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Model Tank Reflectance Study at Two Wavelengths

by

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A scale model laboratory investigation was conducted wherein lasers operating at 1.52μm and 10.6μm irradiated a painted scale model of an M60A1 tank with realistic spot sizes for varying aspect angles and the resulting retroreflections were measured.

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PREFACE

An important tool for evaluating the expected performance of laser radar systems is computer modeling. When a target is irradiated by a known amount of laser energy, it is a straightforward exercise to calculate the amount of reflected energy detected by the system and thereby compute the signal-to-noise (S/N) ratio and thus infer system performance. Typical systems that can be evaluated in this manner include laser radars for ranging, imaging, vibration sensing, obstacle avoidance, and chemical sensing.

One vital parameter in this calculation is the target reflectance which is directly proportional to the S/N ratio. How does one determine the proper value to use for a typical painted military target? At first glance, it might appear that a straightforward bidirectional reflectance measurement of a painted metal plate would yield a useful value; but realistic targets such as tanks have geometrically complex structures which could substantially modify the flat plate result in at least two ways. First, multiple reflections could have the effect of reducing the return. On the other hand, it could be contended that since the target is fairly specular at long laser wavelengths (say 10μm), there will always be some aspect of the target oriented so as to give rise to a specular return (glint) which could increase the effective reflectance. Thus, there are two possibilities which affect the reflectance in opposite senses. To further complicate matters, typical laser systems can operate with wavelengths that differ by a factor of ten; e.g., 1.06μm for Nd:YAG vs. 10.6μm for CO_2. It is not difficult to imagine that target structure and target specularity effects might be wavelength dependent and thereby affect the reflectance differently.

In order to determine the effect of these issues on target reflectance and to obtain useful values for realistic targets, it was decided to conduct a scale model laboratory investigation at two widely varying wavelengths. Lasers operating at 1.52μm and 10.6μm irradiated a painted scale model of an M60A1 tank with realistic spot sizes for varying aspect angles, and the resulting retroreflections were measured. A detailed description of the experiment follows.

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SECTION I. EXPERIMENTAL SETUP AND PROCEDURE

DESCRIPTION OF THE 10.6μm APPARATUS

A diagram of the experimental setup appears in Figure 1 (page A-2). A Line Lite Model 950 CO_2 laser produced an 8W maximum CW beam. The beam was attenuated by means of a variable polarizer so as to not saturate the detectors or heat the model tank target. The beam was chopped via a Laser Precision Model CTX-534 variable speed chopper, referenced to an EG&G Princeton Applied Research Model 5301 lock-in amplifier. A 50% beamsplitter was used to allow for relative measurement of the outgoing power via an HgCdTe detector and a Scientech power meter. The remainder of the beam passed through a variable beam expander, enlarging the beam to a circular spot of approximately 15.5mm diameter at the target. This was done in order to simulate the spot size (approximately 0.5m) of a beam that would be incident upon a realistic military target at a range of 1km. The retroreflected power was focussed onto a moveable PbSnTe detector and was displayed on the lock-in amplifier. An Optical Engineering, Inc. CO_2 spectrum analyzer was available to ascertain that the laser was operating at 10.6μm.

DESCRIPTION OF THE 1.52μm APPARATUS

A diagram of the experimental setup appears in Figure 2 (page A-3). A Melles Griot Model 05-SIR-871 1.52μm HeNe laser produced a 5mW maximum, randomly polarized, CW beam. This beam was also attenuated by means of a variable filter to reduce power levels in order to avoid saturation and heating effects. The beam was chopped with reference to the lock-in amplifier and expanded to the appropriate size as was done in the CO_2 experiment. Since the laser was previously determined to have stable output power after a 1-hour warm-up period, only a periodic measurement of relative outgoing power was necessary. The retroreflected power was focussed onto the 2mm element of a SPEX Model 1429A IR detector and was again displayed on the lock-in amplifier. A video camera was available to view the beam via illumination by a UV lamp and thus beam position was easily displayed on a black and white video monitor.

TARGET AND COATINGS

A 1/35 scale plastic model of an M60A1 tank was used as the target in these experiments, positioned on a variable-height turntable calibrated in degree increments. This type of mount allowed the beam to be positioned at different heights on the tank target at all aspect angles. A sample of canvas with previously characterized reflectivity was mounted on cardboard and periodically placed on the turntable, as indicated in Figures 1 and 2. This was done for the purpose of normalizing the relative measurements made on the tank model to true values of reflectivity.

Two types of paint were used as coatings for the tank: a US Army Green-383 polyurethane CARC, and a commercially available polyurethane green gloss enamel (Red Devil G13 Lawn Green). The former paint is referred to as "flat" and the latter as "glossy" which describes the visible appearance of the paint. It has been reported in the past that some threat vehicles are of a glossier nature than domestic vehicles. Hence, the glossy paint was used in addition to the flat so that any differences in the specularity of the paints could be investigated. The tank model was sprayed with each paint thick enough to ensure opacity at each wavelength of interest. Figure 3 (page A-4), shows actual photographs of the tank model covered with each paint.

MEASUREMENT PROCEDURE

As indicated earlier, the tank model was irradiated at three levels: 24, 48, and 72mm heights, as shown in Figure 4 (page A-5) which correspond to 0.84, 1.68, and 2.52m heights on an actual tank. At each aim level, relative measurements of reflected power were taken, starting with a frontal aspect angle, then every 10 degrees of a 360 degree rotation. Measurements were also taken at 2-degree increments in a 10-degree region centered about the most normal aspects (front, sides, and rear of the tank) due to increased specularity in these areas. The short-term power fluctuations of the 10.6μm laser required that a four-sample average be taken at each position. The measurements were later corrected for any fluctuations in outgoing power using simultaneously recorded values of the reference power levels. Measurements were also normalized at a later time to those taken with the canvas sample at the beginning of each aim level sequence so that calibrated values of reflectivity could be obtained.

SECTION II. EXPERIMENTAL RESULTS

REFLECTANCE DEPENDENCE ON ASPECT ANGLE

Figures 5 and 6 (pages A-6 and A-7) show the 10.6μm retroreflectance at the three aim points as a function of aspect angle for the tank painted flat green and gloss green, respectively. Figure 7 (page A-8) provides a direct comparison of the effect of paint specularity at 10.6μm. In this graph, the retroreflectance has been averaged over the three aim points. Figures 8, 9, and 10 (pages A-9, A-10, and A-11) depict the results of similar experiments performed with 1.52μm radiation impinging on the target. The following observations were made.

10.6μm Case

1. The typical return from the flat green target was higher than that from the glossy green target.

2. Relatively few highly specular glints appeared for either paint, and even then they were confined to narrow angular cones centering about 180° for the flat paint and 90°, 180°, and 270° for the glossy paint. As expected, the glint returns were stronger for the glossy paint.

3. When there was a significant difference, the middle aim point of the target usually provided a higher glint return than either of the other two areas. This was particularly true for the gloss green case, and to a lesser extent for the flat green coating.

4. With the exception of the narrow glint areas mentioned above, the tank retroreflectance did not show a significant dependence on aspect angle.

1.52μm Case

1. In contrast with the 10.6μm case, now the typical return from the flat green target was about equal to that reflecting from the glossy painted tank.

2. As in the 10.6μm, relatively few highly specular glints appeared for either color, with those confined to narrow cones centered around 90°, 180°, and 270°. Evidently, the effects of specularity are much less for 1.52μm radiation than for the 10.6μm case.

3. As in the 10.6μm case, when there was a significant difference, the middle aim point of the target usually provided a higher glint return than either of the other two areas. However, in this situation, a difference was only noticeable for the gloss green coating.

4. The tank retroreflectance exhibited even less dependence on aspect angle than it did for the 10.6μm case.

EFFECTIVE TANK REFLECTIVITY

While the previous results may be instructive in a general sense, they do not directly address the issue of which value target reflectance to use when evaluating the effectiveness of a rangefinder. To some extent, the value obviously depends upon the aspect angle of the tank. Thus, in order to evaluate this quantity, the previous observations must be casted in a more analytic manner. One may account for the possibility of observing a target oriented at a random aspect angle and thereby calculate the probability P(R) that any observation will result in a measured retroreflection value greater than R. These calculations were performed and Figures 11, 12, 13, and 14 (pages A-12 through A-15) are plots of this probability for the tank coated with both paints and irradiated at the three levels with both 10.6μm and 1.52μm radiation. Figures 15 and 16 (pages A-16 and A-17) are averages of those graphs. The abscissa has been expressed as absolute reflectivity by means of direct comparison with a known canvas standard. The following observations were made.

10.6μm Case

1. Most of the time, there was not a significant difference among the three aim points for the glossy coating.

2. For the flat green coating, aiming at the turret slightly increased the probability of a high reflectance return, but the increase probably has marginal value.

3. On the average, most of the time reflectivity values about 1% and 3% were typical for this target when coated with glossy and flat paints, respectively.

1.52μm Case

1. Most of the time, there was a significant advantage in aiming at the turret as opposed to the wheels for the glossy coating.

2. For the flat coating, this advantage was minimal and probably of no practical use.

3. On the average, most of the time reflectivity values of about 24% were typical for this target when coated with either type paint.

SECTION III. DISCUSSION AND CONCLUSIONS

It has been shown that the effective reflectance of an M60A1 tank model was about 3% at 10.6μm and about 24% at 1.52μm when the coating was flat polyurethane green paint. Using a glossy green coating, the value at 10.6μm decreased to about 1% and did not significantly change the result for 1.52μm. In addition, separate measurements showed that a flat plate painted with the same coatings had reflectivities of about 6 to 7% at 10.6μm and 30% at 1.52μm. The following conclusions were drawn from these facts.

1. A geometrically complex target has a reduced reflectance compared to a flat plate. This effect was more pronounced at 10.6μm than at 1.52μm. The cause of this effect was probably multiple reflections of the radiation. The wavelength dependence seemed to be reasonable since these coatings were more specular at longer wavelengths.

2. A target coated with glossy paint exhibited a considerable reflectivity loss at 10.6μm.

Naturally, inherent possible flaws exist in modeling experiments. Not only are the textures of real surfaces different than that of the model, but environmental effects will almost surely be an important factor. For example, will a tank painted a flat color still exhibit a non-specular nature after emerging from a rainstorm? What about the effect of dirt/mud and obscurants on the surface of a tank? Clearly, full scale tests under realistic conditions are needed to completely answer these questions. However, the results presented in this report should be of value in providing practical estimates until the full scale data are available.

APPENDIX OF FIGURES

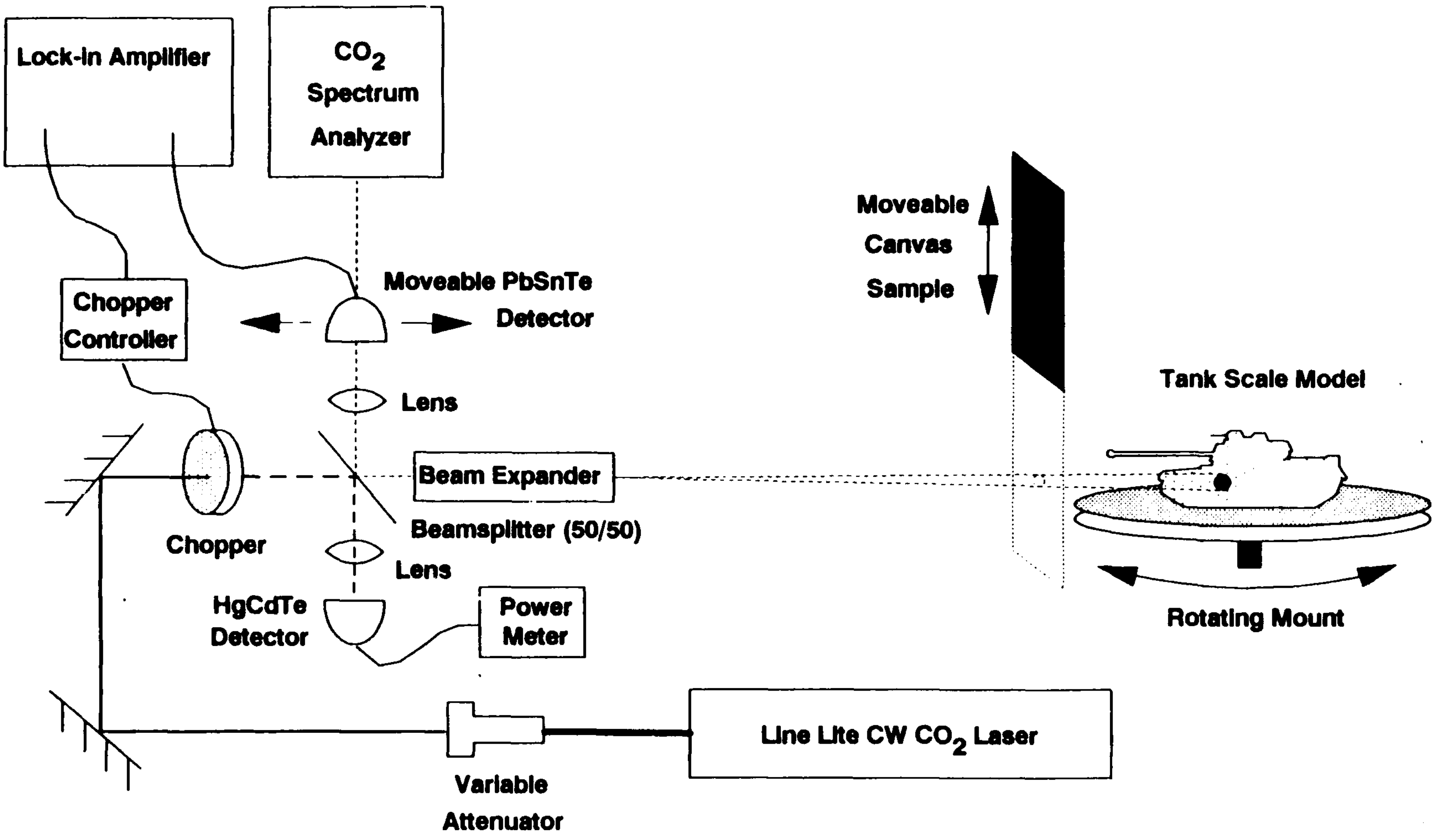

Figure 1. Schematic diagram of the 10.6μm apparatus

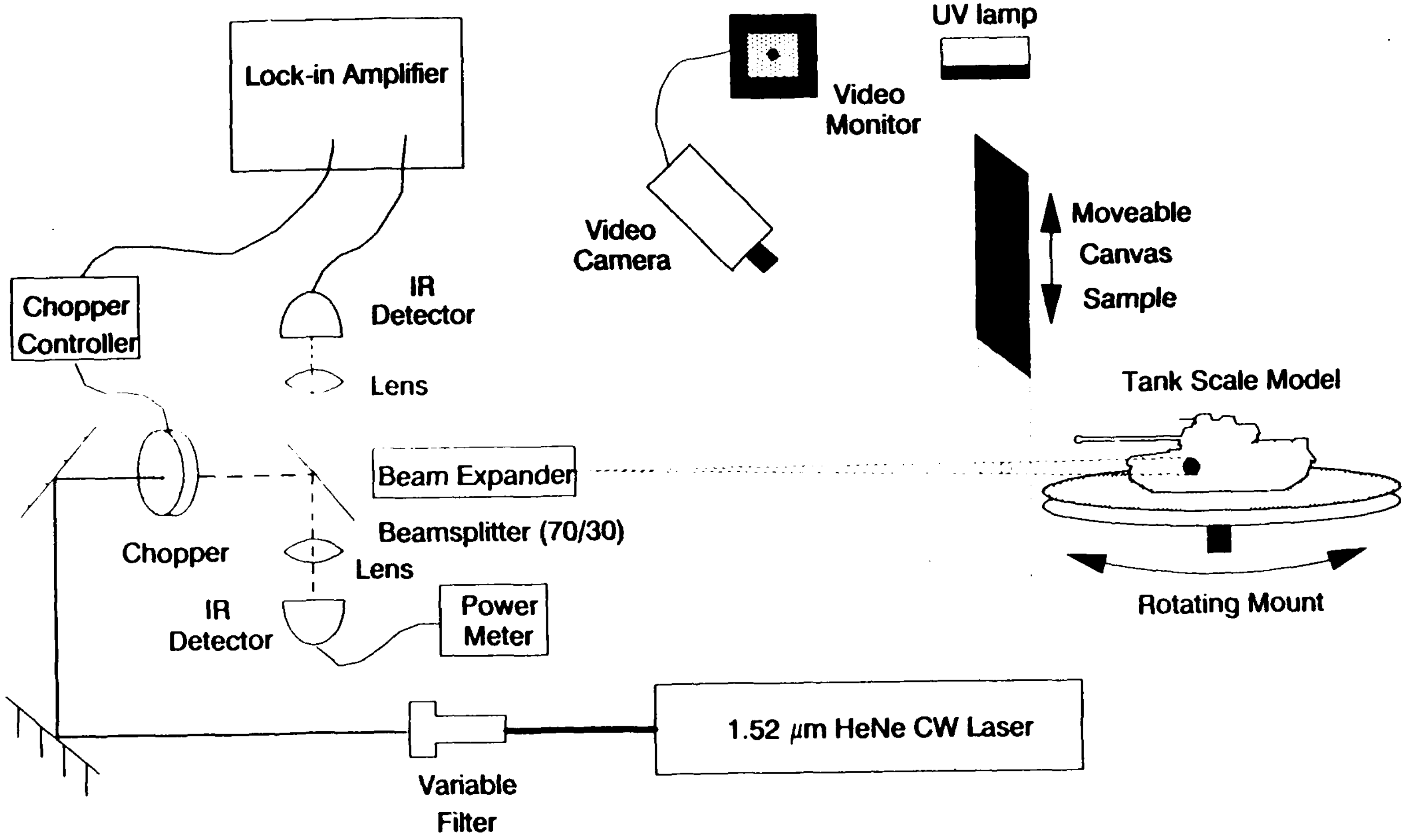

Figure 2. Schematic diagram of the 1.52μm apparatus

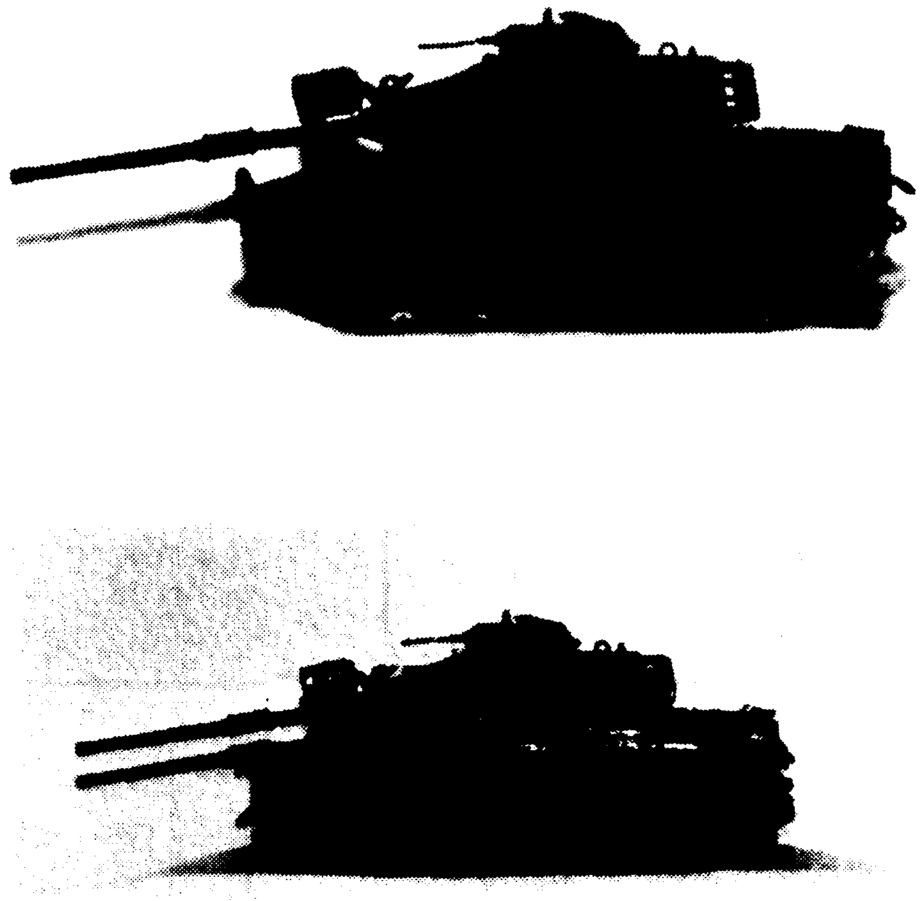

Figure 3. Side aspect of the model painted with flat coating (top) and with gloss coating (bottom)

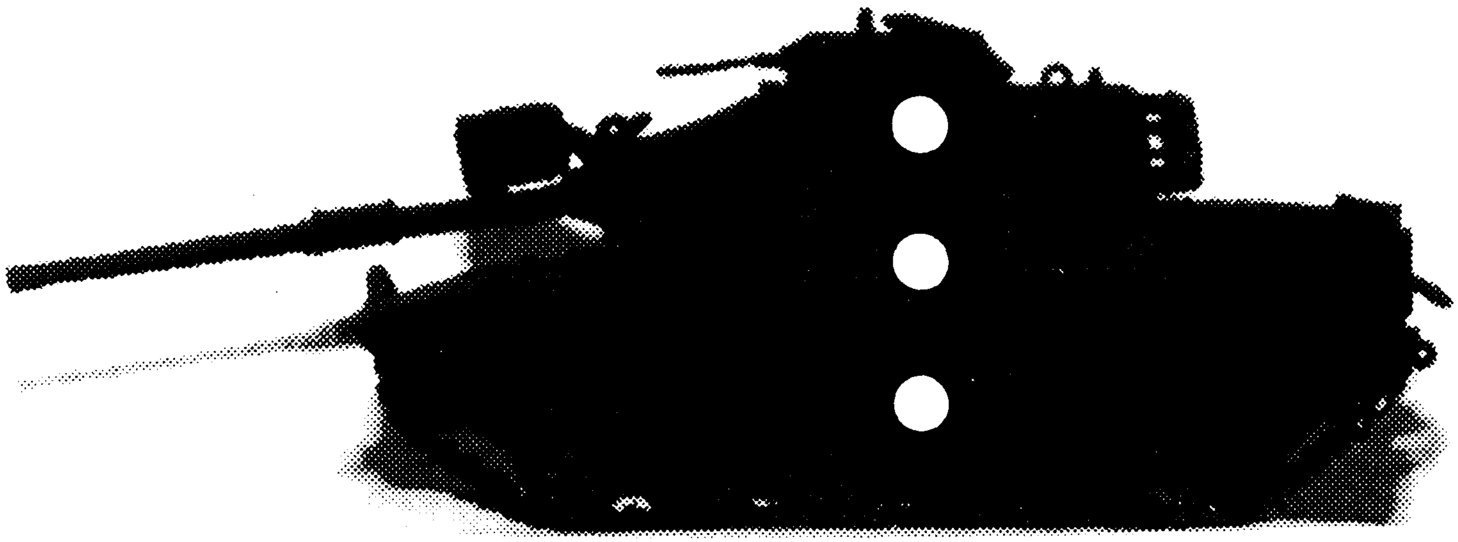

Figure 4. Three aim points corresponding to scaled heights of 0.84, 1.68, and 2.52 meters

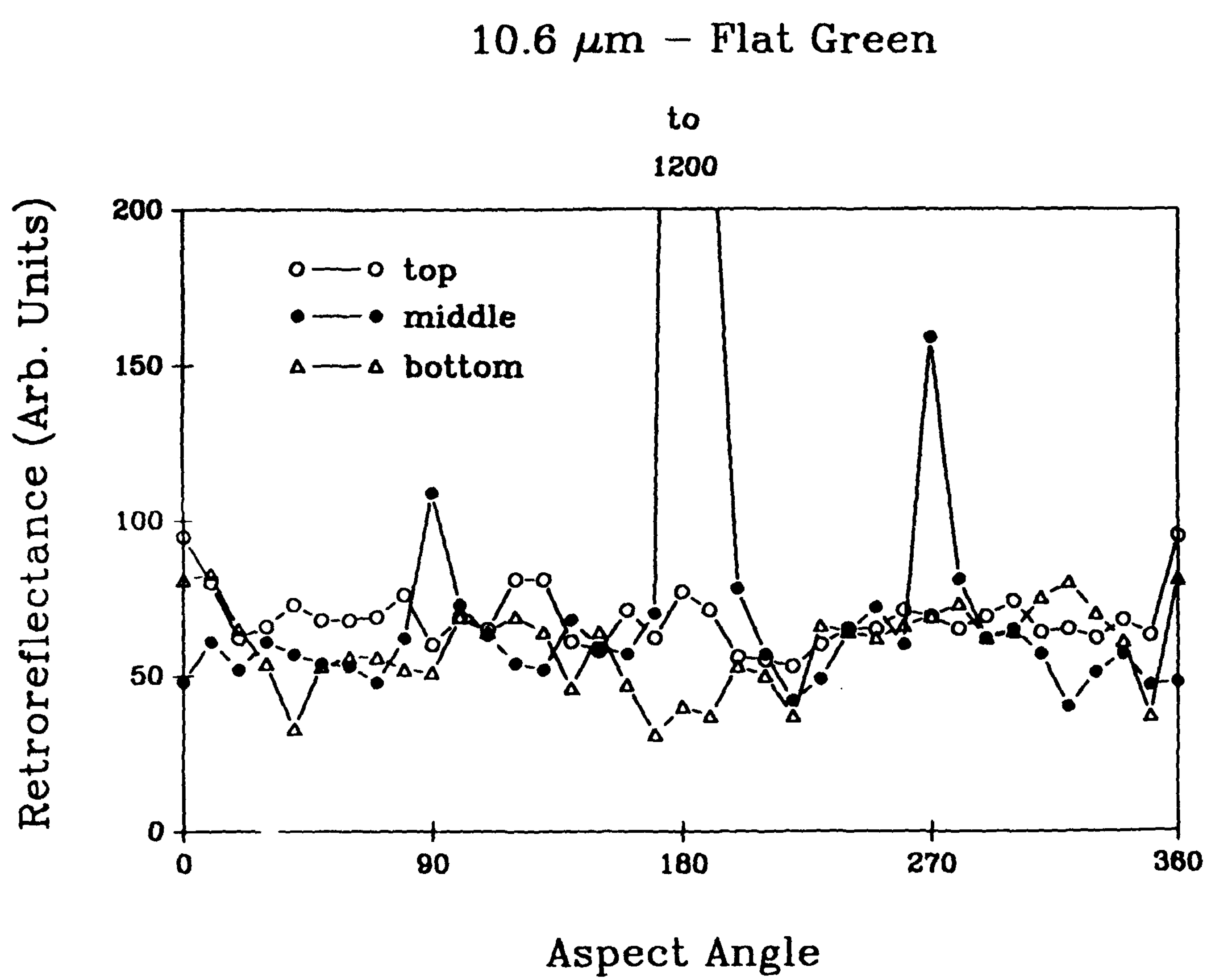

Figure 5. Retroreflectance at 10.6μm for the flat coating

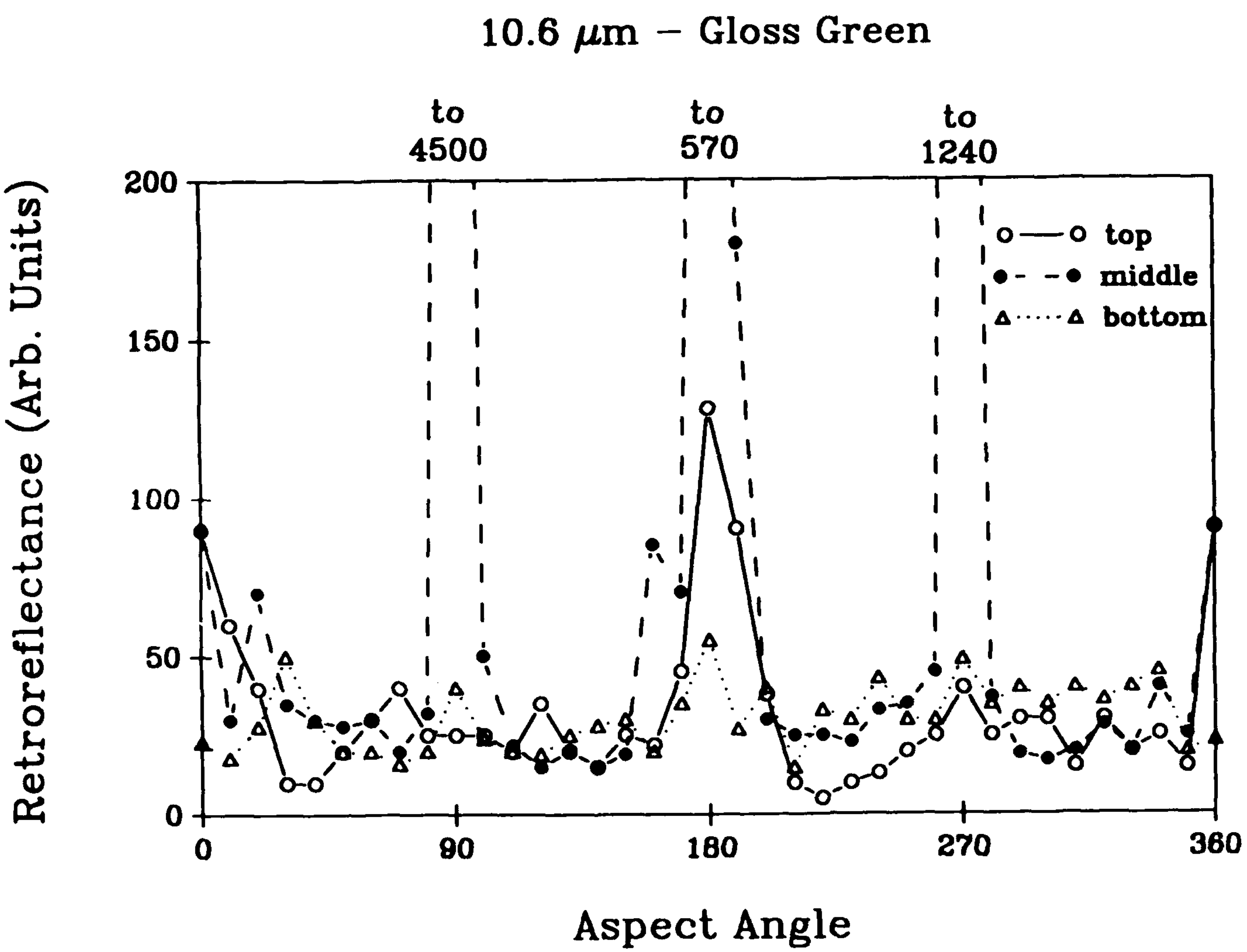

Figure 6. Retroreflectance at 10.6μm for the gloss coating

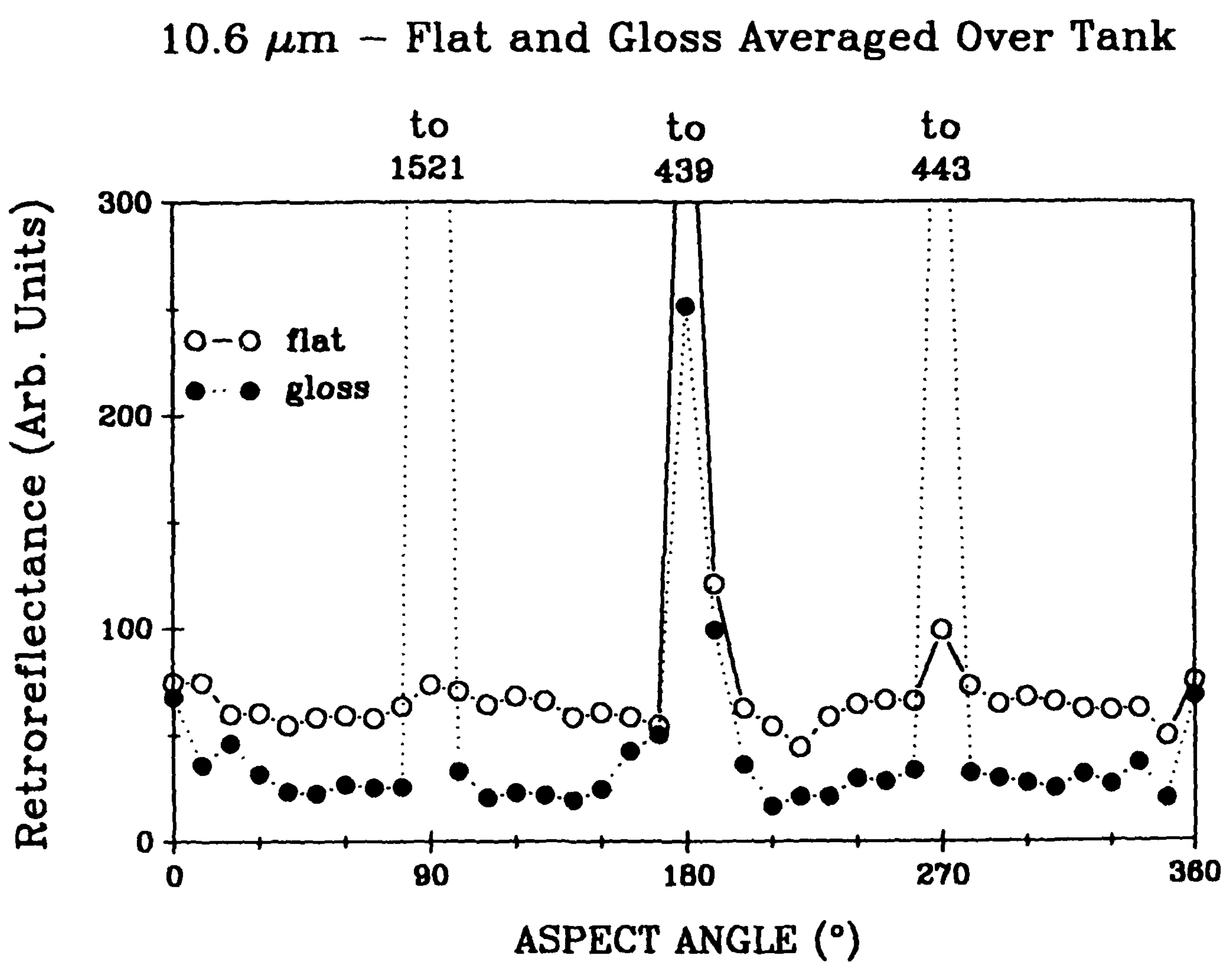

Figure 7. Retroreflectance at 10.6μm for both coatings.
Each reflectance value is the average over the three aim points

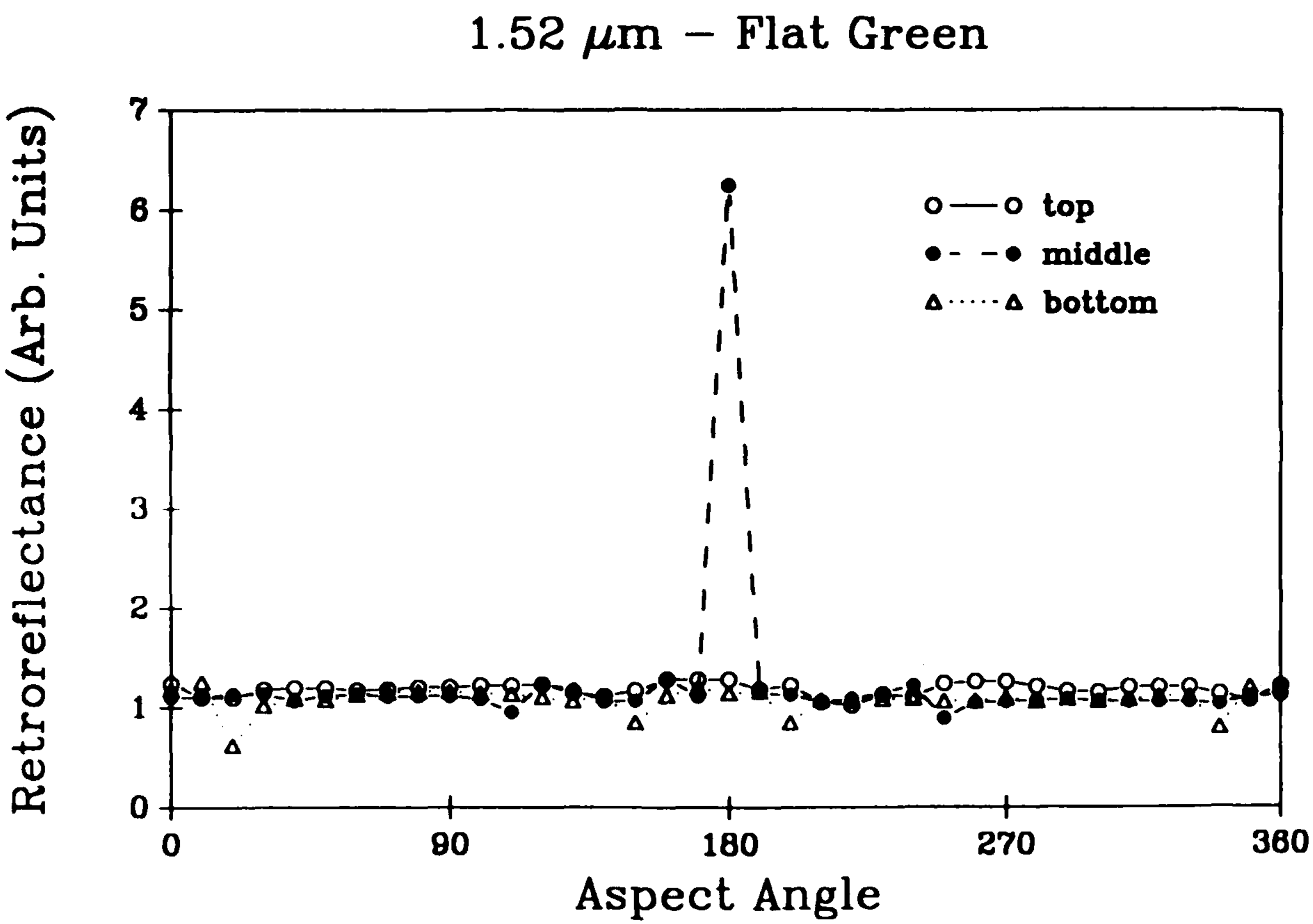

Figure 8. Retroreflectance at 1.52μm for the flat coating

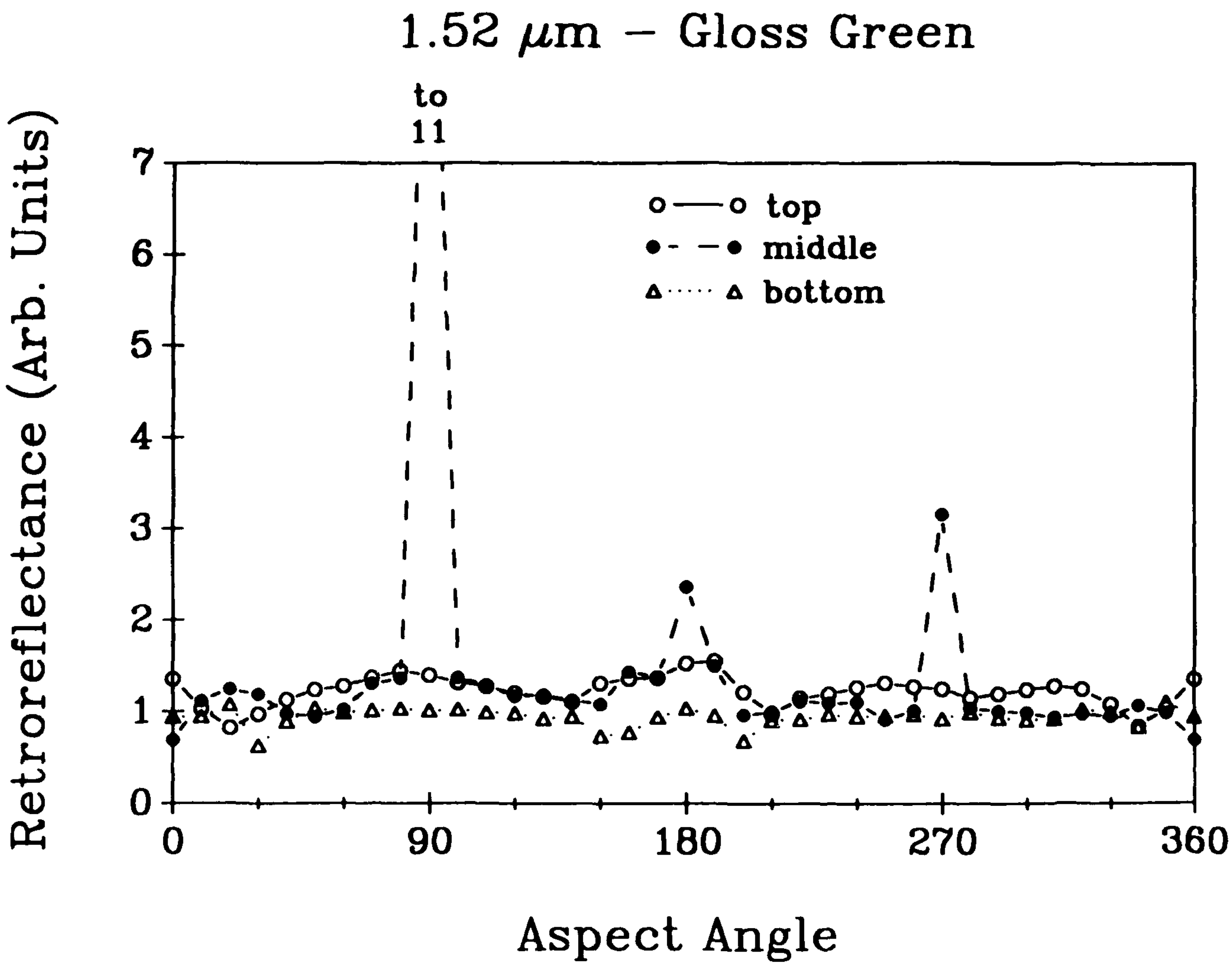

Figure 9. Retroreflectance at 1.52μm for the gloss coating

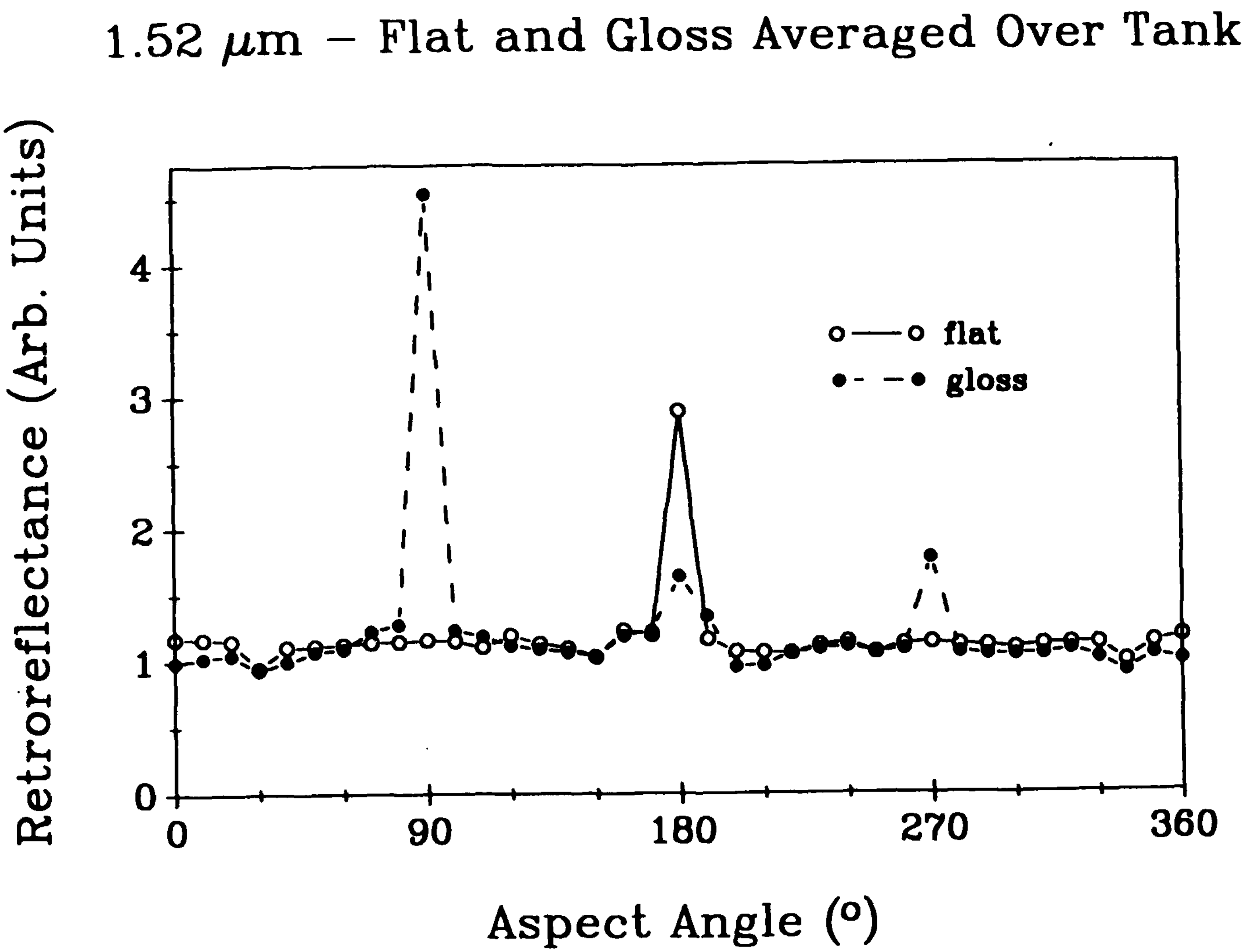

Figure 10. Retroreflectance at 1.52μm for both coatings. Each reflectance value is the average over the three aim points

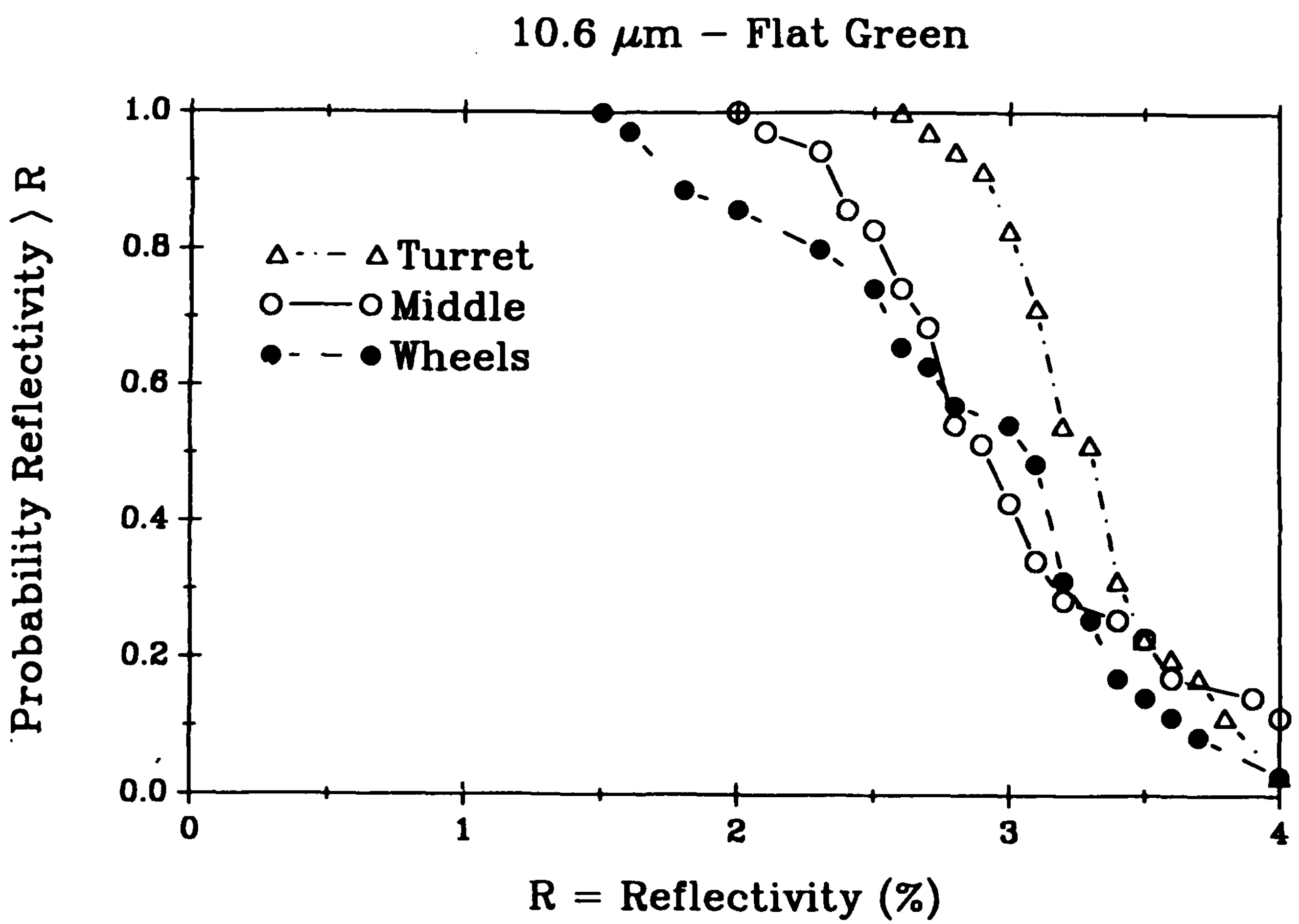

Figure 11. The probability that an observation of the target will result in a measured reflectivity greater than R. The irradiating wavelength is 10.6μm and the coating is flat green

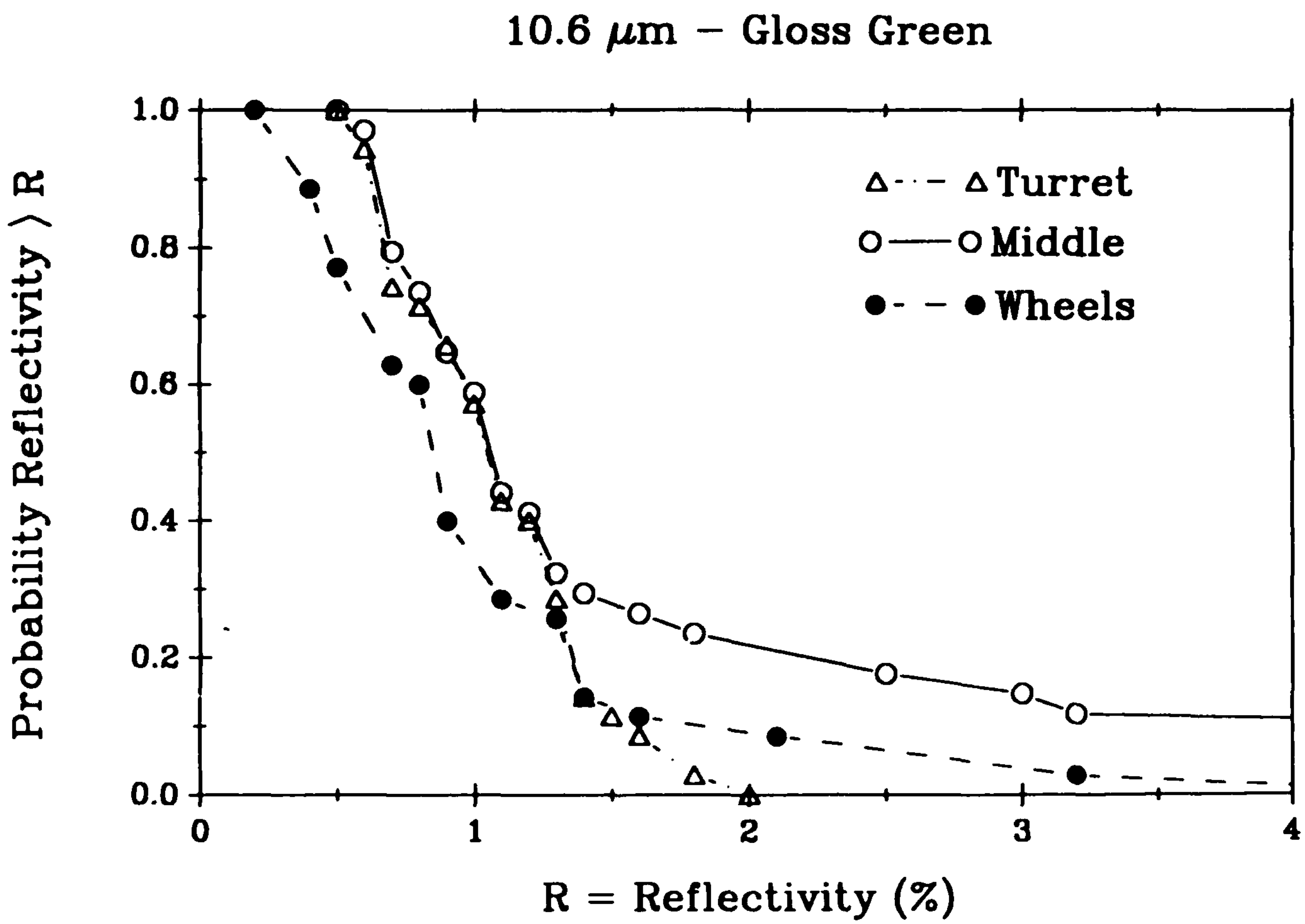

Figure 12. The probability that an observation of the target will result in a measured reflectivity greater than R. The irradiating wavelength is 10.6μm and the coating is gloss green.

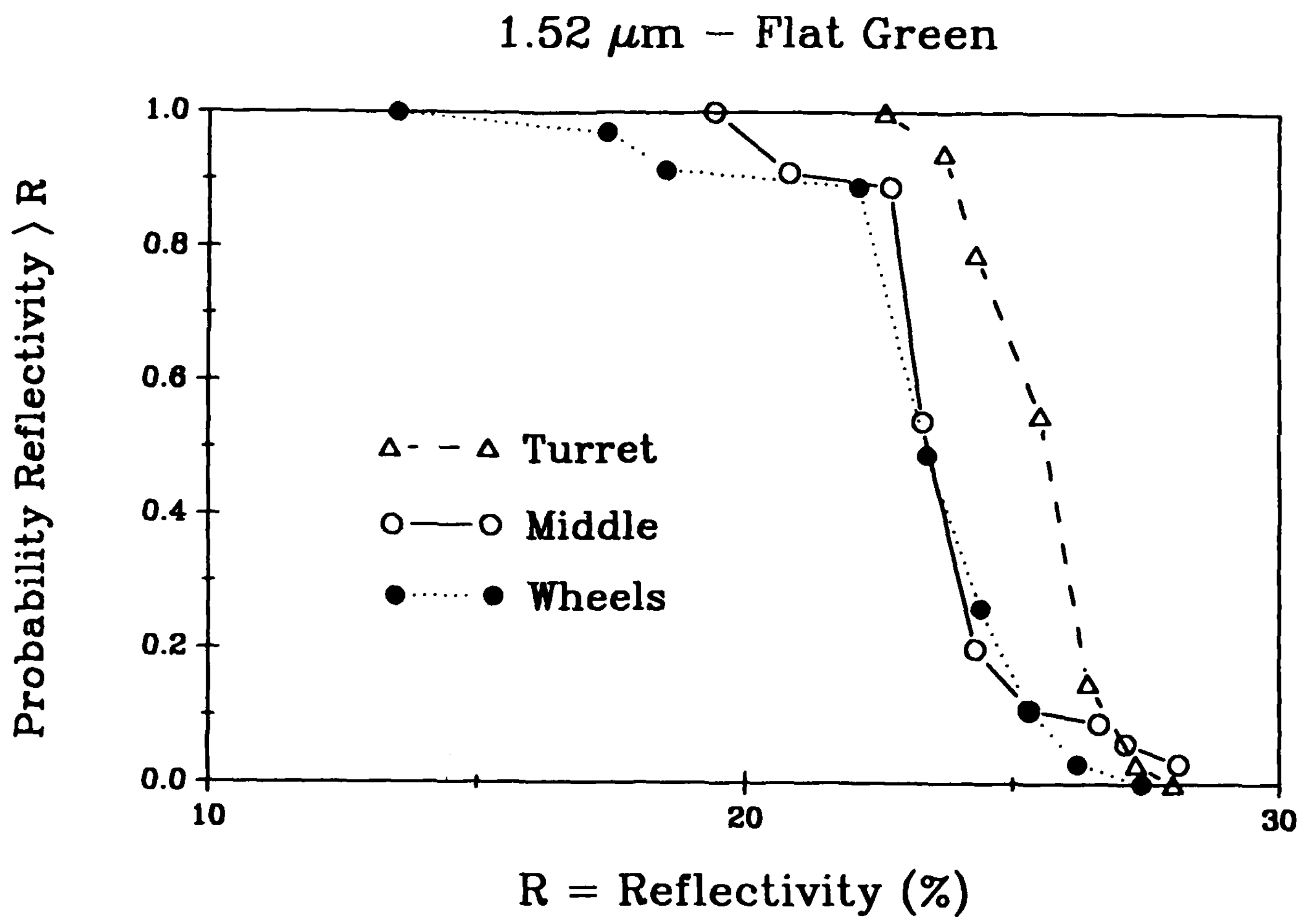

Figure 13. The probability that an observation of the target will result in a measured reflectivity greater than R. The irradiating wavelength is 1.52μm and the coating is flat green.

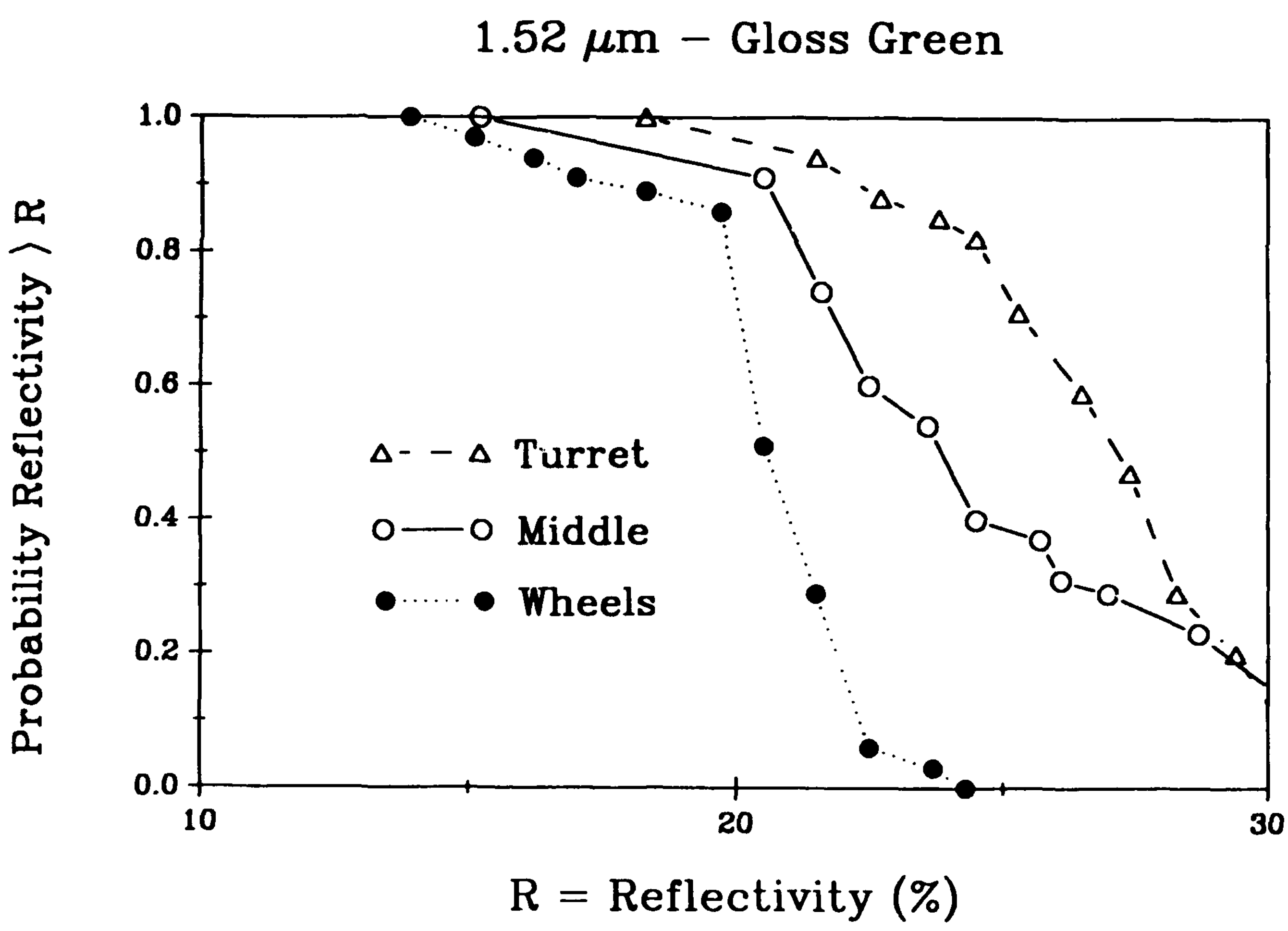

Figure 14. The probability that an observation of the target will result in a measured reflectivity greater than R. The irradiating wavelength is 1.52μm and the coating is gloss green.

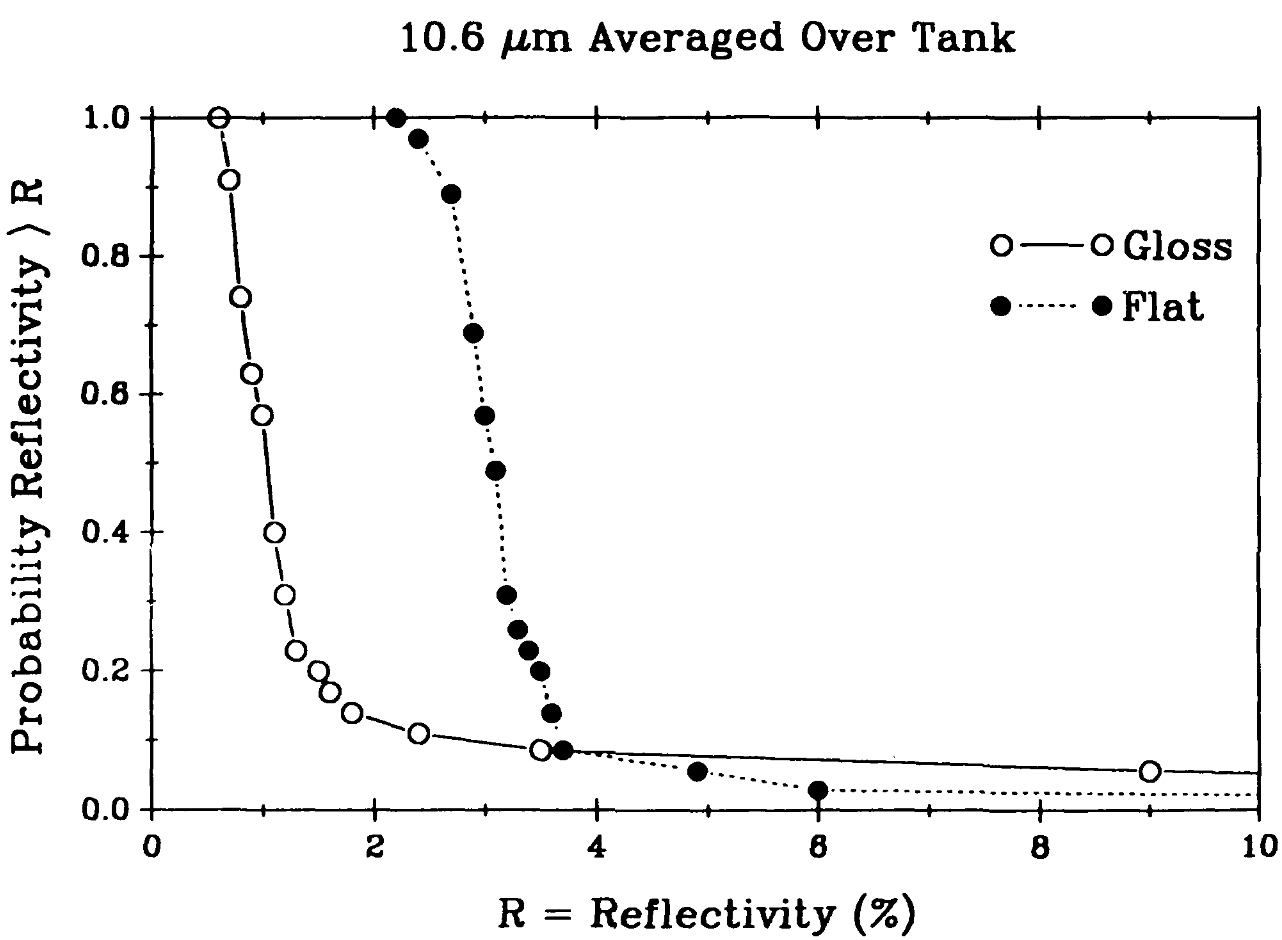

Figure 15. The probability that an observation of the target will result in a measured reflectivity greater than R. Both coatings are shown. The irradiating wavelength is 10.6μm and each point has been averaged over the three aim points.

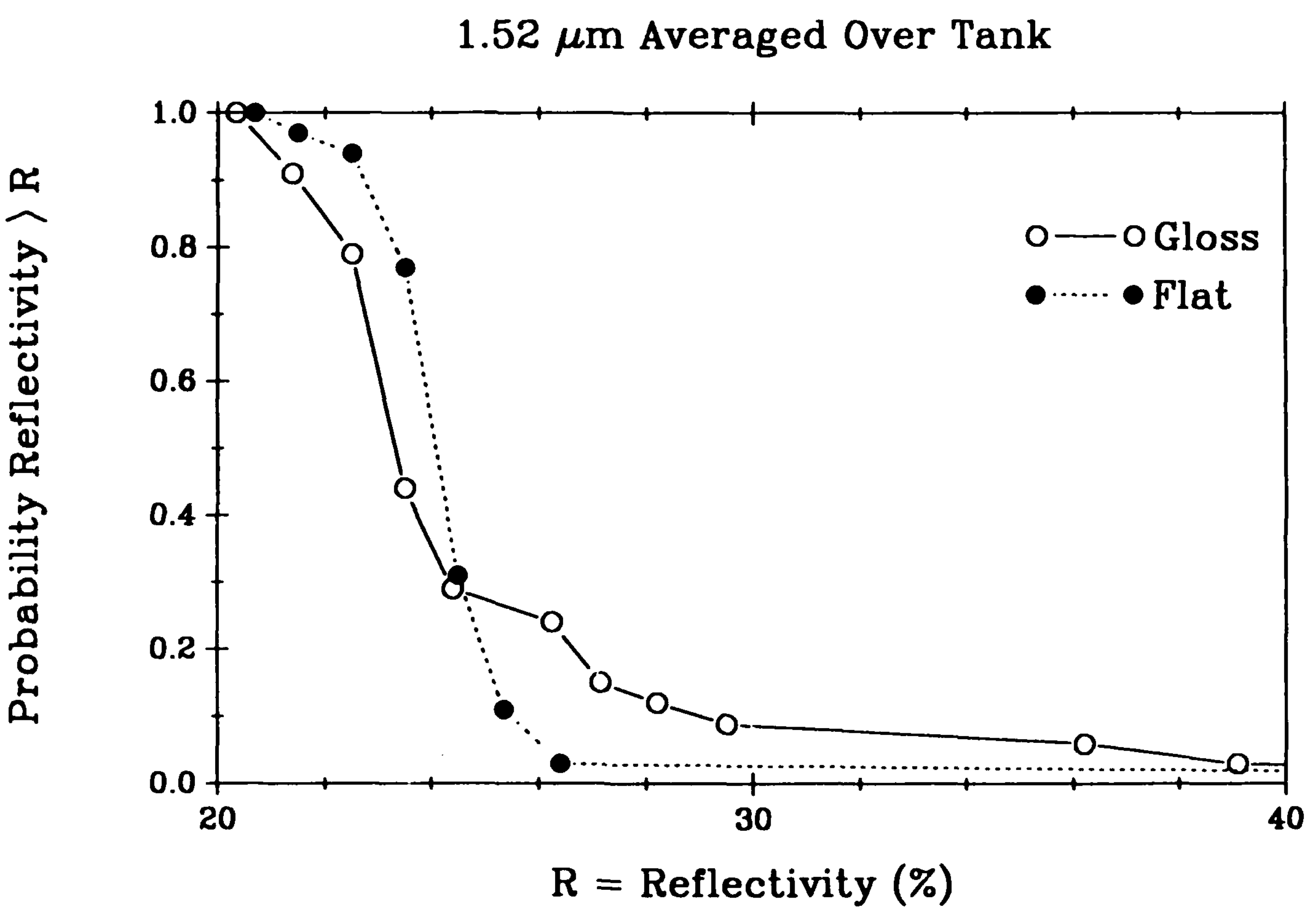

Figure 16. The probability that an observation of the target will result in a measured reflectivity greater than R. Both coatings are shown. The irradiating wavelength is 1.52μm and each point has been averaged over the three aim points.

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