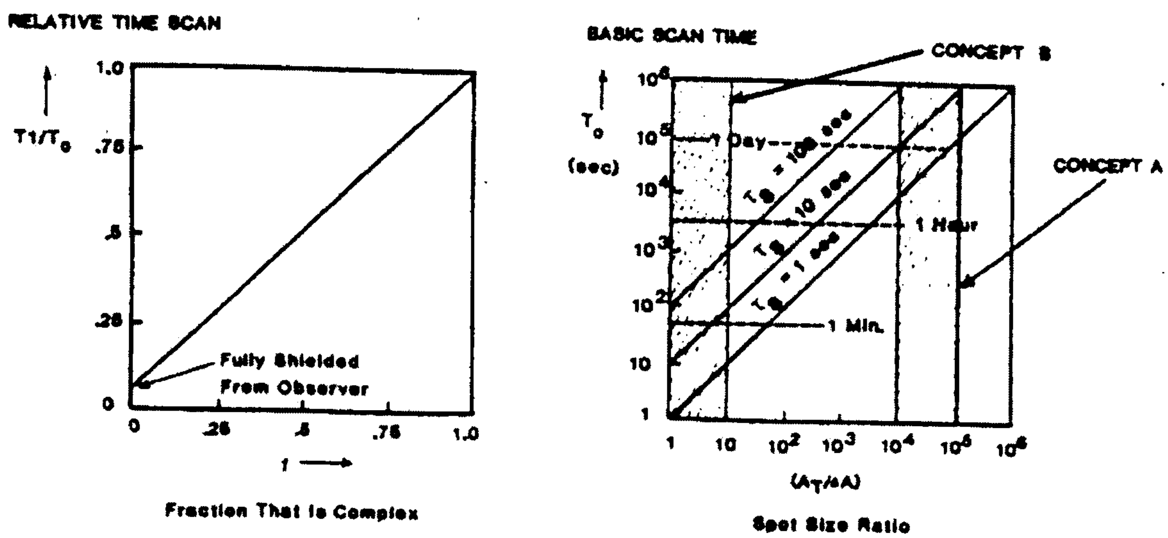

Figure 13. Time-To-Scan Considerations

The scan period will vary for the different concepts. For instance, in Concept B, the scan period would probably be measured in minutes because the spot is moved by moving the object. Scan periods of 10 to 100 seconds might be reasonable for the other concepts. The basic scan time for one illumination angle, T_{ϕ}, might therefore range from roughly an hour to days.

The time to scan through a set of illumination angles will, of course, be directly proportional to the number of angles. We would expect that some 10 to 20 illumination angles would be sufficient so that the total scan time for Concept B might be less than a week, whereas it might be months for the other concept.

3.5 SUMMARY

Table 2 summarizes the advantages and disadvantages of the concepts. Concepts A may be simpler to implement, at least in some ways, than Concept B. There are some serious doubts about the potential accuracy of the visibility estimates derived from these concepts, however. This is particularly true if a solar simulator is used for the illumination source. Concept B largely avoids the synthesis problems by giving a direct indication of visibility, but, in order to do so, requires the construction of a very large heliostat.

Concept B also has the advantage of being faster than the other concepts. If the beam from the heliostat were 10 meters in diameter, for instance, only two measurements per illumination angle would probably be sufficient. Conceivably all the desired measurements could be made in less than a day.

CONCEPTS	ADVANTAGES	DISADVANTAGES	COMMENTS
A. TRANSLATING AND ROTATING OBJECT/ MOVABLE OPTICS (TURNTABLE)	RELATIVELY SIMPLE OPTICAL REQUIREMENT CAN UTILIZE HELIOSTAT AND/OR SOLAR SIMULATOR SOURCES	POSSIBLE SYNTHESIS PROBLEMS	TOTAL SCAN TIMES OF LESS THAN A WEEK FEASIBLE
B. MOVABLE OBJECT/ STATIONARY ILLUMINATOR (FLOOD-LOADING HELIOSTAT AND CEILING CRANES)	ELIMINATES UNCERTAINTIES IN SIGNATURE SYNTHESIS FAST	REQUIRES VERY LARGE, MOVABLE MIRRORS CHOPPING IMPRACTICAL	TOTAL SCAN TIMES OF A FEW HOURS FEASIBLE

Table 2. Summary of Concept Advantages and Disadvantages.

4. SUMMARY AND OUTSTANDING TECHNICAL ISSUES

4.1 SUMMARY

Serious technical uncertainties currently exist in estimating the visibility of large objects. A more careful theoretical analysis augmented by an experimental evaluation of selected parameters is definitely in order.

More specifically, the time to complete measurements remains as the key technical consideration. As discussed previously this is strongly dependent on the characteristics of the objects being tested. For instance, if the objects are very simple (approximately a flat plate), then a few statistical measurements would be sufficient and measurement time should be no problem. Scanning concepts, such as A and B, would be satisfactory and should be a less expensive solution. On the other hand, if the objects are complex, there are some doubts about the suitability of scanning concepts. A complete, time-consuming scan of complex surfaces is probably required. And the potential for systematic and random errors increases with the number of measurements.

4.2 Example, Specific Technical Issues Outstanding

In addition to the above general issues, there are specific technical questions that should be resolved -- likely by simple and inexpensive experiments. Some of the key technical questions include:

> How serious are secondary reflections and how can they be handled?

What is the efficiency of various light trap designs and what is the difficulty in their large scale fabrication?

How do the various detectors and light measurement devices (including the eye) compare?

What specific problems are there in using lasers or solar simulators for illumination?