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TERRAIN REFLECTANCE CAMOUFLAGE

E. R. Hendrix

General Electric Company

Prepared for:

Army Land Warfare Laboratory

May 1974

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The object of this program was to design, fabricate and field test a prototype terrain reflectance camouflage system for use with a parked M60 tank. Operational design requirements dictated that the unit be easy to deploy and repackage. The suggested concept was that the system would cover the hull and tread portion of the vehicle while another camouflage material would be employed on the vehicle turret and gun. This approach would permit the vehicle to utilize its weaponry in the defensive position.			

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This report summarizes the development of the prototype terrain reflectance camouflage system for the M60 tank.

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TECHNICAL REPORT NO. LWL-CR-23C73 A

CAMOUFLAGE BY REFLECTANCE

Final Report

Contract No. DAAD05-73-C-0325

By

E. R. Hendrix

General Electric Company
100 Plastics Avenue
Pittsfield, Massachusetts 01201

May 1974

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U.S. Army Land Warfare Laboratory
Aberdeen Proving Ground, Maryland 21005

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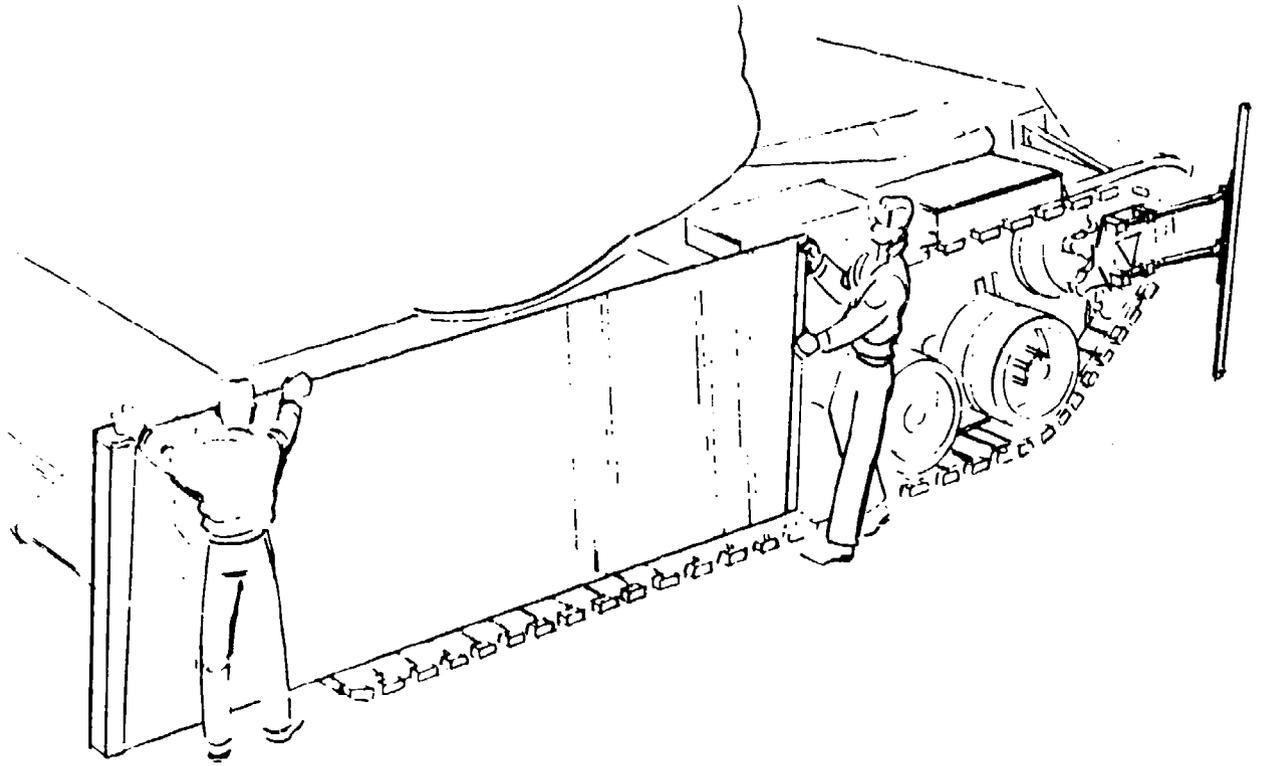
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Frontispiece

Section I
INTRODUCTION

BACKGROUND

The principles of military vehicle camouflage by reflectance was demonstrated under a previous feasibility contract* in which a jeep was successfully concealed using a reflective screen. In that program, the concealment of a 1/4-ton Jeep vehicle was achieved by using an independently supported mirror made of aluminized Mylar.

PROGRAM OBJECTIVES

This program was started in an effort to show the practicality of the same reflective technique applied to the hull of an M60 tank. The size and operational use of this vehicle made it a challenging subject for a camouflage system of this type. In order to meet the requirement of practicality, the camouflage system must not only achieve the primary purpose of concealing the vehicle from enemy observation, but also must not interfere with the major functions of the tank such as movement of the turret and gun. Also, the system must be easy to operate and maintain, and be capable of being quickly erected, taken down and stored. It must be rugged enough to withstand the rigors of combat operations and as small and light as possible for stowage on the vehicle.

ANTICIPATED DESIGN EFFORTS

In order to achieve an initial practical prototype terrain reflectance system, several engineering design requirements and trade-offs had to be developed early in the program. First, it was necessary to establish the system concept. This was achieved by participating early in the program with selected members of the USA LWL's military and engineering staff. These discussions resulted in the requirement for the tank terrain reflectance system to conceal only the hull of the vehicle when parked. The turret and guns were to be camouflaged via other techniques. The concept of using two different schemes to camouflage a vehicle is unique, yet provides the operational capability of being able to utilize the vehicles weaponry in the defensive posture. Further military design requirements were that the system should be capable of being stored on the tank in a non-interfering manner, (e. g., the rack on the turret was not to be considered because it is used for other critical items in combat). The unit was to be rugged and

* DAAD 05-72-C-0314, "Camouflage Through Reflectance of The Natural Environment"

capable of being erected in a rapid time frame (approximately 15 minutes). The engineering requirements were (1) that no drilling or modifications could be made on the vehicle to accommodate the system and (2), that the prototype system would conceal the front and one side of the vehicle's hull. The required effective ranges were 500 meters or greater for ground observation with the unaided eye. The system developed by General Electric may be seen in the frontispiece. The two-man crew is in the process of rewinding the side screen.

SUB-TASK DESCRIPTION & RESULTS

Once the general design considerations were established, several technical investigations were required to support and influence the prototype design. These individual investigations and resulting data are summarized in the sub-task descriptions given later in this report.

Finally, the prototype system was field tested in order to determine if the terrain reflectance hardware was effective and practical as a camouflage concept for the M60 tank. These tests were performed both at the contractor's facility in Pittsfield, Mass., and on the Aberdeen Proving Ground reservation in Maryland. These were primarily ground-to-ground visual observation tests at a range of less than 500 meters. During both the Pittsfield and Aberdeen trials, the government furnished different night observation and thermal viewing optical devices for limited observations. These trials were included to ascertain if the terrain reflectance concept offered any potential as a countermeasure for these devices. The number of trials was not intended to be sufficient to establish definite conclusions - only general trends. The results of these field tests are summarized in this report.

The camouflage technique achieved by the successful application of reflective screens (or mirrors) can be described as a merging or blending of the subject into its surroundings by reflecting the immediate foreground to the observer. The detectability of the screen is made more difficult by its ability to accurately reflect the colors, forms and movements of the surrounding terrain. Terrain characteristics will vary considerably with changes in weather, season and location. However, as long as the background and foreground are similar, the reflected image will blend naturally. A reflective screen camouflage system will adapt to the environment in which it is used and re-adapt as that environment changes.

There are several limitations to the degree a practical camouflage system can produce the desired blend with the background. Some of these limitations can be reduced by engineering design and materials. Other limitations are imposed by nature, and are not as easily overcome.

To be most effective, the mirror had to reproduce the color and brightness of the foreground terrain as faithfully as possible. This dictated high specular reflectance over the spectrum of interest. The mirror also had to be flat enough so that no gross image distortions were created that were noticeable from a reasonable distance. Of great importance was that no distortion of the surface allowed "skylight" to be reflected to the observer. Additionally, the mirror must be rigid enough that no gross movement of the image was presented to the observer as a result of wind disturbance.

The system depends on no noticeable discontinuities or contrasts between the shield and its surroundings. The system is degraded to the extent that the mirror is not able to reflect an image matching the surroundings. This can occur when the foreground vegetation or terrain is different from the background. Lighting differences are also important. If the sun is behind the camouflage vehicle, the observer sees the shaded side of most vegetation: however, the mirror reflects the image of the sunlit side of the terrain. The opposite is true with the sun behind the observer. The mirror will compensate to some degree for these effects by casting a shadow (with the sun behind) or light (with the sun in front) thus neutralizing the contrast in lighting.

In order to efficiently and effectively design and fabricate a prototype terrain reflectance camouflage system for the M60 tank, several preliminary technical problems required investigation. These are covered in the following paragraphs.

a. Determine the feasibility of camouflaging the front, sides and rear of an M60 Tank

Prime consideration was given early in the program to the prevention of interference with the normal operation of the tank's turret and gun, a concept which led to the approach of concealing only the tank hull. With this approach of concealing only the hull (since it presents the most obvious visual signature) with aluminized Mylar* film supported by the vehicle, it is considered feasible to camouflage the front, sides and rear. However, most operational situations would be adequately served by hiding only the front and one side of the hull. This configuration presents a 90° horizontal sector over which the hull is completely concealed. On either side of this sector, the camouflage is partially effective for an additional 90°, as shown in Figure 1. These sectors can be further protected by the use of natural cover. It was recommended that the two-sided configuration be deployed under normal circumstances.

* Trade mark, E. I. du Pont de Nemours & Company

- b. Perform a comparison study of the bisurface reflector configuration with the surface configuration.

Work done on the previous contract showed that there are inherent advantages to both plane (single surface) and bisurfaced reflectors. The General Electric-developed bisurface reflector concept consists of a series of plane surfaces arranged, vertically, at right angles to one another accordion fashion. The bisurfaced reflector was, in effect, a horizontal retroreflector (see Figure 2.)

Figure 2(a) demonstrates that when a mirror moves through an azimuth angle, as would occur under wind-gust conditions, the observed image moves. If the mirror is moved 5° by the wind and the observer is 30 feet away, the image will move about 5 feet. Therefore it is important to reduce motion in the plane surface reflector. This can be done by stiffening it and is most easily achieved by tensioning the reflector within the limitations of other restraints.

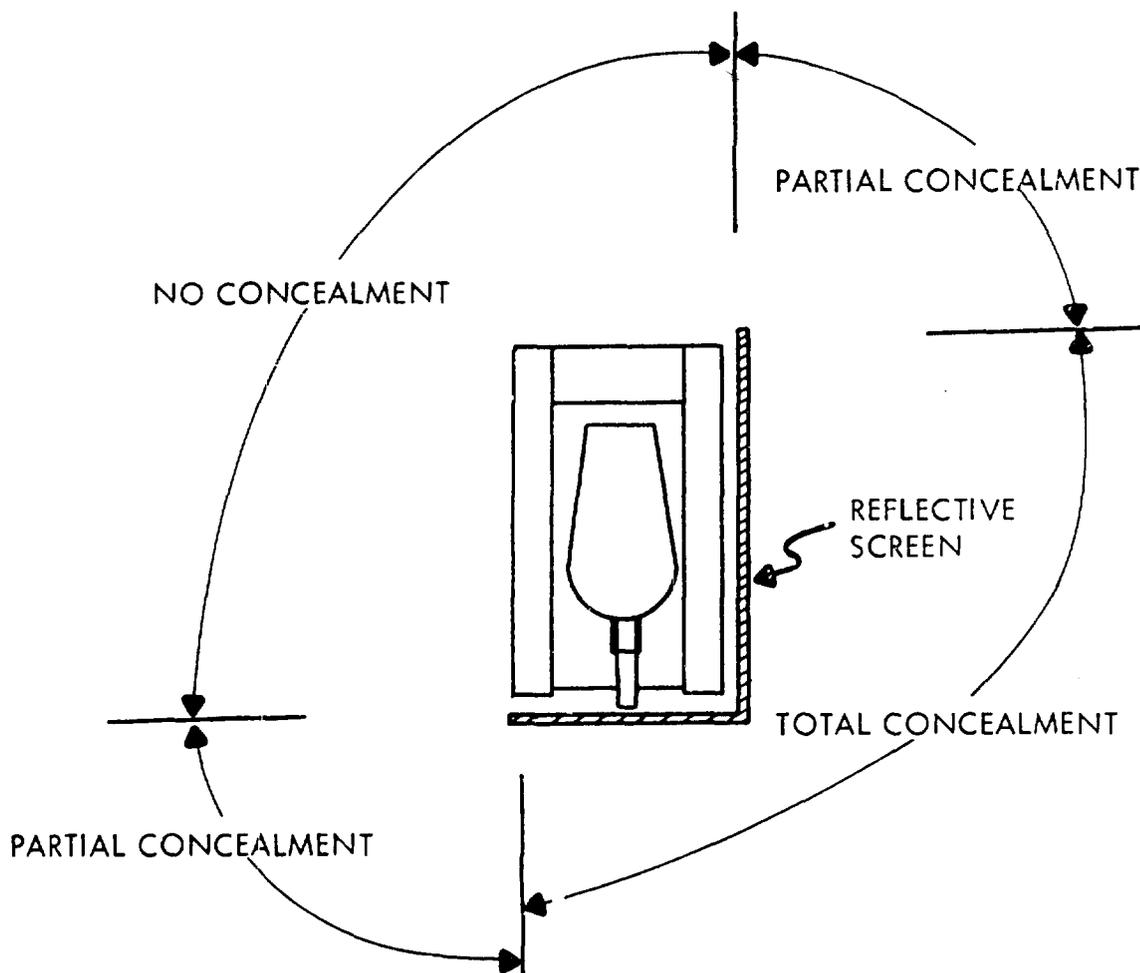


Figure 1. Areas of Total and Partial Concealment

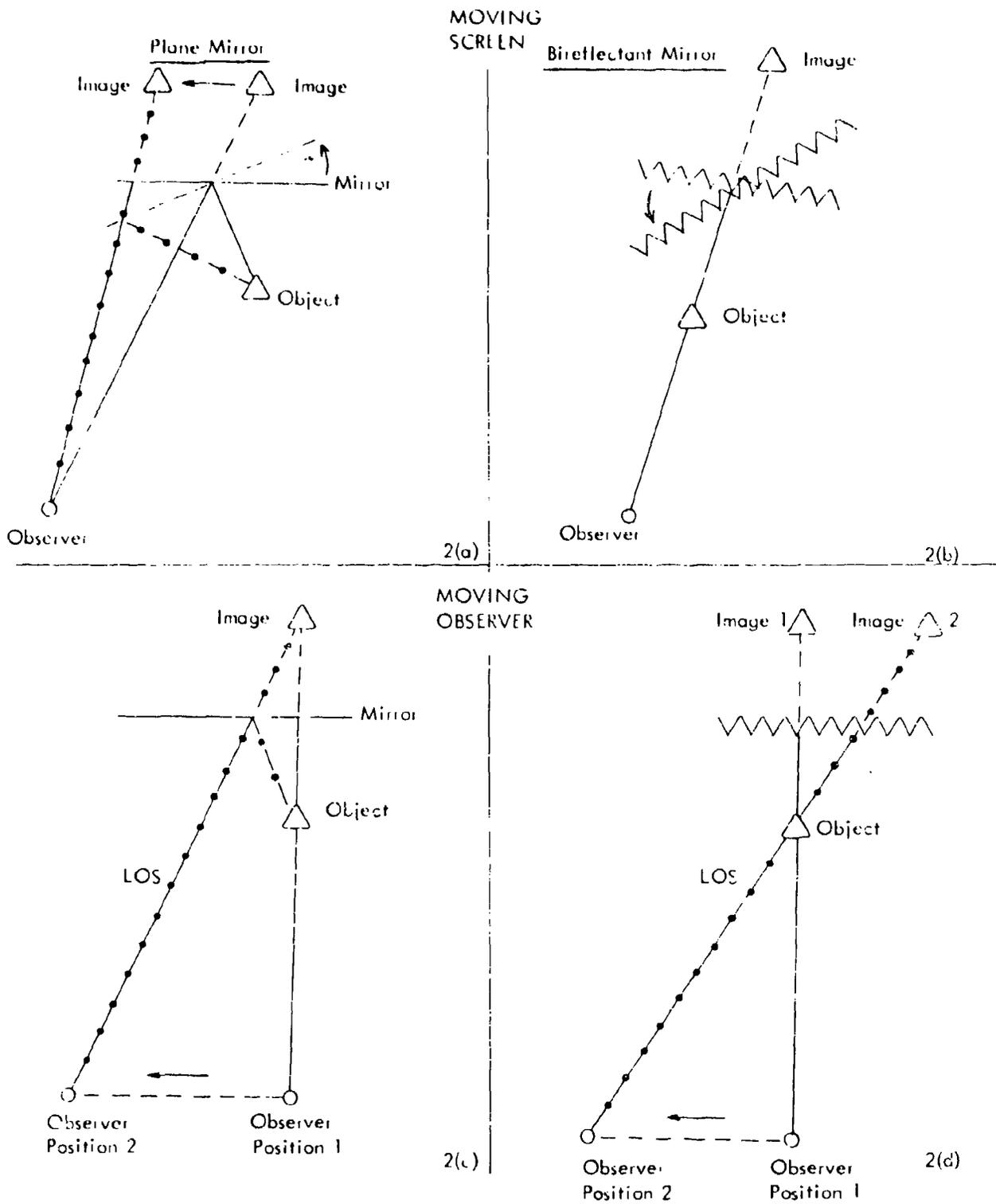


Figure 2. Comparison of Bireflective and Plane Mirrors

The problem of the moving image as a result of screen movement is relieved in the bi-surfaced screen configuration. This configuration has the characteristic that both image and object lie along the line-of-sight, independent of the orientation of the line-of-sight to the screen. This means that as the screen is rotated in azimuth by the wind, the image remains stationary, see Figure 2(b). Conversely, however, as the observer crosses in front of the screen, the image remains stationary as seen reflected by a plane mirror, see Figure 2(c) and moves when observed in the bi-reflective surface, see Figure 2(d). This movement will not be nearly as noticeable to an observer as movement due to plane mirror movement would.

Field observation of small panels show little significant difference between the two approaches. The advantage of the stiffer inherent in the bi-reflective surface is diminished when the vehicle is used for support of the screen. The screen is also less exposed to wind when it is mounted close to the vehicle hull. In balance, the more compact and less complicated plane reflective surface was considered superior for the present camouflage concept.

- c. Conduct additional studies of materials and select the optimum base material and protective coating for the reflective shield. Determine the durability of the selected reflectant material.

In light of the prime concept of rolled reflective screens, a survey of various flexible plastic films for base material was made. Their important characteristics are compared in the accompanying table. The good mechanical characteristics of Mylar and its ready availability in aluminized form made it an excellent choice for the base material. Although Kapton* has mechanical characteristics equivalent to Mylar, it is not as readily available.

The reflective material is subject to degradation from erosion due to handling and weather if the aluminum surface is not protected. The approach which offered the best solution to this problem was a lamination of Mylar film with the aluminum reflective surface sandwiched in between. The final material selected was 0.001" aluminized Mylar with a 0.007" Mylar backing.

- d. Study and test the employment of the reflective shield as a drape rather than as a rigid sheet for camouflaging the vehicle, thereby eliminating the need for supports.

The effectiveness of camouflage by reflectance depends on projecting an image to the observer that matches the background in brightness, color and form to the greatest possible degree. In most situations the background is quite similar to the foreground

*Trade mark, E. I. du Pont de Nemours & Company

COMPARISON OF PLASTIC FILMS

Property (25° C)	Mylar (Polyester)	Kapton (Polyimide)	Polyvinyl Chloride	Polypropy- lene	Polysty- rene	Polycarbonate Lexan	Nylon (66)
Tensile Strength	25K	23K	1-5K	15-32K	7-12K	8K	12K
Yield Point	10K	13K	Low				
Elongation, Ult.	70%	120%	5-500%	40-80%	3-10%	85-105%	250%+
Tensile Modulus	430K	550K	Low				
Area Factor ft ² /lb/ml	135	140	140	210	152	140	154
Clarity	Transp	Transp	Transp	Transp	Transp	Transp	Transp
Res. to Sunlight	Exc (Type W)	Exc	Good	Fair	Fair	Fair	Fair
Storage Stability	Exc	Exc	Exc	Exc	Good	Exc	Exc
Dimensional Change	Nil	None	Nil	-	Nil	Nil	Nil
Res. to Oil & Grease	Exc	Exc	Fair	Good	Good	Good	Exc
Res. to Solvents	Exc	Exc	Poor	-	Poor	Fair	Exc

and so the foreground is used as the object to be projected into and blend with the background. The reflective surface must be tilted forward to present intended effect to the observer.

Although the savings in weight, cost, storage volume and time deployment would be substantial if it were possible to drape the camouflage material on the M60 tank, the risk that this approach might enhance the visibility of the tank by reflecting skylight must be an overriding consideration.

With these restrictions in mind, it is difficult to conceive of a means of draping reflective material on an M60 tank in a way that will meet these basic requirements and not enhance the target by reflecting skylight to the observer. A 6" X 16" drape of .001" aluminized Mylar was made and draped over a small military vehicle. The result is illustrated in Figure 3.

Although Figure 3 illustrates an extreme of skylight reflectance, even a small percentage of this reflectance would result in an obvious enhancement of the tank's position rather than hiding it. For these reasons, it was concluded that draping is not a practical approach to camouflage with reflective material.

e. Study and test the effectiveness of the reflectant material as a silhouette disrupter.

To evaluate the effect of reflectance as a silhouette disrupter, small reflective panels were made and tested for a 1/30-scale model of an M60 tank and full-scale applied to the M113 vehicle. The effect was generally good, as seen in Figure 4. However, small independently supported panels must be attached with extreme care to insure that each panel reflects the foreground back to the observer in the proper manner. They must also be made rigid with appropriate backing material, thereby posing an additional storage problem. The panels shown in Figure 4 were 2 X 4 feet.

f. Perform human factors analysis to establish the best hardware configuration with respect to mission objectives, ease of operation and maintenance.

Human factors studies were concerned initially with the basic parameters of target recognition as a function of distance and contrast. There is an obvious reduction in color discrimination and contrast resolution in direct proportion to viewing distance thereby affecting the recognition threshold. Recognition occurs (the threshold) when there is a discernable difference between the target and its background. In general, the recognition of a camouflaged target is dependent upon such parameters as the size and shape of the target, the contrast with its background, the illumination level, and time available for seeing.

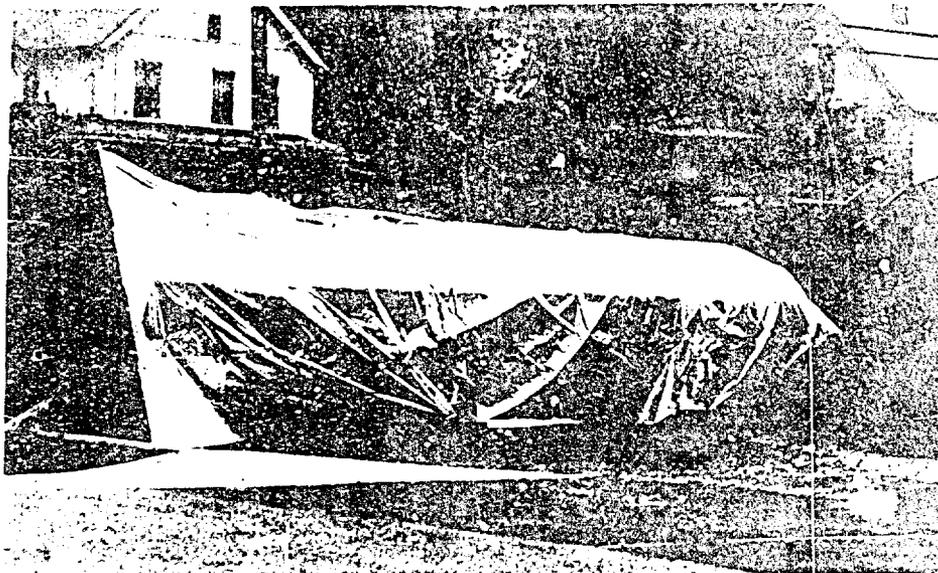


Figure 3. Reflective Material Draped Over Small Vehicle



Figure 4. Silhouette Disruptor with 2 x 4-Foot Panels

Human factors experiments involved the construction and evaluation of five reflector configuration models in a field environment to determine the effect on the observer of different mechanical configurations. Figure 3-A shows, from left to right, the five: venetian blind, flat-slat rollup shade, bi-reflective, flat screen with wind pressure compensation, and flat screen on solid base. A sixth configuration was considered; a series of rollup screens hung vertically along the vehicle's length. This was rejected as being too complex and increasing the elements in the system to an unwieldy number.

The five devices modeled were visually evaluated at distances of from 50 to about 500 meters. The backgrounds were a dead grass field and a brushy creek bottom. Winds estimated at 5-7 miles per hour caused slight movement of the more flexible models.

There were several observations:

1. All units reflected the foreground adequately with the flat screen models performing best. These two, because of their construction, had a higher reflectance coefficient.
2. At 50 meters, all were detectable in the dead grass field. At 200 meters, in the brush, only items 1 and 2 were at the recognition threshold and then only after concentrated study.
3. Slight movements of the reflectors caused by wind action did not significantly increase the recognition threshold.
4. Vertical edges were the most readily detected portion of the reflectors.

There was little optical difference in the five approaches at distances of 200 meters and beyond. Thus, the overall conclusion reached was that the reflector design, assuming a viewing distance in excess of 200 meters, should be primarily determined by assembly and packaging constraints.

During the hardware design phase, General Electric Human Factors personnel provided design consultation to the equipment designers. This included anthropometric evaluations of proposed configurations, formal and informal design review, and a field use consideration of the final hand-crank configuration. Suggestions were made on the design and its operation.

- g. Investigate the effects of meteorological and environmental conditions on the effectiveness and longevity of the reflective shield system.

Several small samples of aluminized Mylar were mounted on a plate and exposed to the weather. During the 5-week exposure period, they experienced temperature cycling, rain, and many hours of direct sunlight. The samples having an aluminum front surface showed considerable deterioration in spots due to erosion of the aluminum surface. One sample had a reflective second surface protecting the aluminum by 0.002"



Figure 3-A. Five Configuration Models Built for Evaluation

of Mylar film. This sample showed no deterioration to the naked eye. It was concluded from this test, and the fact that the exposed aluminum could be removed by rubbing, that a laminated material would be best.

- h. Determine the methods of mounting a reflective system on an M60 tank without interfering with any major function of the vehicle.

With the intent to keep the size and weight of the reflective camouflage scheme to a minimum, and impose the least interference on the major functions of the tank, the following general design approach was developed. The reflective screens should be flexible Mylar films that can be rolled up on spools to keep storage space and system weight to a minimum. Since these flexible films require considerable tension to remain plane surfaces when deployed, a rugged framework is required. The tank hull itself will be used as the main structure of the framework so additional heavy supporting structure will not be required. Attachment points to the tank hull must be strong and stable (e.g., the lightweight aluminum fenders were not acceptable as attachment points). Using these guidelines, the system was conceived as follows. The system will consist of two reflective screens rolled on vertical spools, stiffened at one end by the roll spool and at the other by a rigid bar. The spool and bar will be supported at the top by adjustable brackets clamped to the tank corners, and at the bottom by spikes driven into the ground. Adjustments would be provided to accommodate variations in ground level and tank attitude. The top horizontal edge of the Mylar will be supported by adjustable clamps attached to the tank by brackets clamped to the fender and tool boxes. The lower edge will be similarly clamped using the lower track for support. These clamps will be attached approximately every 6 feet. For the front screen, a vertical rod supported from the tank will provide the mounting for clamps supporting the screen. This concept would be detailed during the design phase.

- i. The contractor shall conduct tests to determine if the reflective shield system increases detection of the vehicle to be camouflaged by techniques (IR, radar, etc.) other than the unaided eye.

Tests were performed on samples of the aluminized Mylar to determine reflectance over the UV, visible, and IR portions of the electromagnetic spectrum. (See Appendix A, for Detectability Analysis. Figures A-5 through A-8 are copies of tracings from a Beckman Spectrophotometer Model IR9.) The sample with aluminum on the second surface showed a considerable drop-off in reflectance in the IR region. Type W polyester (Mylar) was claimed to have much better transmittance characteristics in the IR and a sample was procured and tested. Although some improvement was shown, it was not considered significant enough to warrant applying in the system.

For passive thermal IR detectors, the relative temperatures of objects are the most important factors affecting detection. In analyzing performance with these devices, calculations of contrast of the shield (relative to the background) and the tank (relative to the background) were made. Three different shield temperatures (17°, 22°, and 27° C) were used. Ground temperature was held at 22° C and target temperature held at 27° C. The ratios of these contrasts are tabulated below:

(All in Degrees C)

<u>Shield Temp.</u>	<u>Tank Temp.</u>	<u>Foreground Temp.</u>	<u>Contrast Shielded/Contrast Unshielded</u>
17	27	22	0.12
22	27	22	0.78
27	27	22	1.7

Since the amount of thermal energy radiated from the foreground and reflected by the shield to the observer was so slight (compared to the energy directly radiated by the shield) it was not considered a factor in this analysis.

The reflective shield was designed with a .007 in. thick Mylar backing for strength and an aluminum coating protected by a .001 in. thick Mylar front surface. This sandwich with a total thickness of only .008 inches was designed to have high visual reflectivity and has very low mass or weight. Since both the outer surfaces are of Mylar which has a high coefficient of thermal radiation, the shield will radiate its energy and stabilize at a temperature lower than the adjacent ground. Also, losing energy through convection the shield will be at a temperature approximately the local air temperature.

When a tank-sized object has a temperature significantly different from its background, heat-sensing devices can detect its location. An example of this "detectability by contrast" would be, in the visible spectrum, the difference between the black and white keys on a piano. If the shield is cool relative to the tank a net improvement in concealing the tank results. Conversely, if the shield is equal to or warmer than the tank and warmer still than the background, it will be more conspicuous. However, since the thermal capacity of the shield is small compared to the tank (due to their vastly different masses) the shield will normally be cooler than the tank. This is especially true at night when thermal detectors are most apt to be used. A detailed analysis is given in Appendix A.

Upon completion of field testing, all deliverable material was forwarded to LWL.

Section II

TECHNICAL DESCRIPTION OF THE TERRAIN REFLECTANCE SYSTEM

INITIAL DESIGN CONCEPTS

The initial system concept was essentially an extension of the previous contract approach, i. e., a screen large enough to conceal the whole front view of the vehicle. Several approaches to this concept were developed to determine the best one. The initial concept was for the screen to be 16' wide and 13' feet high to provide acceptable shielding of the front profile of the M60 tank.

After review of this concept with LWL technical and military personnel, it was decided to limit the design requirements to camouflage the M60 tank hull only. Again, several designs were evaluated. This new requirement to conceal the hull only made it possible to bring the screen closer to the tank hull and allowed the use of a somewhat smaller screen to hide the hull. In this approach, the tank forms the main support for the system. Concepts including the storage on, or main support from, the fenders were eliminated since the fenders do not survive long in an operational environment. It was concluded that the system would have to be stowed away from its operational position, and therefore it was decided to limit the length of stowed components to approximately 6 feet.

The most economical concept in terms of bulk and weight was to roll up the screens on vertical rolls or spools. This presented some problems that required solution before such an approach could be pursued. The reflective screen must be relatively flat and rigid, therefore appreciable tension ($\sim 150\#$) must be applied to the flexible material. This required that rugged support points be used to take these forces. For this reason, the sprocket and compensating idler wheel were chosen as the main support points since their integrity could be counted on. Another requirement for satisfactory operation was that the support ends of the flexible screen be self-aligning so that no wrinkles are produced in the screen when tension is applied. To accomplish this, both support ends are pivoted so they align automatically when tension is applied. Thus no adjustments are required of the user personnel and erection can be performed rapidly. There was also concern that difficulty would be experienced in rolling up the screen for stowage. It was felt that a long flexible screen with gravity acting adversely would tend to work off the roll. The roll was made large in diameter to reduce the number of turns, and flanges were added to assist in guiding the screen. A full scale model of this approach was built and tried with satisfactory results.

The plates connecting the system to the tank wheel and sprocket were designed to grip the inside diameter of the wheels with lever actuated cams. Initially it was assumed the wheels were steel as indicated in the available drawings. However, it was learned some M60 tanks were converted to aluminum road and compensating idler wheels with smaller inside diameters. The design of the plates attaching to the compensating idler wheels was modified to accommodate either steel or aluminum wheels.

Drawings were made for the fabrication of the hardware in the General Electric Ordnance Systems development shop. Most hardware was fabricated from aluminum to reduce total weight. The reflective material is a 0.001" film of aluminized Mylar laminated to a film of 0.007" Mylar with the aluminum coating sandwiched in between.

Section III

FIELD TEST

The general objective of the field test was to evaluate the effectiveness of the system from the standpoint of the user and the viewpoint of the observer. Both aspects are subjective in nature and do not lend themselves to precise measurement. However, the time required to perform various functions was recorded, and photographs were made to illustrate the system's effectiveness under various environmental and simulated combat conditions.

Tests conducted at General Electric facilities in Pittsfield during the week of September 10, 1973 were in accordance with the Integrated Test Plan. Since an M60 tank was not available, an M113 vehicle was modified by rigging M60 wheels at appropriate positions, as support points. The results of these tests are summarized in the following paragraphs.

Weather conditions varied during the test week from clear skies to light drizzle, and from calm to winds of 7.5 mph. The terrain, consisting of low rolling hills and rises, was covered generally with low brush, grass and a few clumps of trees. The area was restricted to initial viewing distances of less than 400 meters.

Two General Electric Company low-level, non-exempt technicians whose respective educational backgrounds are equivalent to vocational high school graduates neither of whom had performed any military service were employed to erect this reflective camouflage system. In spite of their total unfamiliarity with the system and with no more than 15 minutes orientation and "on-the-job" training in the field, these two young men erected the system satisfactorily in seven to eight minutes and were able to disassemble it in five to six minutes. (It is expected that erection after dark would take somewhat longer.) Some difficulty was experienced in attaching the bracket plate to the aluminum compensating idler wheel. This was overcome through the use of knurled rings in the cam-locking mechanism which increased the contact surface. No special tools were required and in general, the hardware worked well (from the user standpoint).

Results of the observer tests indicated that under certain conditions of terrain, wind, and lighting, untrained personnel may approach to within 50 meters before locating the tank. The average detection distance was approximately 230 meters.

During the night tests, a Thermal Viewer (AN-PAS-7) and a Starlight Scope (AN-PAS-2A) were used against the system. Even when the exact location of the vehicle was known to the observers, the target was not detected with either instrument until the range had closed to 35 meters.

The following clues were the primary contributors to detection:

1. Whenever the wind blew or gusted above 5 mph the screens (particularly the side screen) waved enough to be spotted if the observer was looking in that area.
2. With the sun behind the vehicle shining at the observer (especially low in the sky) the screen reflects its own shadow. When parked against trees or high bushes, this reflection is not obvious; however, in an open area or low scrub, the reflection

appeared as a large dark area that was noted by several observers when at 300 meters or less.

3. When the background and foreground were not perfectly similar, the rectangular shape projected by the screen was noticeable. This clue is detectable at 250 meters and possibly more when the background is some distance from the vehicle. Attempts to break up the straight lines using cut brush met with fair success.

The final field test consisted of a demonstration of the camouflage by reflectance system applied to an M60 tank at Aberdeen Proving Ground. The demonstration was conducted by LWL and General Electric personnel at Aberdeen during the week of 10 October 1973. The equipment was mounted on an M60 tank for form-and-fit trials. Some minor modifications to the equipment were required and these were accomplished at the LWL model shop. The field test and results are discussed in detail in a separate report entitled "Camouflage by Reflectance", Report of Field Test, Technical Report # LWL-CR-23C73 dated May 1974.

Section IV

CONCLUSIONS & RECOMMENDATIONS

Camouflage by reflectance was applied to an M60 tank with good results. From an operational standpoint, there is no other known approach that can match and blend with such a large variety of backgrounds. When the user erects the system with an awareness of brightness and color contrast effects, an observer may approach to within 50 meters before detection is made. The system was designed to shield only the hull of an M60 tank and therefore must be used in conjunction with other camouflage for the turret and cupola to completely conceal the tank.

The system was designed to be attached with no modification to the M60 vehicle. Consequently, some components are larger than would be necessary if the system were designed integrally with the tank. Some components, particularly the wheel attachment hardware, could be made lighter and easier to attach to the tank wheels. A better design for these hardware components was difficult since there was no M60 available at or near the General Electric plant in Pittsfield, Mass. Since the M60 was not designed to provide deck space for stowage, not having a tank locally precluded any approach other than four containers which would be tied to the attachment points on the hull.

The system is regarded as meeting all other objectives of the contract and bettering the quantitative requirements of erection time and effective distance. Figures 5 through 10 show the major components of the system in their order of erection. Figures 11 - 14 show the system's effectiveness during field tests using the modified M113 vehicle. In Figure 13, the camouflaged vehicle is at the intersection of the horizontal and vertical reference lines.

The system demonstrates the feasibility and effectiveness of applying reflective camouflage to large military land vehicles, and specifically, to the M60 tank. It is recommended that further field evaluation be performed with the system to evaluate the suitability of this type of camouflage for large vehicle application. If this evaluation concludes that reflective camouflage should be further developed for land vehicles, it is recommended that the design be integrated with the vehicle body in such a manner that deployment and stowage would be simplified.

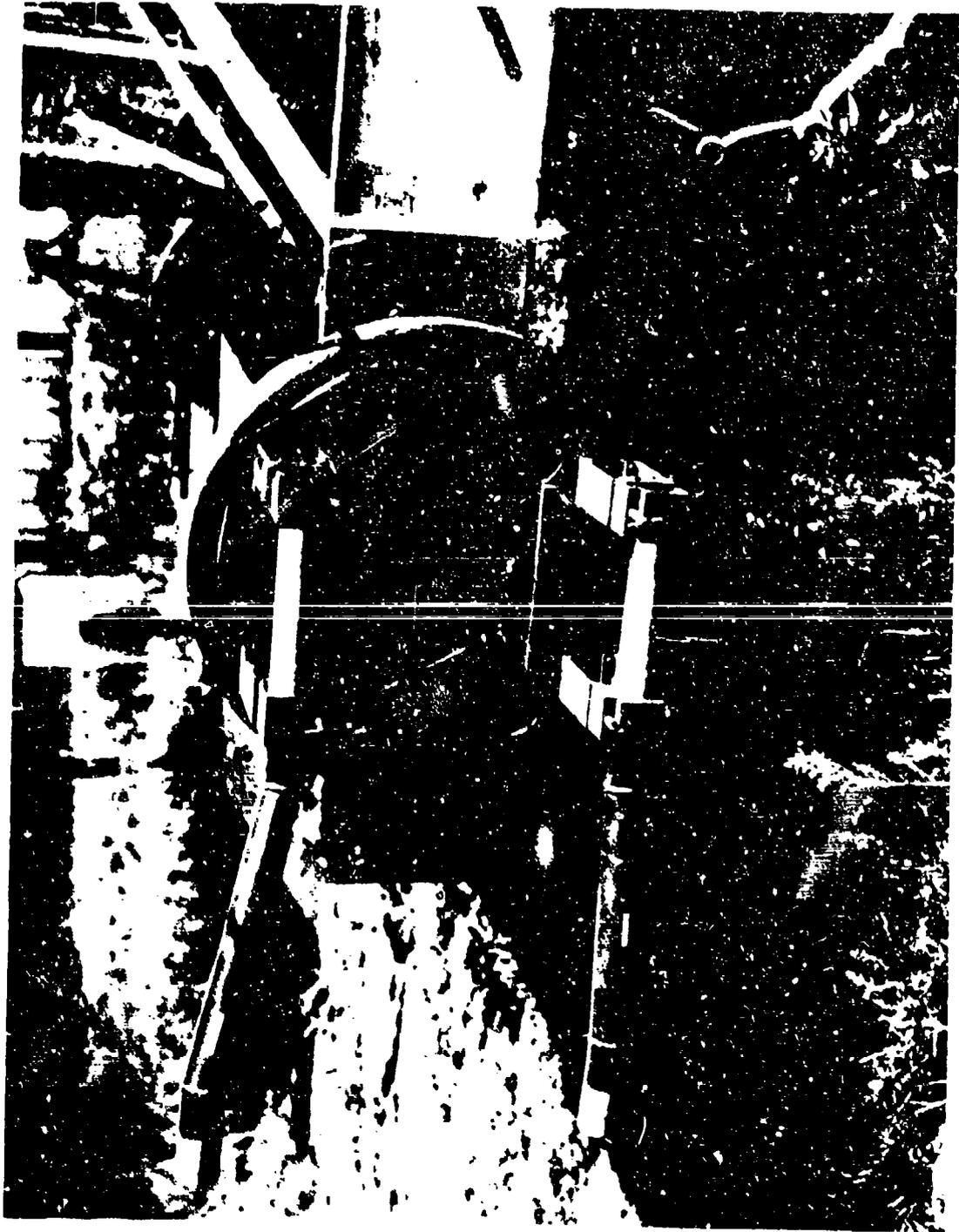


Figure 5. Left Compensating Idler Wheel Plate in Place Showing Mirror Case Support Arms

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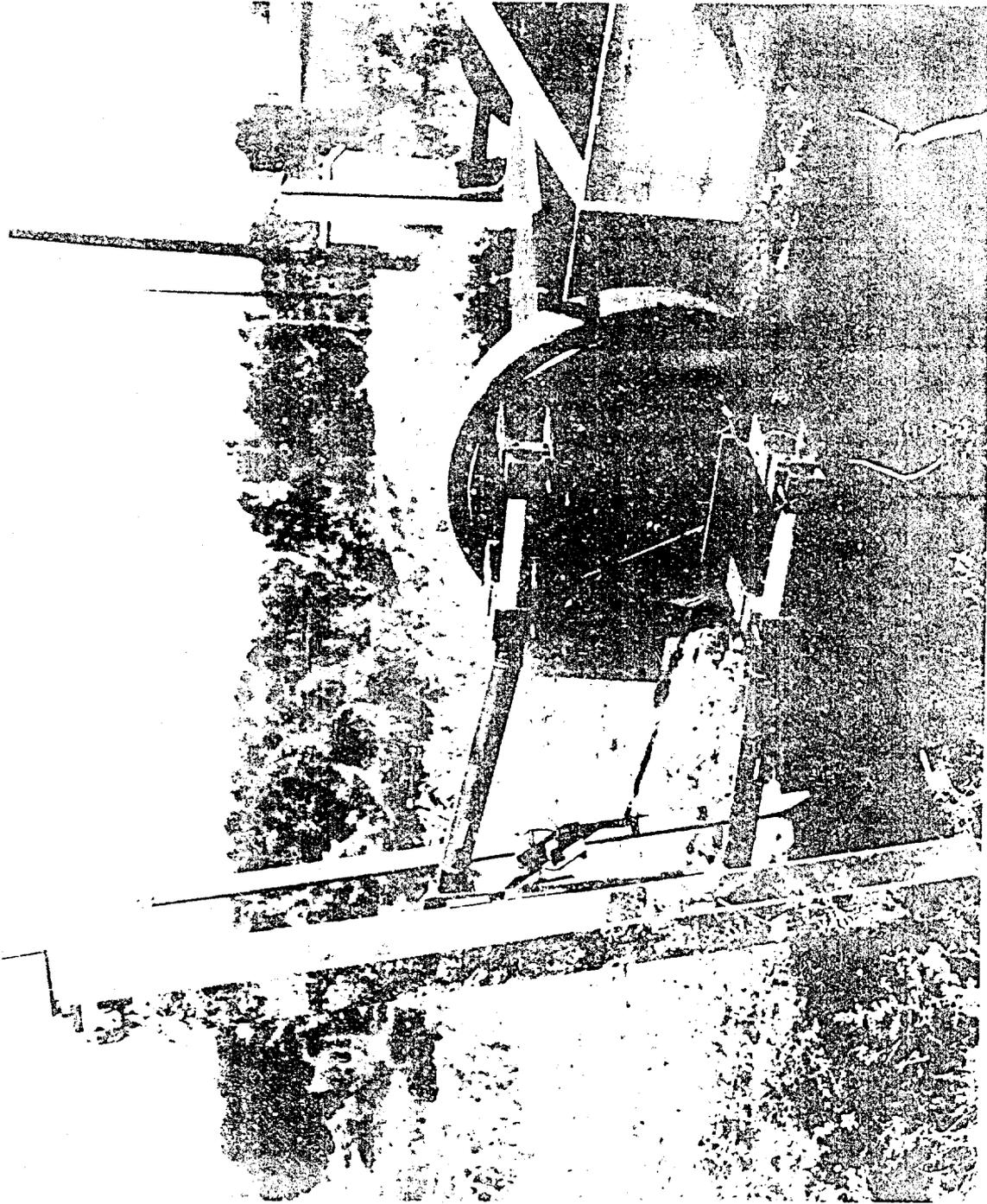


Figure 6. Left Side Mirror Case With Sprocket Plate

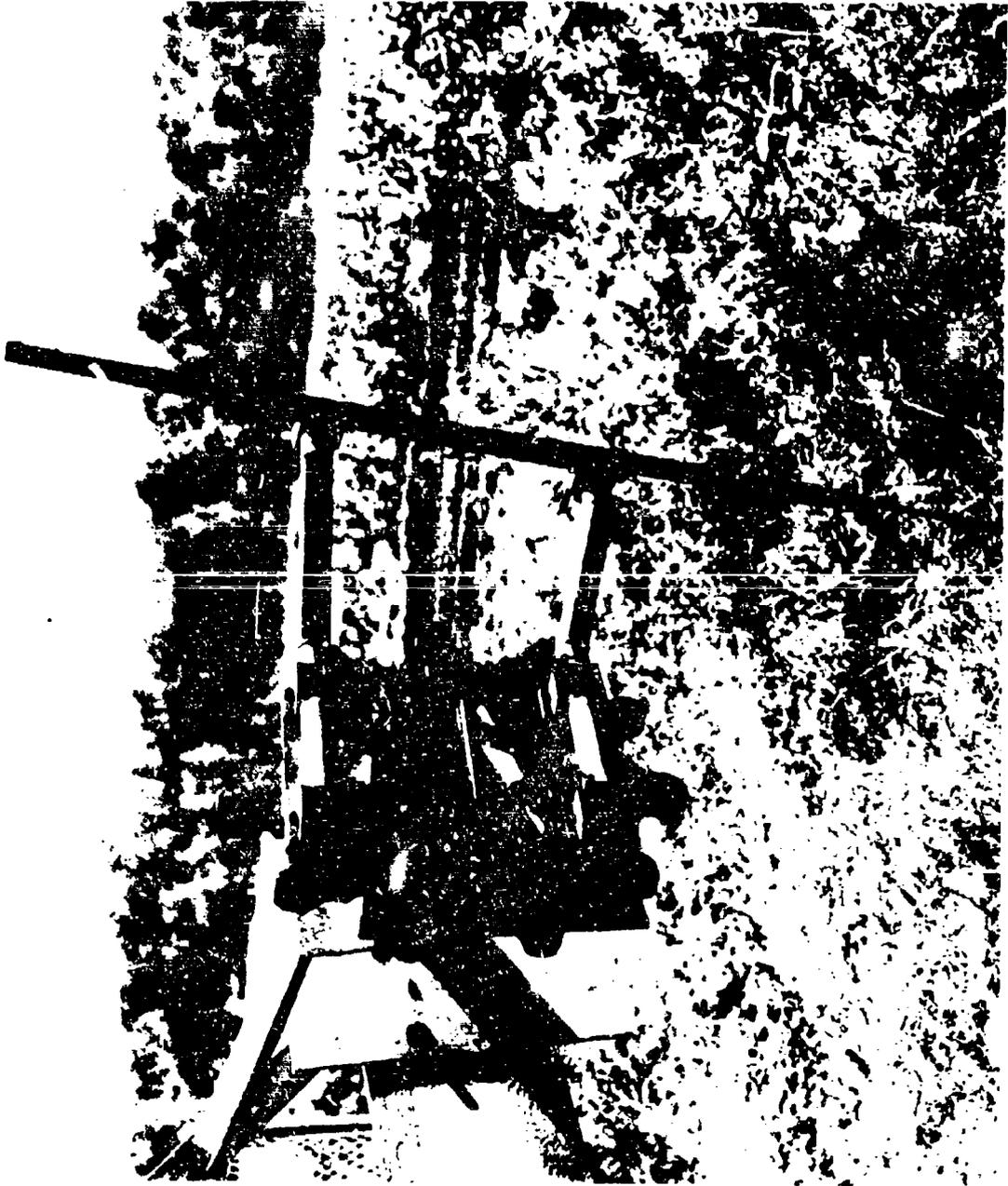


Figure 7. Rotating Bar in Place Showing Support Arms



Figure 8. Left Side Mirror Being Extended



Figure 9. Right Compensating Idler Wheel Plate in Place Showing Support Arms

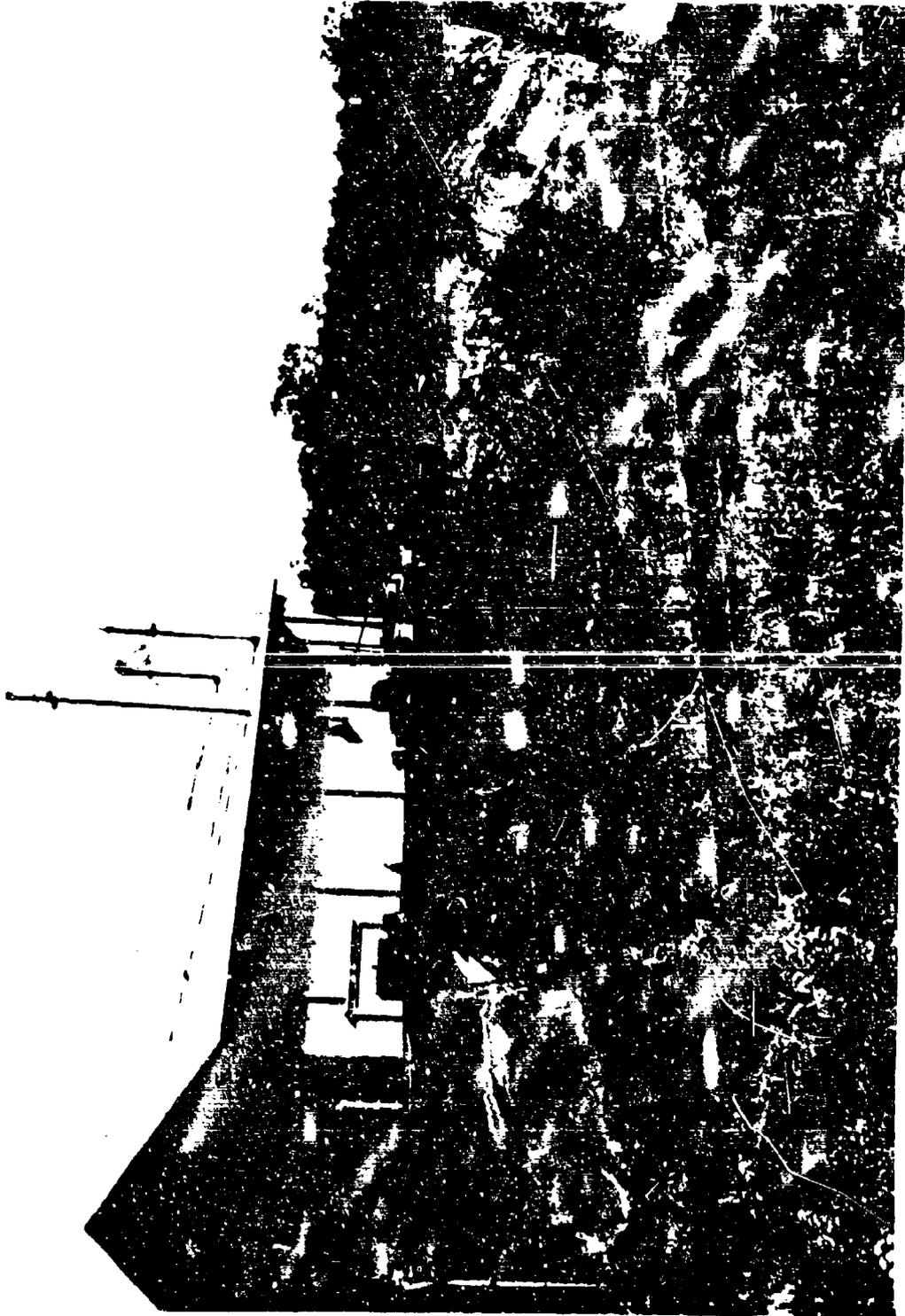


Figure 10. Total Reflective Camouflage System

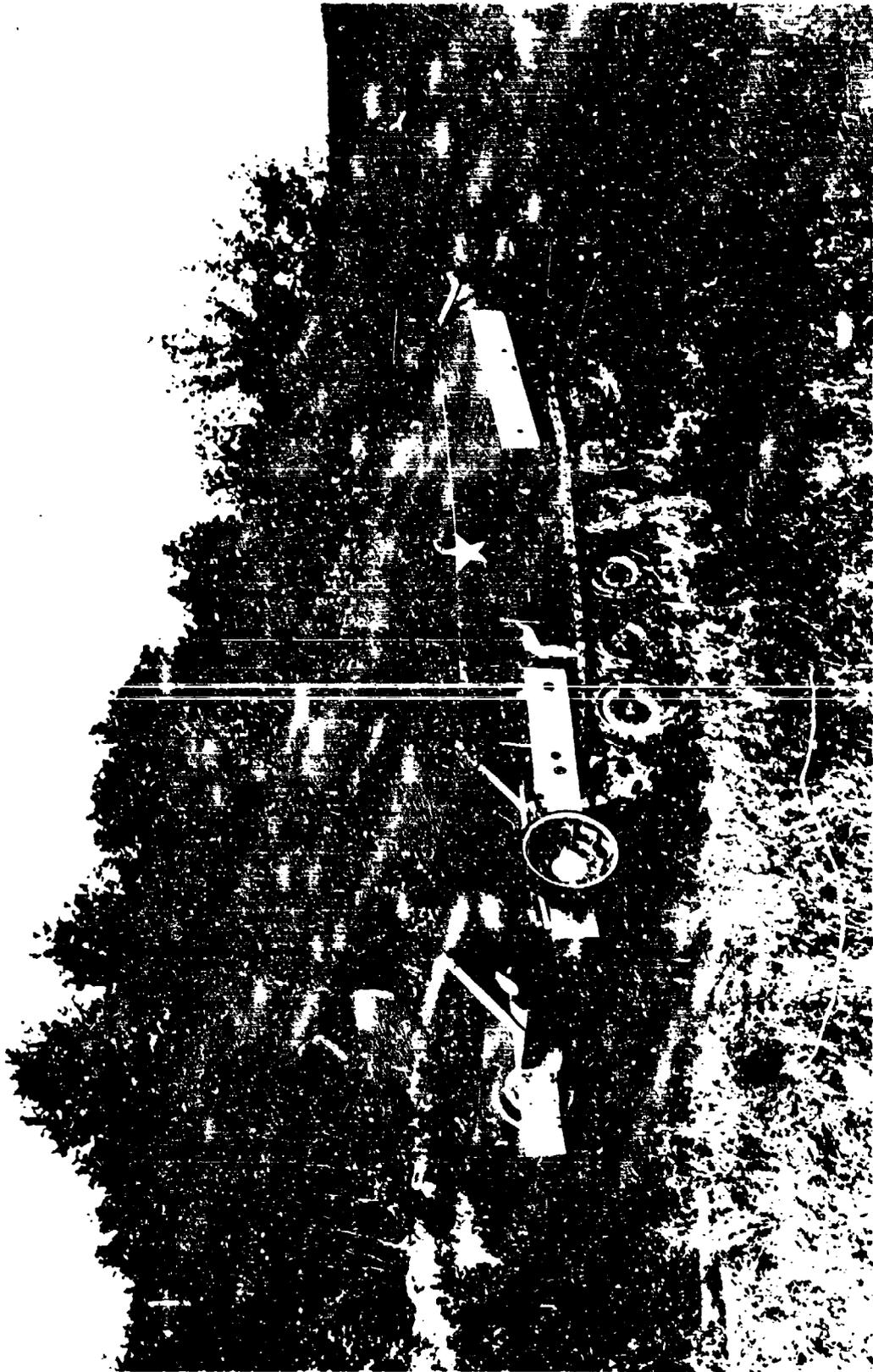


Figure 11. M113 Vehicle with M60 Sprocket and Compensating Idler Wheels in Place



Figure 12. M113 Test Vehicle from 200 Meters

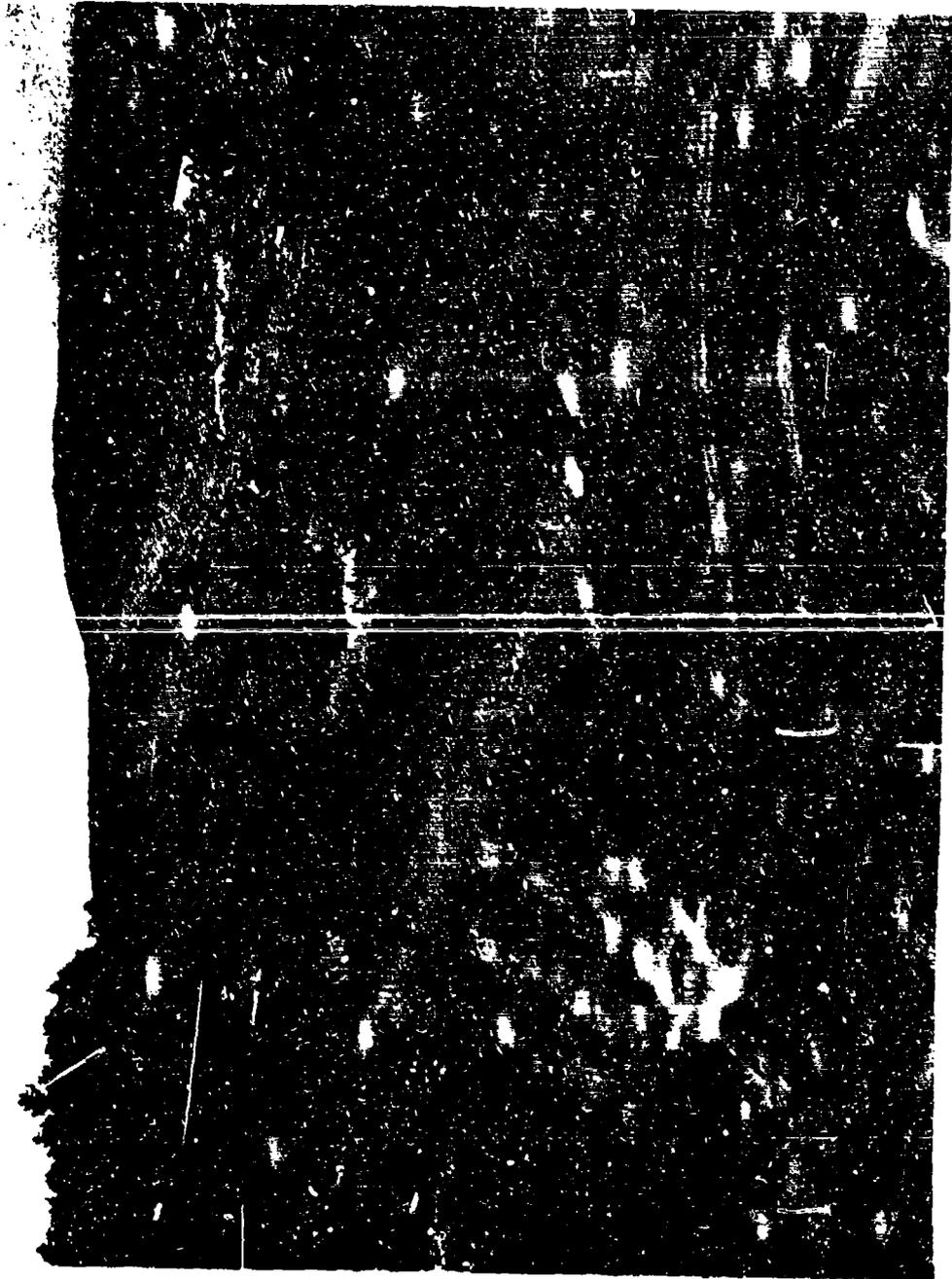


Figure 13. Camouflaged Test Vehicle at Approximately 100 Meters
(At Intersection of Reference Lines)

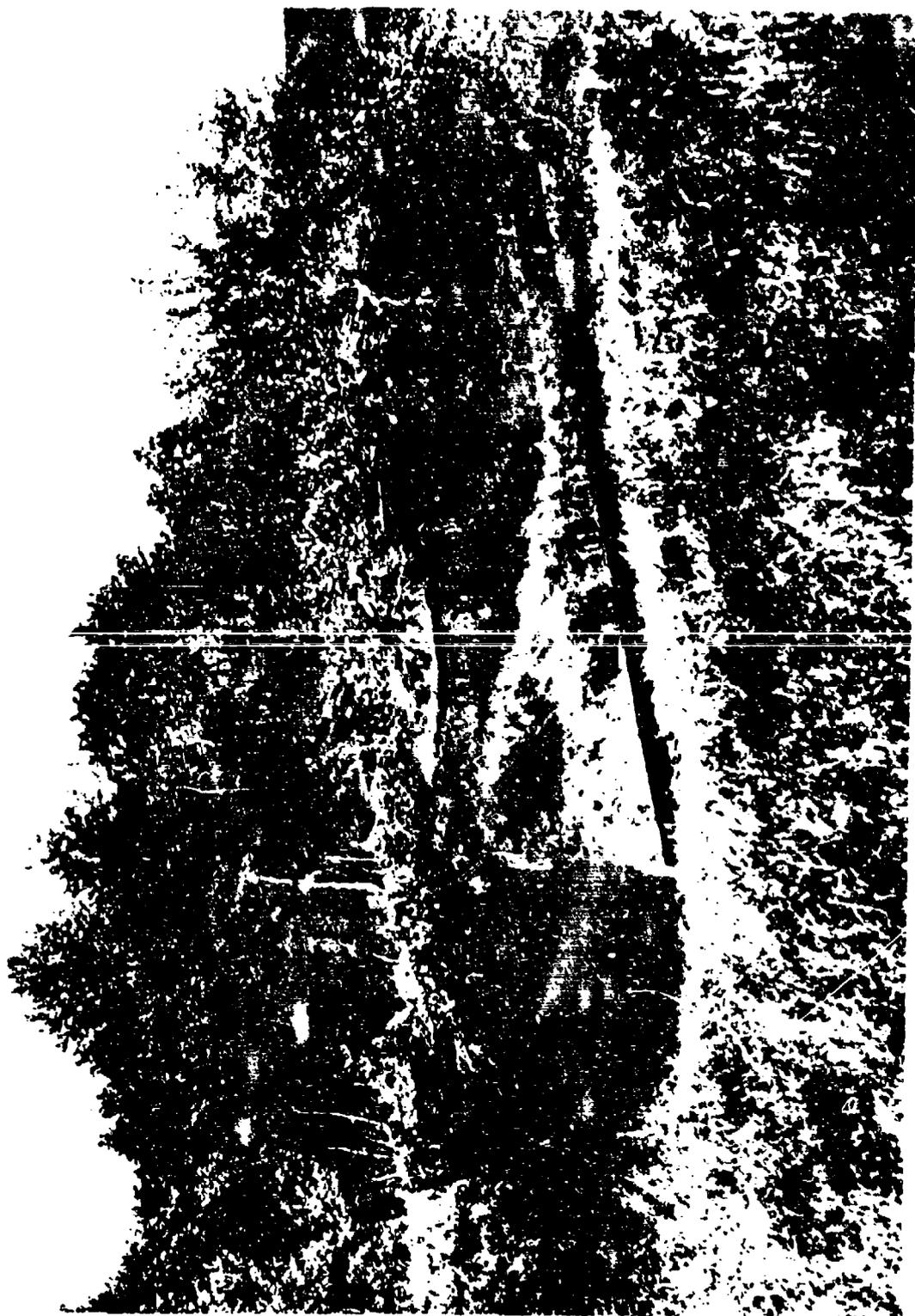


Figure 14. Camouflaged Test Vehicle at Test Site

Appendix A

INFRARED DETECTABILITY ANALYSIS

An analysis was made to determine whether or not the reflective shield would affect the detectability of a target in the long wavelength IR region of the spectrum. The investigation was concerned with a Forward Looking Infrared (FLIR) type threat because this is typical of sensors expected. The long wavelength IR sensor was assumed to produce high resolution, television-like thermal images utilizing the IR radiation emitted by objects in the scene in the 8- to 14-micrometer wavelength band. The detectability of a target in such a TV image is primarily a function of the contrast between the target and its surroundings for targets of equal size. Therefore, the contrast between a target and the ground in front of it was calculated and compared with the contrast between the shield and the ground in front of it assuming that the target and shield would be about the same size. The analysis was developed using the following terms and symbols:

Radiance (N). Radiance is defined as the IR watts per unit area radiated into a unit solid angle. In the long wavelength IR portion of the spectrum (7- to 14-micrometers wavelength) everything at room temperature radiates IR. The incident sunlight radiation is negligible compared to this "self radiance" so that only the self-radiation of objects in the scene was considered in the analysis.

Contrast (C). The contrast between an object and its surroundings is the ratio of the radiance difference between the object and its surroundings and the radiance of the surroundings. Using subscripts G, S and T for the ground, the shielded target and the unshielded target object respectively,

$$C_T = \frac{N_T - N_G}{N_G}$$

$$C_S = \frac{N_S - N_G}{N_G}$$

Contrast Ratio (R). This is a figure of merit for the shield and is defined here as:

$$R = \frac{C_S}{C_T}$$

If $1 > R > -1$, then the shield is more difficult to detect than the unshielded target. If $R = +1$, the shield and target are equally detectable. If $1 < R < -1$, the shield is more easily detected than the target.

Emissivity (E). An ideal radiator is an object which radiates according to Planck's Law. Most objects do not radiate as efficiently as an ideal radiator but radiate a fraction, E, as much. The radiance of an object can be given as the product of the radiance from a Planckian radiator times the objects emissivity, E. This is useful because the radiance of a Planckian radiator is completely determined at all wavelengths by its temperature. Emissivity is independent of object temperature for ambient temperatures, so a complete description of an object's radiance can then be found knowing only its temperature and its emissivity.

Reflectivity (r). This is the usual ratio of reflected-to-incident radiation.

Transmission (τ). This is the ratio of transmitted-to-incident radiation. For an opaque object, τ is zero.

Temperature (T). This is the absolute temperature in degrees Kelvin.

Subscripts. In addition to subscripts G, S and T (for ground, shield and target) previously mentioned, the subscripts A and R are used to refer to the atmosphere and the receiver (IR sensor). Subscript B is used to denote a Planckian (black body) radiator.

Primes ('). Primes are used to indicate apparent (as opposed to inherent) quantities. For instance, N_T is the inherent radiance of the target. N'_T is the apparent radiance of the target as seen by the IR detection system after transmission through the intervening atmosphere and the optics and detector of the detection system.

Wavelength (λ). All of these variables are assumed to be wavelength dependent.

The figure of merit to be calculated is R' , the ratio of apparent target-to-foreground contrast of the shielded target to the apparent target-to-foreground contrast of an unshielded target. Using the definitions given above,

$$R' = \frac{C'_S}{C'_T}$$

$$R' = \frac{(N'_S - N'_G) / N'_G}{(N'_T - N'_G) / N'_G} \quad R' = \frac{N'_S - N'_G}{N'_T - N'_G}$$

The radiation appearing to come from the ground in front of the target is actually coming from two sources; the ground itself and the intervening atmosphere. Thus:

$$N'_G = \int \tau_R \tau_A \cdot E_G \cdot N_B[T_G] \cdot d\lambda + \int \tau_R \cdot E_A \cdot N_B[T_A] \cdot d\lambda$$

The notation $N_B(T_G)$ denotes "the radiance of a black body at the temperature of the ground". Similar notations are used extensively with different subscripts.

The apparent radiance of the target arises from three sources: the inherent self-radiance of the target; radiation from the ground adjacent to the target reflected from the target in the direction of the sensor; and the radiation from the intervening atmosphere. It follows:

$$\begin{aligned} N'_T &= \int \tau_R \tau_A E_T N_B(T_T) d\lambda \\ &+ \int \tau_R \tau_A \frac{r_T}{2} E_G N_B(T_G) d\lambda \\ &+ \int \tau_R E_A N_B(T_A) d\lambda \end{aligned}$$

It then follows that:

$$C'_T = \frac{\int \tau_R \tau_A E_T N_B(T_T) d\lambda - \int \tau_R \tau_A (1 - \frac{r_T}{2}) E_G N_B(T_G) d\lambda}{\int \tau_R \tau_A E_G N_B(T_G) d\lambda + \int \tau_R E_A N_B(T_A) d\lambda}$$

For a shielded target, there are four significant sources of apparent radlance: the shield itself; ground radiation reflected from the shield; target radiation transmitted through the shield; and radiation from the intervening atmosphere. Hence,

$$\begin{aligned}
 N'_S &= \int \tau_R \tau_A E_S N_B(T_S) d\lambda \\
 &+ \int \tau_R \tau_A \tau_S E_G N_B(T_G) d\lambda \\
 &+ \int \tau_R \tau_A \tau_S E_T N_B(T_T) d\lambda + \int \tau_R E_A N_B(T_A) d\lambda
 \end{aligned}$$

so that:

$$C'_S = \frac{\int \tau_R \tau_A [E_S N_B(T_S) - (1 - \tau_S) E_G N_B(T_G) + \tau_S E_T N_B(T_T)] d\lambda}{\int \tau_R \tau_A E_G N_B(T_G) d\lambda + \int \tau_R E_A N_B(T_A) d\lambda}$$

and by direct substitution and with a little manipulation:

$$R' = C'_S / C'_T$$

$$\begin{aligned}
 R' &= \frac{\int \tau_R \tau_A [E_S \{N_B(T_S) - E_G N_B(T_G)\} + \tau_S \{E_T N_B(T_T) - E_G N_B(T_G)\}] d\lambda}{\int \tau_R \tau_A [E_T N_B(T_T) - \frac{1}{2} (1 + E_T) E_G N_B(T_G)] d\lambda}
 \end{aligned}$$

For the case where the transmission of the shield, τ_S , is so low it makes the transmitted component of radiation negligible, the preceding equations for the shield become;

$$N'_S = \int \tau_R \tau_A [E_S N_B(T_S) + \tau_S E_G N_B(T_G)] d\lambda \\ + \int \tau_R E_A N_B(T_A) d\lambda$$

$$C'_S = \frac{\int \tau_R \tau_A [E_S \{N_B(T_S) - E_G N_B(T_G)\}] d\lambda}{\int \tau_R \tau_A E_G N_B(T_G) d\lambda + \int \tau_R E_A N_B(T_A) d\lambda}$$

So for the case $\tau_S \approx 0$

$$R' = \frac{\int \tau_R \tau_A [E_S \{N_B(T_S) - E_G N_B(T_G)\}] d\lambda}{\int \tau_R \tau_A [E_T N_B(T_T) - \frac{1}{2}(1 + E_T) E_G N_B(T_G)] d\lambda}$$

To compute R' , representative values of τ_R , τ_A , E_S , E_G and E_T as functions of wavelength are required. $N_B(T_G)$, $N_B(T_S)$ can be calculated as functions of wavelength using Planck's equation once the temperatures T_G , T_S and T_T are specified.

The values that we selected are as follows:

- a. τ_R was assumed to be the relative spectral response of a mercury-doped germanium detector, the detector used in all current operational FLIR systems. The spectral data was taken from the readily available open literature.
- b. τ_A is a function of the range from the detection equipment to the target, the absolute humidity and the altitude. For this analysis, a 1-kilometer path along the ground was assumed with 1 mm of precipitable water in the path. Substantial variations in range and humidity would probably have little effect on R' . However, this should be verified by additional calculations.

c. E_S , the shield emissivity, was calculated from transmission measurements on 0.001" Mylar and reflection measurements on uncoated aluminized Mylar because samples of coated aluminized Mylar were not available at the time the analysis was made.

d. E_G was derived from measured data taken from the Air Force Avionics Laboratory (AFAL) data library. Emissivity of several representative foliage and soil samples were averaged to produce a composite emissivity vs. wavelength.

e. E_T , also derived from AFAL data, is the average of several paint spectra plus several soil spectra and provides a composite emissivity spectrum representative of paint with dirt on it. The paint samples selected were chosen because they matched the soil and foliage spectra reasonably well. This test was applied in the selection of paints, assuming that the paint for a combat vehicle would be selected for its IR as well as visual camouflage properties.

The computation of R' was done on a Honeywell 6000 series computer. The program is written in time-share Fortran 4 and can be run on any computer with a Fortran 4 time-share system capability. Figures A-1, A-2 and A-3 are plots of the data obtained. As the plots show, the shield makes the target harder to detect over a significant range of parameters and is most effective when the target is hottest, i. e., most detectable. On the other hand, the shielded target is more detectable under some conditions and this is undesirable. On each graph, one curve departs radically from the others. This occurs for target temperatures about 5° below ground temperature. At this temperature with the data used, C'_T is very small and thus, for almost any finite value of C'_S , R' blows up. Since R' is highly variable under these conditions, the values of C'_S and C'_T are more significant than R' .

Figure A-4 illustrates a desirable shield modification which would improve the IR performance of the shield. By using a highly transparent protective coating for the front of the shield so that it has a high (80% assumed) reflectivity in the long wavelength IR region (as it does in the visible) the shield works much better. For instance, polyethylene has the transmission characteristics desired.

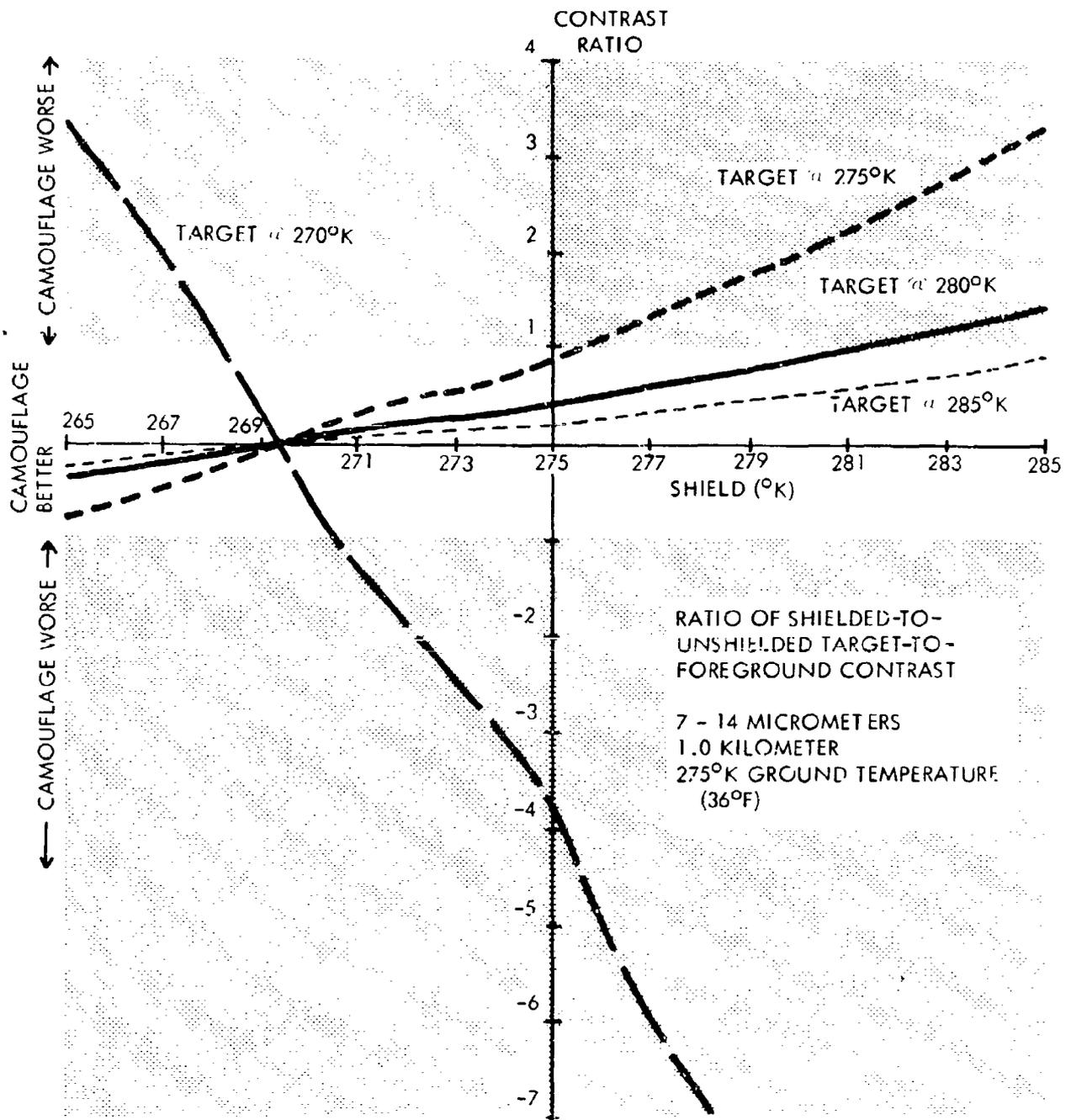


Figure A-1

A-4

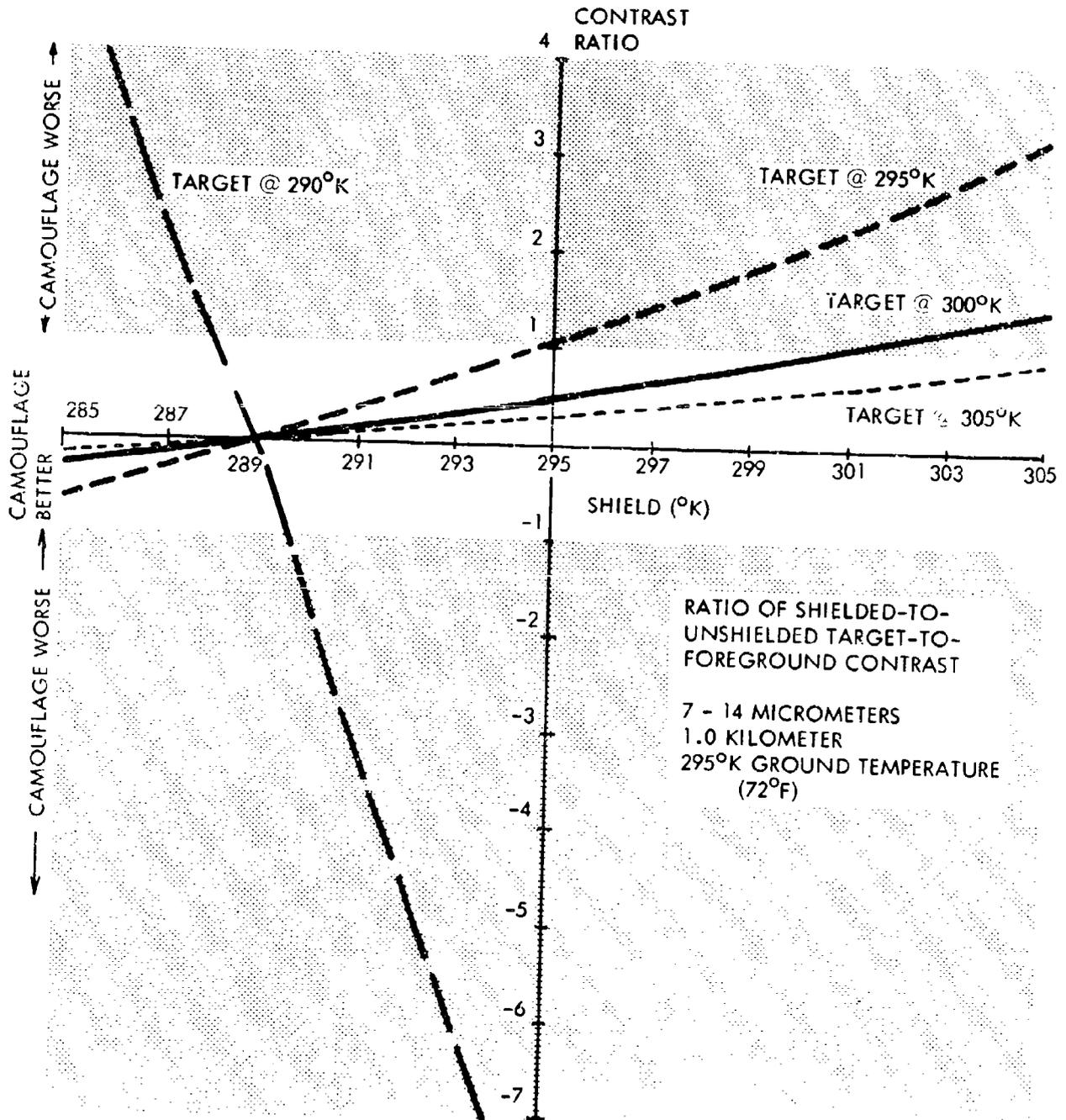


Figure A-2

A-5

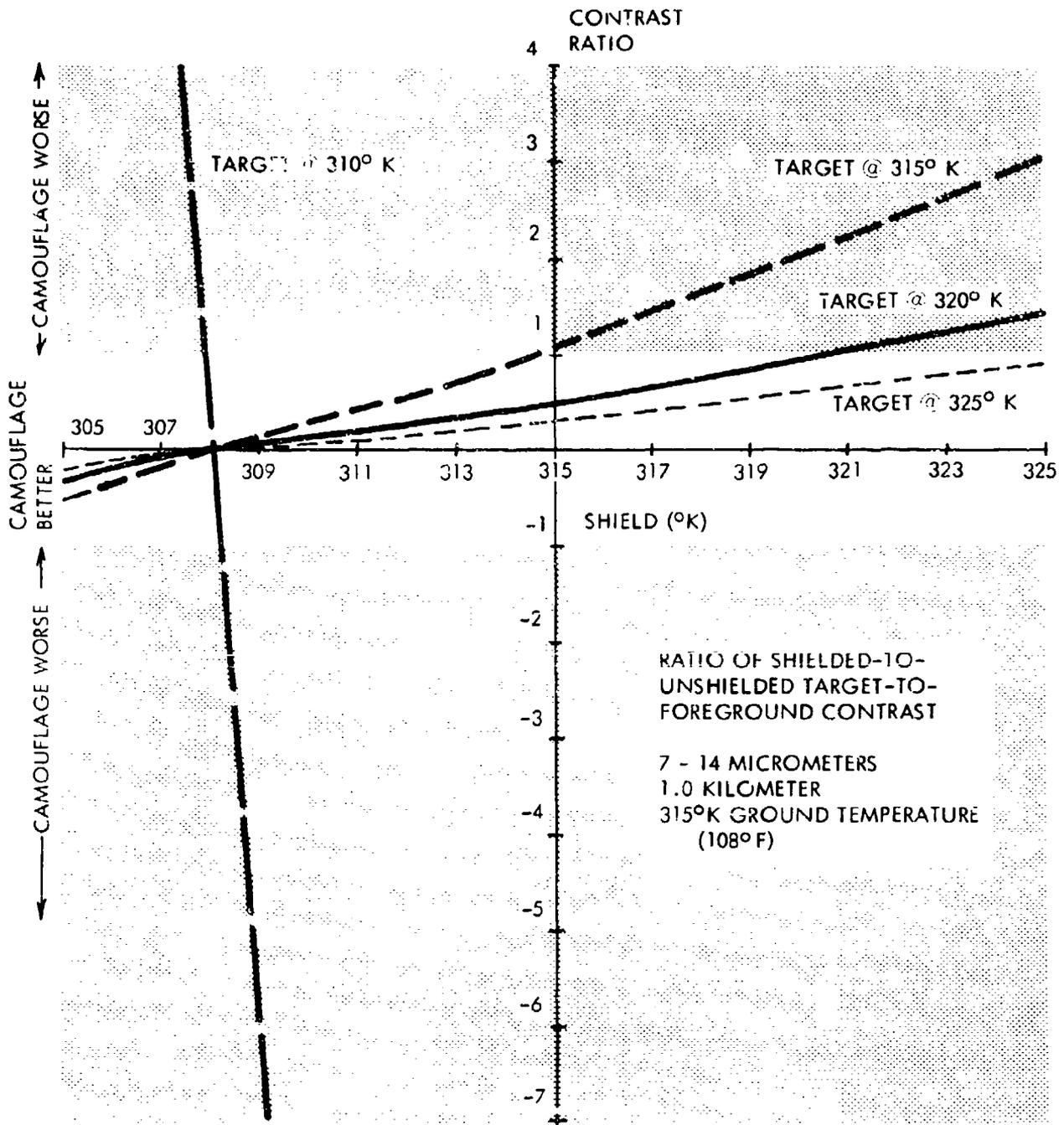


Figure A-3

A-6

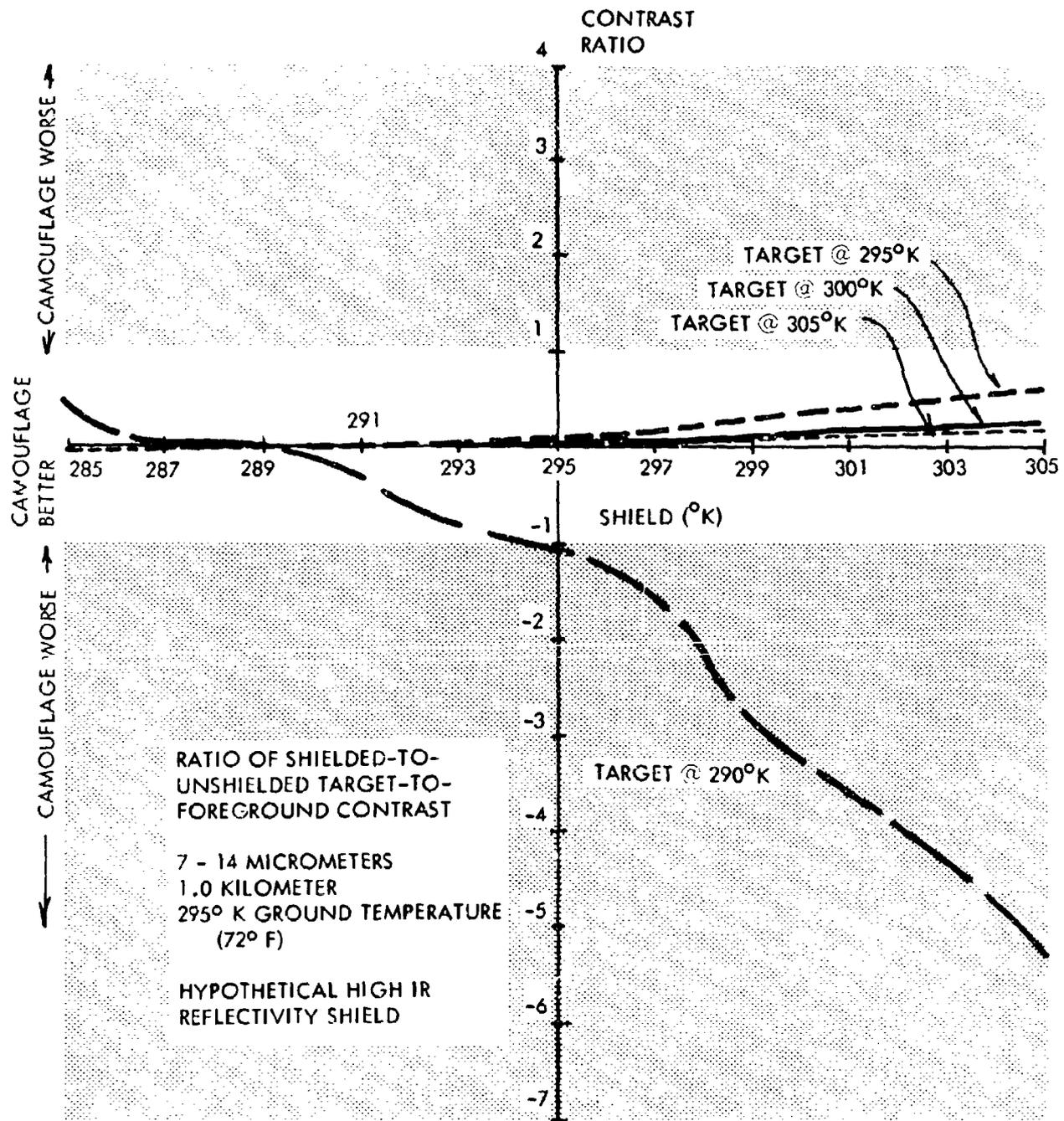


Figure A-4

A-7

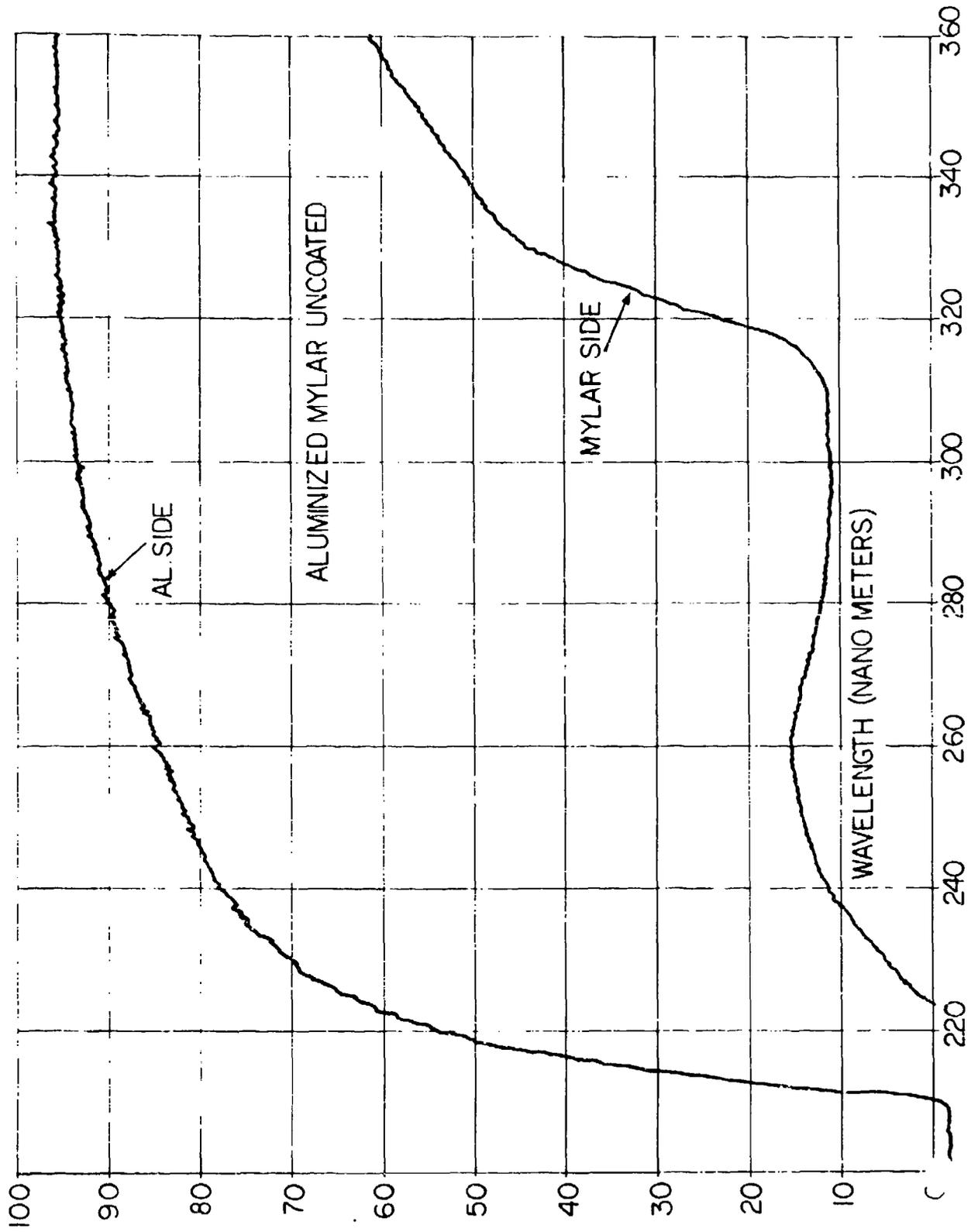


Figure A-5. ULTRA-VIOLET SPECTRUM

A-8

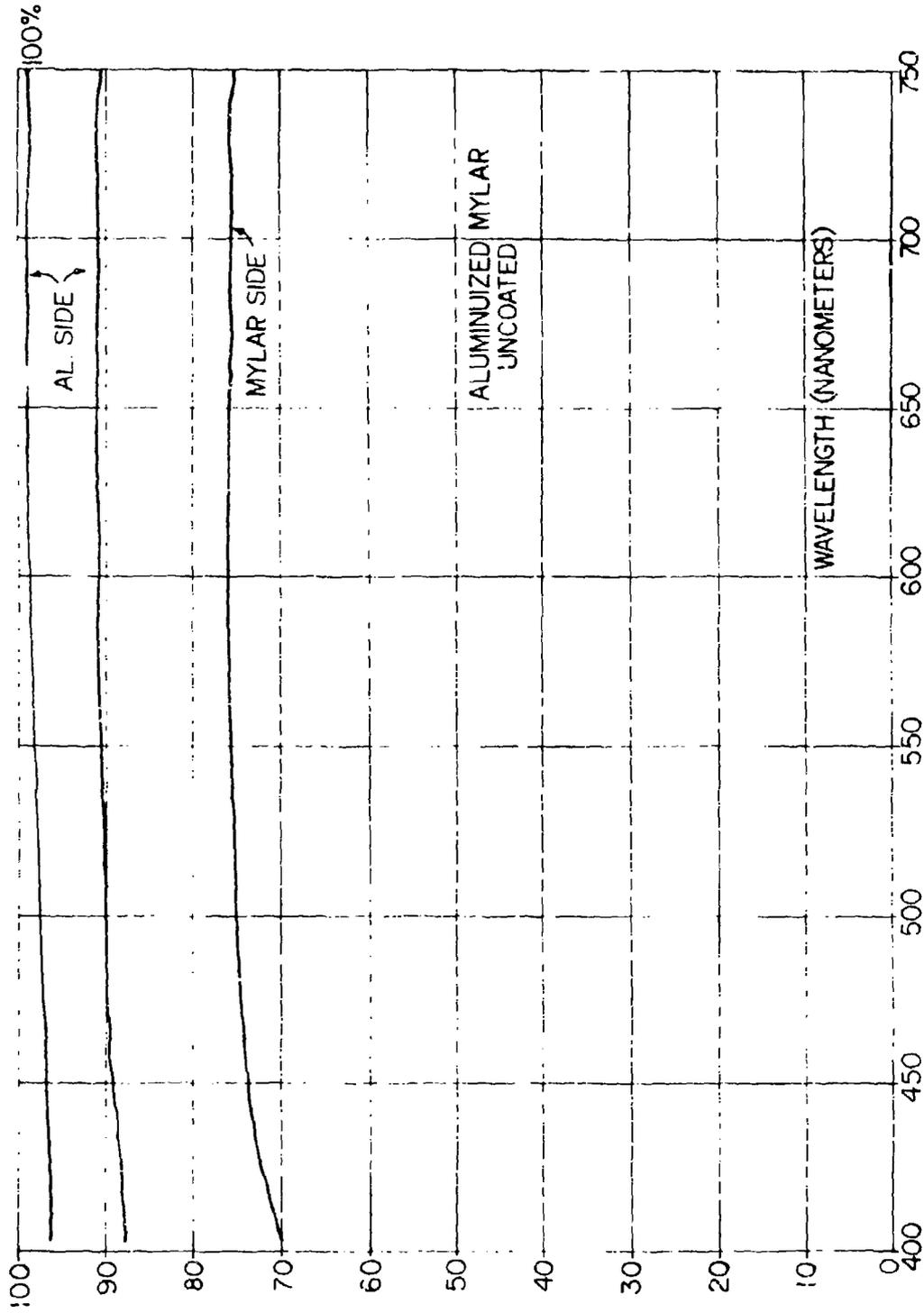
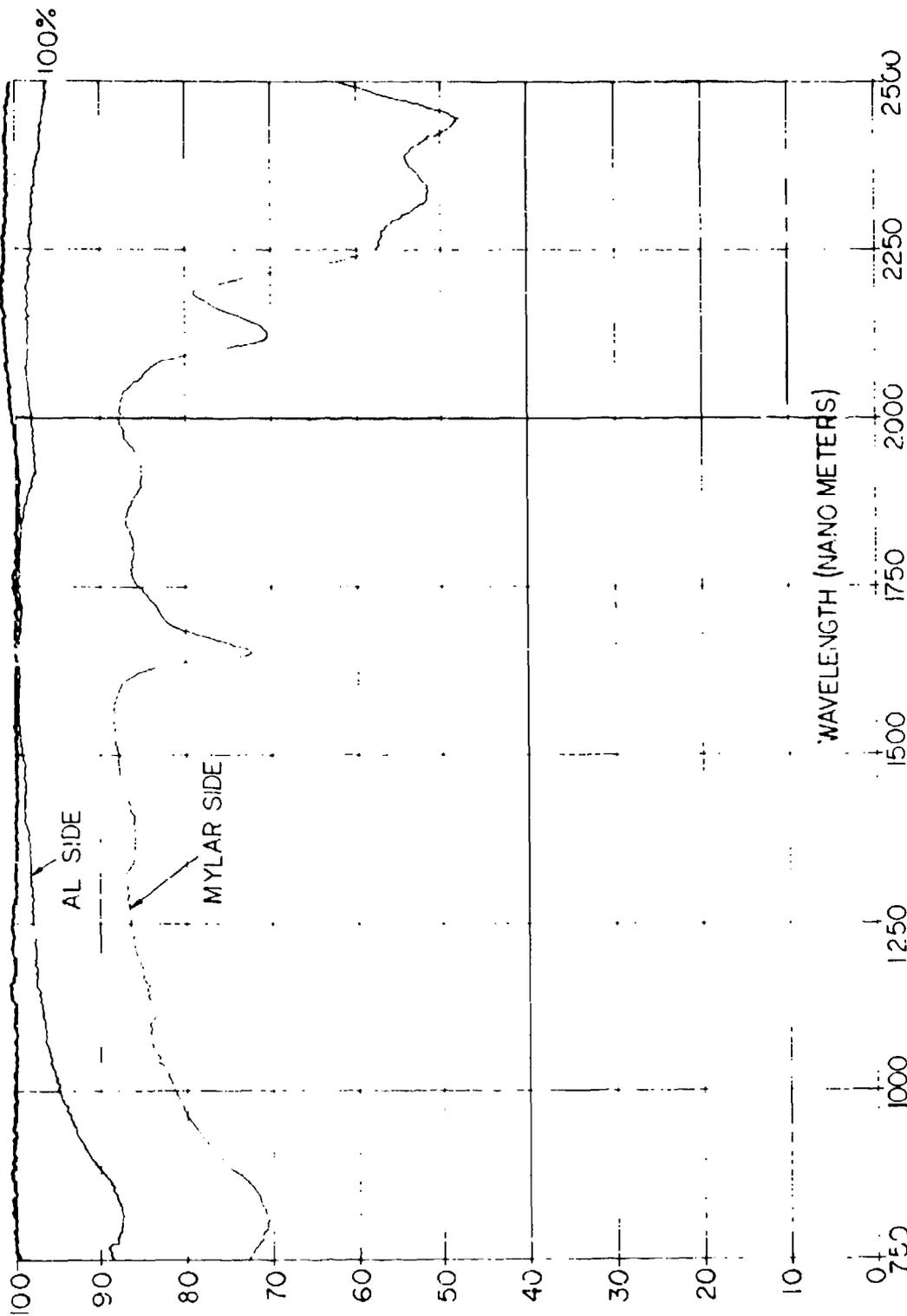


Figure A-6. VISIBLE SPECTRUM



A-10

Figure A-7. NEAR INFRARED SPECTRUM

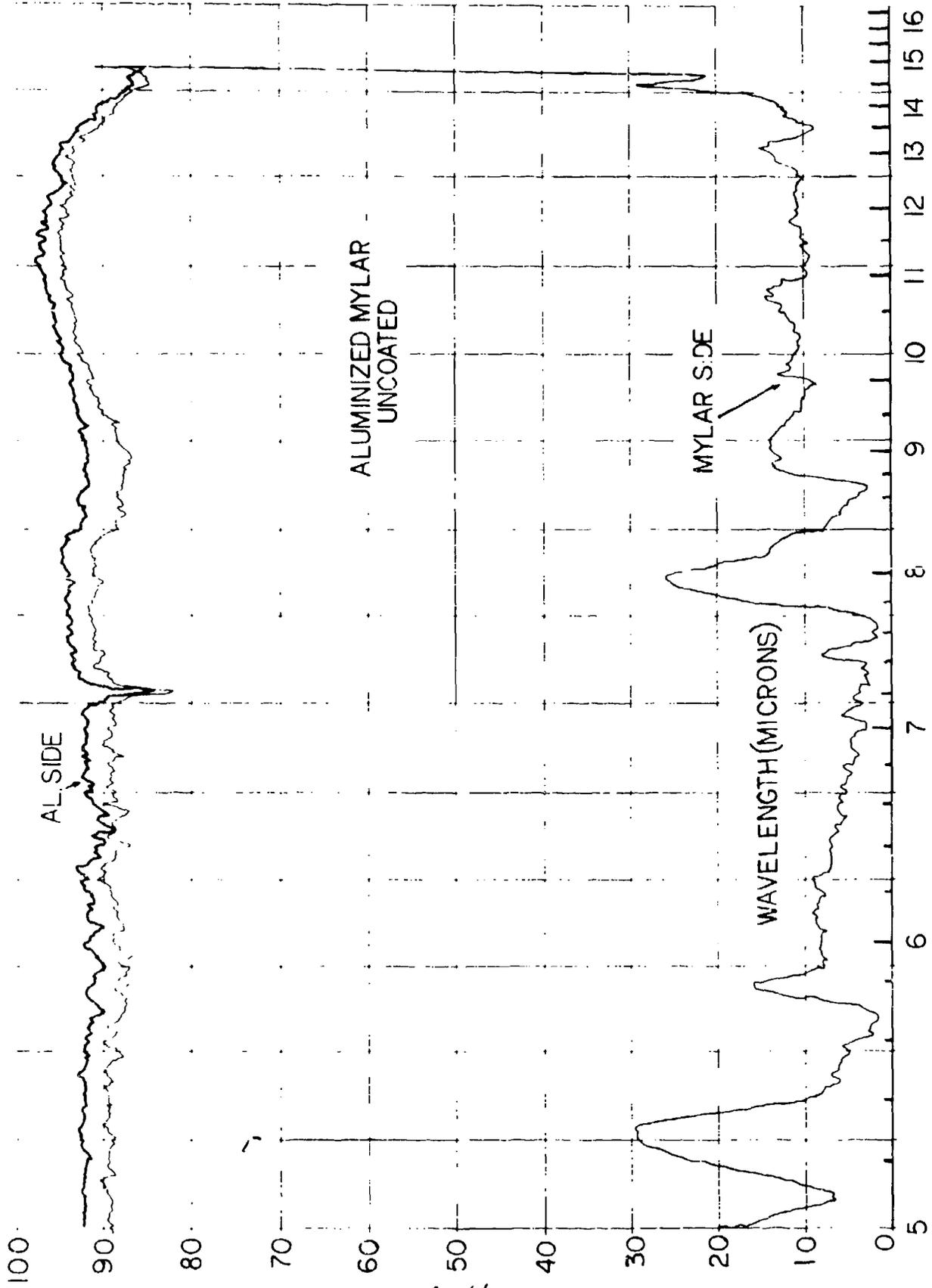


Figure A-8. FAR INFRARED SPECTRUM