TECHNIQUES AND ANALYSIS OF THERMAL INFRARED CAMOUFLAGE IN FOLIATED BACKGROUND.

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PREFACE

This report covers work accomplished under contract DAAG53-76-C-0134. The contract was for the survey and analysis accomplished and did not include any other sub-tasks.
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I. INTRODUCTION

The objective of this effort was to investigate thermal infrared (3-5 μ and 8-14 μ) camouflage measures for military targets in foliated backgrounds. Common lightweight materials were considered as the possible emulators of the foliated backgrounds. These materials were considered to be cloth like material with very low thermal inertia.

Since the thermal infrared camouflage problem exists throughout the day, the infrared signature was considered for the emulator and the foliage during the entire day. Both analytical and experimental evaluation of the foliage signature and analytical evaluation of a proposed emulator were examined.

Successful evaluation of the thermal infrared signature of foliage for a 24 hour period depends upon the modeling of the energy exchange mechanism of the foliage. The energy exchange of foliage, in general terms, cannot be modeled successfully because of the many independent variables, however the energy exchange for an individual element of the foliage, such as a single leaf, may be modeled. If camouflage materials
are produced which emulate the infrared signature of an individual leaf and if these materials are properly distributed on netting, the emulation of background foliage should be possible. For this reason, the major thrust of this effort was toward the modeling of an individual leaf rather than a gross foliage background.

Both a leaf and the leaf emulator, or camouflage material, exist in an environment which exchanges energy with them by two basic mechanisms, convection and radiation. The convection mechanism is controlled by the external flow field, wind velocity and turbulence, and by the physical dimensions of the object. These mechanisms have been extensively investigated and are reported in many standard texts and references, however, the results for the specific case of leaves was reported by Parkhurst, et al. in reference 1.

In the case of radiation energy exchange, the leaf environment is logically divided into two broad radiant energy wavelength regions. These are the thermal, wavelengths of about 2.5 micrometers to 20 micrometers, and the solar, wavelength of about 0.3 micrometers to 2.5 micrometers, regions. Both environments have been extensively investigated and may be modeled under specific meteorological conditions. However, with the very large number of meteorological and other environmental variables possible, modeling must be accomplished with average conditions. These average conditions, while useful for comparison of IR signatures from camouflage materials and leaves, may never be duplicated by natural conditions.
II. THERMAL MODEL FOR LEAF

Basic Considerations

The transient thermal response of a leaf is governed by the energy exchange with the environment at the leaf boundaries and the thermal capacitance of a leaf. By considering a typical leaf thickness, the rate of response or time constant is of the order of 300 seconds [2]. Since the time periods of interest in this study are much longer, the leaf was modeled assuming steady state occurs in each time period. With this basic assumption the model becomes simplified in that the environmental input may be equated to the leaf energy loss to determine the leaf temperature.

Environmental Conditions

Convective Environment: The convective environment for a leaf consists of the air temperature and velocity. Since both of these are meteorological quantities the approach taken was to assume a typical variation for diurnal temperature variation and a constant air velocity. The air temperature was specified over the twenty four hour period by the ASHRAE recommended procedure [3]. Maximum and minimum temperatures were chosen for the type season of interest.

Wind velocity was considered constant at a value input into the program. Values from 6.7 m/s (15 mph) to calm were examined.
Radiation Solar Environment: The solar energy incident upon a leaf was determined using the ASHRAE method to determine the intensity of the direct solar beam and the diffuse or scattered component [3]. The solar declination for any day was used as a program input. From this information and the leaf direction parameters, i.e. the angle of tilt and the azimuth angle, the solar energy incident on the leaf upper surface was evaluated. Reflected solar radiation was assumed to be negligible.

Longwave Radiation Environment: Longwave radiant energy impinges on the leaf from three sources. First, from the warm humid atmosphere; second from the ground below the leaf; third from any object in view of the leaf. The radiant energy originating in the atmosphere is a function of the atmospheric dry bulb temperature and the moisture content. This radiant flux is approximated by several authors using an equation of the form: [4]

$$q''_{atm} = \sigma T_a^4 (A + B\sqrt{e})$$

in which

- $q''_{atm}$ is the radiant flux in cal./cm$^2$/min.
- $T_a$ is the absolute air temperature in °K
- $e$ is vapor pressure of the water in the air in millibars
- $\sigma$ is the Stefan-Boltzmann Radiation constant

A and B are constants varying from author to author in approximate ranges of $0.4 \leq A \leq 0.75, \ 0.047 \leq B \leq 0.08$

The long wavelength energy flux on the leaf from the ground is given by:
\[ q''_{gr} = \varepsilon_{gr} \sigma T^4_{gr} F_{l-g} \]

in which,

\[ q''_{gr} \] is the radiant flux in cal/cm²/min.

\[ T_{gr} \] is the absolute temperature of the ground,

\[ \varepsilon_{gr} \] is the long wavelength emittance of the ground, i.e., \( \varepsilon_{gr}(T_{gr}) \),

\[ F_{l-g} \] is the fraction of the ground seen by the leaf, i.e., one for the bottom of a horizontal leaf, \( \frac{1}{2} \) for one side of a vertical leaf, etc.

The third component of the long wavelength radiant energy is a variable dependent upon the individual case studied. For the purpose of this work, this term was assumed to be negligible. This assumption was made on the basis that an emulator would react to surroundings exactly like the leaf if the emulator reacts to the simplified surroundings like the leaf.

In order to evaluate radiant input to the leaf from the ground, the ground temperature must be determined. Modeling of the ground to obtain this temperature requires a transient model. In this case the ground was modeled as a semi-infinite slab with constant thermal properties. Properties used were obtained from reference 5. One of the most uncertain variables in this sub-analysis was the convective heat transfer from the ground surface to the air. This was finally obtained from reference 6 using reasonable vegetation heights. The expression used was

\[ h = \left( \frac{C_f}{2} \right) \rho C_p \left( \frac{F_r}{U} \right)^{-\frac{2}{3}} \]

Budyko [7] presents results of a study of drag caused by vegetation on the earth’s surface and proposes a drag coefficient as follows:

\[ C_f/2 = \left[ 2.51n(\gamma/Z_o) + 5 \right]^{-2} \]
in which:

- \( h \) is the convective coefficient in cal/cm\(^2\)/min.°C
- \( C_f \) is the drag coefficient depending upon surface roughness,
- \( \rho \) is the density of air g/cm\(^3\),
- \( C_p \) is the specific heat of air cal/gm-°C,
- \( Pr \) is the Prandtl number of air,
- \( U \) is the wind velocity cm/min,
- \( \gamma \) is the height of wind velocity measurement assumed to be 76 cm,
- \( Z_o \) is the height of vegetation in cm.

Leaf Energy Balance:

Radiant Input: The radiant energy input to a leaf was divided into the two parts, solar energy input and long wavelength energy input. The solar normal or beam intensity was obtained from: [3]

\[
q''_{SN} = \frac{A}{\exp(\beta/\sin a)}
\]

in which

- \( q''_{SN} \) is the normal solar intensity \( \text{W/m}^2 \)
- \( a \) is the solar altitude in degrees
- \( A \) is the apparent solar irradiation at air mass=0
- \( \beta \) is the atmospheric extinction coefficient

The actual energy incident on the leaf consists of the solar beam radiation projected on the leaf surface plus the scattered solar energy. Scattered solar flux was determined from: [3]

\[
q''_{SD} = Cq''_{SN} F_\text{s}
\]

in which
q''_{SD} \text{ is the diffuse or scattered solar irradiation,}

q''_{SN} \text{ is defined in equation 5}

C is a constant which depends on atmospheric dust, moisture, and air mass,

F is the fraction of the sky seen by the leaf, configuration factor from the leaf to the sky.

These two energy fluxes were assumed to be incident on the leaf upper surface and the energy input was taken to be their sum multiplied by the solar absorptance of the leaf upper surface.

\[ q''_{TOT} = (q''_{SD} + q''_{SN}) \alpha_{su} \]

Values for the solar absorptance of leaves are available in many sources but the values used were from Birkebak and Birkebak. [8]

Long wavelength energy input to the leaf from the air (q''_{atm}) and the ground (q''_{gr}) as given in equations 1 and 2 were treated as follows. The energy input from the atmosphere was assumed to be the same for both the upper and lower surfaces of the leaf and the ground energy input was assumed to be to the leaf lower surface only. Thus the total energy input per unit area of leaf was \( \alpha_{tu} q''_{atm} + \alpha_{t} q''_{atm} + \alpha_{gl} q''_{gr} \) where \( \alpha_{tu} \) is the long wavelength absorptance of the leaf upper surface and \( \alpha_{gl} \) is the long wavelength absorptance of the leaf lower surface.

Convective Energy Input: The convective energy input was evaluated from the standard convective heat transfer expression

\[ q''_{\text{conv}} = h_c (T_{atm} - T_{leaf}) \]

in which
q''_{\text{conv}} \text{ is the convective heat flux in cal./min. cm}^2
\n\text{h}_c \text{ is the convective heat transfer coefficient in cal/min-cm}^2{\cdot}^\circ\text{C}
\nT_{\text{atm}} \text{ is the atmospheric temperature in } ^\circ\text{C}
\nT_{\text{leaf}} \text{ is the leaf temperature in } ^\circ\text{C}
\nValues of h_c were obtained using the procedures of reference 1. These are based on standard equations for free and forced convection and therefore require the evaluation of the following dimensionless parameters:

1) The average Nusselt Number
   \[ \bar{\text{Nu}} = h_c L / k. \]

2) The Reynolds Number
   \[ R \mu L = U \rho L / \mu \]

3) The Grashof Number
   \[ \text{Gr}_L = \beta \rho g L \Delta t / \mu^2 \]

in which

L is the effective leaf dimension in cm
U is the wind velocity in cm/min
\[ g \] is the acceleration of gravity in cm/min\(^2\)
\[ k \] is the thermal conductivity of air in cal./cm-min-\(^\circ\text{C}\)
\[ \beta \] is the temperature coefficient of volume expansion in cm\(^{-1}\)
\[ \mu \] is the absolute viscosity of air in gm/cm-min
\[ \rho \] is the density of air in gm/cm\(^3\)

The standard correlations using the dimensionless parameters are

1) For free convection from vertical plates
   \[ \bar{\text{Nu}} = 0.480 \text{ Gr}_L^{\frac{4}{3}} \]
(2) For free convection from the upper surface of a horizontal plate warmer than air or to the lower surface of such a plate cooler than air:

\[ \overline{Nu} = 0.497 \text{Gr}^{\frac{1}{4}} \]

(3) For free convection from the lower surface of a warmer than air horizontal plate or to the upper surface of a cooler than air horizontal plate:

\[ \overline{Nu} = 0.249 \text{Gr}^{\frac{1}{4}} \]

(4) For forced convection to or from a plate having a uniform temperature:

\[ \overline{Nu} = 0.595 \text{Re}^{\frac{1}{2}} \]

---

**Fig. 1.** Values of R for ten real leaves. X = flow perpendicular to stem; L = flow parallel to stem; FORC. = forced convection in laminar flow; FREE = free convection in laminar flow; TURB. = forced convection in turbulent flow. (Reproduced from Ref. 1.)
A decision as to whether the flow field was strong enough to cause forced convection was made by comparing the values of \( \text{Gr}_L \) and \( (\text{Re}_L)^2 \). If \( (\text{Re}_L)^2 \) was larger than \( \text{Gr}_L \), the forced convection equation was used. Values of \( L \) for use in these expressions were obtained from \( L = R L_{\text{max}} \) in which \( R \) was obtained from figure 1 and \( L_{\text{max}} \) was the average maximum dimension of the leaf under consideration.

Transpiration Energy Loss: The energy loss from a leaf by transpiration of the leaf moisture was extensively studied by several authors. In this work, the results and methods presented by Gates in references 9 and 10 were used. The expression for transpiration energy loss is

\[
q''_e = \left[ \frac{\rho_g(T_L) - \varphi \rho_g(T_a)}{r_L + r_a} \right] h_f g
\]

in which

- \( q''_e \) is the transpiration energy flux in cal./cm\(^2\)-min.
- \( \rho_g(T_L) \) is the density of saturated water vapor at the leaf temperature in gm/cm\(^3\),
- \( \rho_g(T_a) \) is the density of saturated water vapor at the air temperature in gm/cm\(^3\),
- \( h_f g \) is the latent heat of vaporization of water at the leaf temperature
- \( \varphi \) is the relative humidity of the air,
- \( r_L \) is the internal leaf diffusion resistance in min/cm
- \( r_a \) is the boundary layer resistance given by equation 17.

\[
r_a = k_2 \frac{w^{0.20} U^{0.55}}{L_{\text{max}}} \]

17
in which

\[ W \] is the leaf dimension transverse to the wind in cm,

\[ L \] is the leaf dimension in the direction of the wind in cm,

\[ U \] is the wind velocity in cm/min

\[ k_2 \] is the dimensional constant of 0.247 cm/min.

Values for the internal diffusion leaf resistance are presented by Gates for several common leaves. These values are presented as constants although it is known that water stress or high environmental temperatures cause these resistances to change. In this work constant leaf resistance values were assumed.

Leaf Radiant Energy Loss: The radiant energy loss of the leaf was calculated assuming the upper and lower surfaces had the same emittance. This results in

\[ q''_r = 2\varepsilon \sigma T^4 \]

in which

\[ q''_r \] is the radiant loss per unit area of leaf in cal./cm\(^2\)-min

\[ \varepsilon \] is the emittance of the leaf at the leaf temperature

\[ T_L \] is the absolute leaf temperature in °K

The leaf was assumed to have negligible thermal mass, therefore, the sum of the energy gain was set equal to the energy loss to calculate the leaf temperature.
Leaf Radiance in the 3-5 and 8-14 Micrometer Wavelength Region

3-5 Micrometer Wavelength Region: The radiant flux from a leaf in the 3-5 micrometer wavelength range was assumed to consist of three components. These components were; (1) energy emitted as a function of the leaf temperature; (2) energy reflected off the leaf upper surface from incident solar energy and, (3) solar energy reflected off of the ground and transmitted through the leaf. The components were calculated as follows:

\[ R_{3-5}^{(\text{Thermal})} = \varepsilon \sigma F_1 T_1^4 \]

where

- \( R_{3-5}^{(\text{Thermal})} \) is the first component cal. / cm\(^2\) / min.
- \( \varepsilon \) is the leaf emittance
- \( T_1 \) is the leaf temperature, °K
- \( F_1 \) is the fraction of energy radiated between 3 and 5 micrometers by a Plankian radiator.

\[ R_{3-5}^{(\text{Solar})} = \rho_{\text{su}} F_2 G \cos \theta \]

where

- \( R_{3-5}^{(\text{Solar})} \) is the second component, cal. / cm\(^2\) / min.
- \( \rho_{\text{su}} \) is the solar reflectance of the leaf upper surface
- \( F_2 \) is the fraction of the solar insolation which is in the 3-5 micrometer wavelength range
- \( G \) is the solar insolation in the 3-5 micrometer range, cal. / cm\(^2\) / min.
- \( \theta \) is the zenith angle
\[ R_{3-5}^{\text{(Solar Reflected)}} = \tau_\ell \rho_{SG} F_2 G_s \cos \theta \]

where

\[ R_{3-5}^{\text{(Solar Reflected)}} \] is the third component, \( \text{cal.} / \text{cm}^2 / \text{min.} \)

\[ \tau_\ell \] is the leaf transmittance.

The sum of these three would be the energy flux at the leaf surface which would be detected by a 3-5 micrometer wavelength energy sensor system.

8-14 Micrometer Wavelength Region: The radiant flux from the leaf in the 8-14 micrometer wavelength range was assumed to be from the same three components as used in the 3-5 micrometer wavelength range. In calculating the values, the only change in equations 19, 20, and 21 are the fractions \( F_1 \) and \( F_2 \). Thus the same equations were used with different values for these fractions.

III. EXPERIMENTAL VERIFICATION OF THERMAL MODEL

Experimental Procedure: In order to test the validity of the thermal model used, an experiment was designed and run. This consisted of instrumenting leaves on two living trees, measuring the leaf temperature and the environmental conditions for the leaves.

Leaf Measurements: A nearly horizontal leaf on a common burr oak (Quercus Macrocarpa), a vertical leaf on a silver maple (Acer Saccharnum) and a horizontal leaf on the silver maple were instrumented. In order to minimize the effect of the measurement probes, small gage (40 gage) thermocouples were installed on the lower surface of the leaves. These thermocouples were shielded from direct solar insolation by being on the lower leaf surface and were in contact with the leaf for about 2 cm which
should reduce thermocouple conduction effects. Temperatures were continuously recorded on a 12 point Leeds and Northrup Speedomax W recorder. As a check on the measured temperatures, total radiation pyrometric temperatures were measured with a Barnes PRT-10 radiometer.

Ground Temperature Measurement: Ground temperatures at depths of 5 and 6.4 cm were made using 24 gage thermocouples. Surface temperature could not be measured directly, due to short grass on the surface, therefore, the radiometric temperature was measured with the Barnes PRT-10 radiometer. Actual ground temperatures were estimated from the radiometric measurement by assuming a ground emittance consistent with the actual ground surface.

Environmental Conditions: The environmental variables needed for this study were dry bulb air temperature, wet bulb air temperature, wind velocity and solar insolation. Dry bulb temperatures were measured continuously using a shielded thermocouple and wet bulb temperature was measured each 30 minutes using a hand sling psychrometer. Wind velocity was measured at 1.1 meters above the ground using a ball and cup anemometer. Solar insolation was measured continuously using an Eppley 8-48 black and white pyranometer. Experimental data is summarized in Table I.
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<th>Camouflage Material Temperature</th>
<th>Maple Leaf Temperature</th>
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<th>Solar Flux (cal/cm²/min)</th>
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<td>30</td>
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<td>Data Point</td>
<td>Local Time</td>
<td>Local Solar Time</td>
<td>Camouflage Material Temperature</td>
<td>Maple Leaf Temperature</td>
<td>Oak Leaf Temperature</td>
<td>Ground Temperature</td>
<td>Air Temperature</td>
<td>Relative Humidity</td>
<td>Solar Flux (cal/cm²/min)</td>
<td>Wind Speed (cm/min)</td>
</tr>
<tr>
<td>------------</td>
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<td>------------------</td>
<td>---------------------------------</td>
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<td>22.9</td>
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</tr>
</tbody>
</table>
Results of Experimental Verification

The thermal model was used to calculate the leaf temperatures and ground temperature for the 72 hour experimental period. Measured values of air temperature, relative humidity, wind speed, and solar insolation on a horizontal plane were used at one half hour intervals to calculate leaf and ground temperatures. The calculated values of leaf and ground temperatures and the experimental values are shown in figures 2 through 7. Each figure is for one full days data, i.e., for the entire diurnal cycle. The figures are in pairs, that is figure 2 and 3 are for 4 September 1976, figure 4 and 5 for 5 September 1976, figures 6 and 7 for 6 September 1976. The leaf temperature measured and calculated are shown on figures 2, 4, and 6. Calculated and measured ground temperatures along with measured air temperatures are shown in figures 3, 5, and 7.

In order to assess the accuracy of the thermal model, the errors were statistically examined. This analysis indicated the mean error, i.e., the measured leaf temperature minus the calculated leaf temperature to be 0.21 degrees Celsius with a standard deviation of the errors of 4.00 degrees. From this information the leaf temperature calculated has a mean error with 95% confidence of -0.46 or +0.89° Celsius.

IV. CAMOUFLAGE MATERIAL REQUIREMENT

Leaf Temperature Emulator: The thermal model prepared was used to determine the necessary properties of a material which would emulate leaves thermal response during one day. A study of the leaf response and characteristics indicated that an emulator could be produced if the material
GROUND TEMPERATURES AND AIR TEMPERATURE
SEPTEMBER 4, 1976
OKLAHOMA STATE UNIVERSITY

Figure 3
Figure 5

GROUND TEMPERATURES AND AIR TEMPERATURE
SEPTEMBER 5, 1976
OKLAHOMA STATE UNIVERSITY
emittance and reflectance could be controlled. As an example of this figure 8 shows the thermal response, as predicted from the thermal model, for a maple leaf, an aspen leaf, and a material designed to emulate the maple leaf. This material would be a material with low thermal mass, clothlike, with solar absorptance of 0.47 and long wavelength emittance of 0.95. As can be seen from figure 7, this material would satisfactorily emulate the diurnal temperatures of maple leaves but would not emulate the diurnal temperatures of aspen leaves. This is because the transpiration rate for an aspen leaf is greater than the transpiration rate of a maple leaf. An emulator for the aspen would have different properties which could be found using the thermal model presented.

Camouflage Material Detectability: In order to assess the detectability of the leaf emulator with a maple leaf background, the total radiant energy leaving the emulator and the leaf were evaluated for the 3-5 micrometer and 8-14 micrometer wavelength bands. These values are plotted in figures 9 and 10. Within the accuracy of the model, the leaf radiance and the emulator material are identical. This indicates that the camouflage role of the material would be well fulfilled in the 3-5 and 8-14 micrometer wavelength ranges.

Visual Camouflage Problem: The solar absorptance of the camouflage material which was used to obtain the results shown was 0.47. The solar absorptance of a material is a function of the spectral reflectance over the wavelength range in which the sun's energy reaches the earth's surface.
Figure 10

RADIANCE IN THE
8-14 MICROMETER
WAVELENGTH RANGE
MAPLE LEAF
CAMOUFLAGE MATERIAL
OKLAHOMA STATE UNIVERSITY

TIME - LOCAL SOLAR

RADIANCE - CAL/CM² X 10²

LEAF
MATERIAL
This wavelength range is approximately from 0.3 to 2.5 micrometers. Since the visual range is overlapped by the solar range, the visual reflectance is not independent of the solar reflectance. This causes a camouflage material suitable for a leaf emulator to be more reflective than the typical visual camouflage material. [11] The ideal material to be used for both visual and thermal emulation of leaves would be one which had a visual reflectance around 0.3 or lower and a solar reflectance of 0.53. Such materials were reported in reference 11 for the near infrared, i.e., 0.7 to 1.2 micrometers. Values reported are shown in Table II.

Table II. Infrared Reflectance for Camouflage Cloth (Reference 11)

(From National Military Establishment Specification JAN-C-765)

<table>
<thead>
<tr>
<th>Fabric Color (No.)</th>
<th>Color</th>
<th>Infrared Reflectance Percentages Relative to Magnesium Oxide (Minimum %)</th>
<th>(Maximum %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light green</td>
<td>37.0</td>
<td>57.0</td>
</tr>
<tr>
<td>2</td>
<td>Dark green</td>
<td>37.0</td>
<td>57.0</td>
</tr>
<tr>
<td>3</td>
<td>Sand</td>
<td>24.5</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Field drab</td>
<td>24.5</td>
<td>57.0</td>
</tr>
<tr>
<td>5</td>
<td>Earth brown</td>
<td>24.5</td>
<td>57.0</td>
</tr>
<tr>
<td>6</td>
<td>Earth yellow</td>
<td>24.5</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>Earth red</td>
<td>24.5</td>
<td>57.0</td>
</tr>
<tr>
<td>9</td>
<td>Olive drab</td>
<td>24.5</td>
<td>57.0</td>
</tr>
<tr>
<td>10</td>
<td>Black</td>
<td>0</td>
<td>24.5</td>
</tr>
<tr>
<td>11</td>
<td>White</td>
<td>57.0</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>Forest green</td>
<td>24.5</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>Desert sand</td>
<td>24.5</td>
<td>100</td>
</tr>
</tbody>
</table>

However, it was reported that the production of such materials was quite difficult. Similar work was reported in reference 12.
Transparent Cover Analysis: Since it may be difficult to obtain the desired visual and thermal infrared camouflage with a single material, the possibility of using a visually transparent cover over an opaque material was examined.

Solar Radiation, Sky Radiation
Atmospheric Radiation

- Transparent Sheet

Convection Transfer

- Opaque Sheet

Ground Radiation

Basis for Transparent Cover Analysis

Figure 11

The basic system analyzed is shown in figure 11. A transparent sheet not in contact with an opaque sheet with radiant and convective heat transfer was considered. The energy exchange between the sheets and the atmosphere was analyzed by considering the convective, radiation in solar wavelengths and radiation at long wavelengths energies as uncoupled variables. The basic radiant energy quantities considered as shown diagrammatically in figure 12. In this figure the fluxes indicated

Sheet 1, Transparent

Sheet 2, Opaque

Radiant Fluxes for Transparent Sheet Analysis

Figure 12
are defined as follows:

\[ q_{\text{sol}}'' \] is the solar insolation
\[ q_t'' \] is the long wavelength (terrestrial) insolation
\[ J_{s1} \] is the solar wavelength radiosity of the \( i \)th surface
\[ J_{t1} \] is the terrestrial wavelength radiosity of the \( i \)th surface
\[ E_{b_i} \] is the Plankian radiation of the \( i \)th surface, \( \sigma T_i^4 \)
\[ \varepsilon_i \] is the terrestrial emittance of the \( i \)th surface
\[ \rho_s \] is the solar wavelength reflectance
\[ \rho_t \] is the terrestrial wavelength reflectance

and

\[ \tau_s \] is the solar wavelength transmittance.

The radiosities were evaluated in terms of the boundary values resulting in the following equations:

\[ J_{s1} = \frac{\tau_{s1}}{1 - \rho_s \rho_{s2}} q_{\text{sol}}'' \]

\[ J_{s2} = \frac{\rho_{s2} \tau_{s1}}{1 - \rho_s \rho_{s2}} q_{\text{sol}}'' \]

\[ J_{t1} = \frac{\rho_{t1} \varepsilon_{t2} E_{b2} + \varepsilon_{t1} E_{b1}}{1 - \rho_{t1} \rho_{t2}} \]

\[ J_{t2} = E_{b2} (1 - \varepsilon_{t1} + \varepsilon_{t1} \rho_{t2}) + \frac{(1 - \varepsilon_{t2}) \varepsilon_{t1} E_{b1}}{\varepsilon_{t2}} \]
Using these values, energy balances on sheet 1 and 2 including convective energy transfer to the surrounds and between the two sheets results in two coupled non-linear equations. These equations are functions of the environmental parameters: \( q''_{\text{sol}} \), ambient air temperature, ground temperature, and the radiative properties of the two sheets. In order to assess the possible usefulness of the transparent outer sheet an inner sheet with solar absorptance of 0.6 (dark green) was considered. Using ambient air temperature of 30°C, relative humidity of 50%, ground temperature 40°C, \( q''_{\text{sol}} \) of 800 W/m², wind speed of 2.5 miles per hour the dark green material temperature calculated was 41°C. With a transparent sheet over the dark green material the calculated temperatures of the transparent sheet (\( T_1 \)) and the dark green sheet (\( T_2 \)) with several different transparent sheet properties, is given in Table III. Notice the transparent sheet temperature runs from 37 to 40°C Celsius where the uncovered material temperature was 41°C Celsius. This indicates the transparent sheet over the camouflage material might be useful if the proper material cannot be obtained. Limited experimental results for this type system are reported in Appendix B.

<table>
<thead>
<tr>
<th>Sheet Reflectance</th>
<th>Sheet Transmittance</th>
<th>Sheet Absorptance</th>
<th>( T_1 ) °C</th>
<th>( T_2 ) °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.80</td>
<td>0.10</td>
<td>37</td>
<td>46</td>
</tr>
<tr>
<td>0.05</td>
<td>0.80</td>
<td>0.15</td>
<td>37</td>
<td>46</td>
</tr>
<tr>
<td>0.05</td>
<td>0.75</td>
<td>0.20</td>
<td>39</td>
<td>46</td>
</tr>
<tr>
<td>0.10</td>
<td>0.70</td>
<td>0.20</td>
<td>40</td>
<td>45</td>
</tr>
</tbody>
</table>
V. CONCLUSIONS

The thermal model prepared to emulate foliage satisfactorily predicts the diurnal temperature of leaves. This model, like all models, finally depends on the quality of the boundary or driving functions. In this case, the boundary conditions are particularly difficult to predict since the micro-climatological values are quite unique for each location. However, the model is quite satisfactory for the evaluation of camouflage materials in that whatever boundary conditions are used the model will indicate the response of the candidate material relative to a particular leaf type.

From the studies made with the thermal model it was determined that thermal infrared camouflage is feasible with simple clothlike material if the radiant properties can be properly tailored to the background. For example, it was found that a material with a solar absorptance of 0.47 and long wavelength emittance of 0.95 would emulate maple leaves. It was also determined that this material would not emulate leaves with larger transpiration rates, e.g. aspen. These leaves are more difficult to emulate but probably could be satisfactorily emulated considering the canopy of trees will have large temperature variations due to shading.

In the process of preparing the thermal model it was noted that the camouflage material must be opaque to thermal infrared if an object is to be camouflaged. Any object above the background temperature will "shine" through a partial camouflage net. This fact makes the physical
construction of the camouflage net more difficult. A successful net must have multiple layers of leaf sized camouflage elements. These elements must allow free circulation of ambient air in order to attain temperatures similar to the temperature of the background leaves. Furthermore, the material must have good visual camouflage characteristics. A material with both satisfactory visual and solar reflectance may be difficult to obtain due to the overlap in these spectral regions. Materials with these characteristics have been prepared for the near infrared but have not been reported for the thermal infrared.
Reference


APPENDIX A

COMPUTER PRINTOUT
The following data is read in on namelist. If this program is run on a CDC computer the namelist data cards must be modified for the CDC.
Additional constants are initialized in subroutine block DATA.

HRS is the number of hours you wish to run the simulation.

H can be the time increment (in minutes) you wish to use in the calculations.

DEL is the time increment (in minutes) used in subroutine GTEMP to calculate the ground temperature.

LAT is the latitude in radians.

C is the declination angle of the sun in radians.

SC is the value of the apparent solar radiation at air mass of 0.5 and varies with the time of the year, in CAL/CM**2-MIN.

C4 is the atmospheric extinction coefficient and varies with the time of year.

C1 is the fraction of beam radiation appearing as diffuse rad.

C2 is the local solar time when the simulation is started.

C3 is the characteristic dimension of the leaf in the direction of the air flow (CM).

RL is the internal resistance of the leaf, in SECM.

SL is the slope (in radians) of the surface measured from the hoz.

AZM is the azimuth angle (in radians) of the leaf surface measured from the south. Positive azimuth is east facing, negative is west.

ASU is the solar absorptivity of the upper surface of the leaf.

ASL is the solar absorptivity of the lower surface of the leaf.
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A IS THE LONG WAVELENGTH ABSORPTIVITY OF THE LEAF.
E IS THE LONG WAVELENGTH EMISSIVITY OF THE LEAF.
Rt IS THE LONG WAVELENGTH REFLECTIVITY OF THE UPPER SURFACE OF
THE LEAF.
T IS THE LONG WAVELENGTH TRANSMITTANCE OF THE LEAF.
Ka IS THE THERMAL CONDUCTIVITY OF AIR, IN CAL/CM-MIN-°C
RH IS THE RELATIVE HUMIDITY OF AIR.
TMAX IS THE MAXIMUM AIR TEMPERATURE DURING THE SIMULATION PERIOD
IN DEGREES C.
TVAR IS THE MAXIMUM VARIATION IN THE AIR TEMPERATURE DURING THE
SIMULATION TIME, IN DEGREES C.
V IS THE AIR VELOCITY IN CM/MIN.
OfS IS THE THERMAL DIFFUSIVITY OF SOIL, IN SQCM/MIN.
Cond IS THE THERMAL CONDUCTIVITY OF SOIL, IN CAL/CM-MIN-°C.
Kg IS THE LONG WAVELENGTH REFLECTIVITY OF SOIL.
Ag IS THE LONG WAVELENGTH ABSORPTIVITY OF SOIL.
EG IS THE LONG WAVELENGTH EMISSIVITY OF SOIL.
ASG IS THE SOLAR ABSORPTIVITY OF SOIL.
RSG IS THE SOLAR REFLECTIVITY OF SOIL.
G021
NAMELIST /IN1/HRS,DT,DELT /IN2/LAT,DEC,SC,C1,C4,LST
I/IN3/UR,LSL,AS/IN4/ASU,ASL,A,E,RU,T /IN5/KA,KH,TMAX,TVAR,V
2/IN6/UPS,COND,RG,AG,EG,ASG,KSG
L072
C023
10 READ(5,1,NU=1000)
J024
K(AO(5,IN2))
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MAIN

0025       READ(5,IN3)
0026       READ(5,IN4)
0027       READ(5,IN5)
0028       READ (5,IN6)
0029       NR=NR+1
0030       GO TO (20,30,50)
0031       WRITE (6,107)
0032       GO TO 40
0033       WRITE(6,108)
0034       WRITE (6,106)
0035       WRITE(6,IN1)
0036       WRITE(6,IN2)
0037       WRITE(6,IN3)
0038       WRITE(6,IN4)
0039       WRITE(6,IN5)
0040       WRITE (6,IN6)

C   C   INITIALIZE CONSTANTS
C

0042       M=PI
0043       M=0.0
0044       L=0
0045       I=0
0046       SIND=SIN(DEC)
0047       COSD=COS(DEC)
0048       SINL=SIN(LAT)
0049       COSL=COS(LAT)
0050       SINS=SIN(SLP)
0051       COSS=COS(SLP)
0052       SINA=SIN(ALM)
0053       COSA=COS(ALM)
0054       N=U3.*HRS/UT
0055       WRITE (6,100)
0056      50 CONTINUE
0057       M=PI-LST*0.242
0058       CUSH=COS(H)
0059       SINS=SIN(H)
0060       CUSZ=CUSL*COSH*SINS*SIND
0061       M=1.0/COSZ
0062       IF(M.LT.1.0K.M.GT.6.51M=0.0
0063       IF(COSZ.LT.0.0)COSZ=0.0
0064       CALL RAD
0065       CALL LEAF
0066       RISL=RA-WR-QC-WE
0067       T=TL
0068       TL=TL+2.

C   C   C   CALCULATING THE STEADY STATE TEMPERATURE OF THE LEAF OR MATERIAL
C

0069

0070       K=1.10
0071       CALL LEAF
0072       K=0.1264
0073       IF(A35(AE5)<.LE.EPS1)GO TO 70
0074       LV=(1.*N-1L)*RES2/(RES2-RES1)
**FORTRAN IV 0.1 RELEASE 2.0**  

```fortran
MAIN

0075    \texttt{IN=TL}
0076    \texttt{TL=TL+CV}
0077    60 \texttt{RES1=RES2}
0078    70 \texttt{CONTINUE}
0079    \texttt{CALL JDETECT}
0080    \texttt{WRITE(6,101) LST, QATM, QS, QSL, QSU, QA, QR, QE, QC}
0081    \texttt{LST=LST+DT/60.}
0082    \texttt{IF(RL.LT.0.0)GO TO 80}
0083    \texttt{I=I+1}
0084    \texttt{X1(I)=LST-(UT/60.)}
0085    \texttt{X2(I)=TA}
0086    \texttt{X3(I)=TL}
0087    \texttt{X4(I)=QB3}
0088    \texttt{X5(I)=QB8}
0089    \texttt{GO TO 90}
0090    80 \texttt{CONTINUE}
0091    \texttt{I=I+1}
0092    \texttt{X6(I)=TL}
0093    \texttt{X7(I)=QB3}
0094    \texttt{X8(I)=QB8}
0095    \texttt{X9(I)=TCR}
0096    90 \texttt{IF(I.LT.4)GO TO 50}
0097    \texttt{I=NR.GT.0) GO TO 10}
0098    \texttt{WRITE (6,104)}
0099    \texttt{WRITE (6,103) (X1(I),X2(I),X3(I),X4(I),X5(I),X6(I),X7(I),}
0100    \texttt{X8(I),X9(I),I=1,N)}
0101    \texttt{GO TO 10}
0102    \texttt{STOP}
0103    \texttt{END}
```
SUBROUTINE RAD
COMMON/DATAIN/P1,C2,SIG,TL,EP,G,KZ,CP2
COMMON DT,M,AL,DEC,NST,UA,QR,TX,TV,TMAX,TVAR
COMMON Q3,UG,AG,WE,RE,TS,SC,COSTH
COMMON QC,HG,ASL,EA,AR,AG,ASG,RSG,AG,QT,OSU,OL,QQ,C4
COMMON RH,KA,RE,GR,RL,UFF,CUND,DELT,TGR
COMMON SIN,CO,SINF,COF,SL,SINA,COSA,SINS,COSS,SMH,COSH,COSZ
COMMON REAL LAT,LST,MA,KA,K2

SUBROUTINE RAD PERFORMS THE FOLLOWING: (1) ESTIMATES THE SOLAR AND
DIFFUSE RADIATION ON CLEAR DAYS AND THE ATMOSPHERIC AND GROUND
RADIATION, (2) CALCULATES THE RADIANT ENERGY ABSORBED BY A LEAF
OF ANY SURFACE ORIENTATION AND, (3) ESTIMATES THE AIR TEMPERATURE
BASED ON THE MAXIMUM AIR TEMPERATURE AND THE MAXIMUM VARIATION
IN THE AIR TEMPERATURE DURING THE SIMULATION TIME.

SOLAR BEAM RADIATION

QST=SQ/EXP(4*M)
IF(M.LT.1.O) M.GT.6.5 QST=0.0

DIRECT SOLAR IRRADIATION OF LEAF UPPER SURFACE

COSTH=SIND*SINL*COSS
COSTH=COSTH-SIND*CSSL*SINS*COSA
COSTH=COSD*CSSL*COSV*CSS*CSSH
COSTH=COSD*SIND*SINS*CSSA*COSH*COSTH
COSTH=COSD*SIND*SINS*CSSA*COSH*COSTH
IF(COSTH.LT.0.0) COSTH=0.0
QST=COSTH*QST

DIFFUSE SOLAR RADIATION(QDF) INCIDENT ON A SURFACE

QDF=Q1*QST
QDFT=(1.0+COSS)/2.0
QDF=QDF*FRAC+QDF*(1.0-FRAC)*RSG

TOTAL SOLAR RADIATION ABSORBED BY THE TOP SURFACE OF THE LEAF

OSU=ASU*(QST+QDFT)

AIR TEMPERATURE CALCULATIONS

IIM=1ST*PI/12.
VAR=5.6*29+29.32*COS(TME)+38.48*SIN(TME)-3.48*COS(12.*TME)-8.35*SIN(12.*TME)
TA=TMAX-((TVAR*VAR)/100.0)

CALCULATING VAPOR PRESSURE OF H2O IN AIR AT TA

P=(4.6*EXP(TA/16.13))*K
FOKTRAN IV U1 RELEASE 2.0
RAU

C WATM= INCIDENT ATMOSPHERIC RADIATION

TAK=TA+273.
WATM=SIG*TAK**4.*(1.44+.08*SQRT(P))
CALL GTEMP

C SOLAR RADIATION ABSORBED BY THE LOWER SIDE OF THE LEAF

UDFL=QDF*(1.0-FRAC)+QDF*FRAC*RSU
JSL=ASL*(QDFL+QST+QSL*RSU*FRAC)

C TOTAL RADIANT ENERGY(QA)ABSORBED BY THE LEAF

QA=A*(QATM+QG+RG*QATM)+QSL+QSU
RETURN
END
SUBROUTINE LEAF

COMMON/DATAIN/P1,C2,SIG,TL,EPS,G,K2,CP,Z
COMMON DT,M,LT,DEC,H,LST,L,QA,UR,TA,V,TMAX,TVAR
COMMON QB3,UB8,C1,QATM,QG,WE,RU,T,SC,COSTH
COMMON QC,HC,ASU,ASL,E,A,RA,RG,ASG,AG,QST,OSU,QLT,OSL,QDF,C4
COMMON KH,DK,KA,KE,GR,RL,DFS,COND,DELT,TGR
COMMON SIND,GUSL,SINL,GUSL,SINA,COSA,SINS,COSS,SINH,COH,COZ

REAL LAT,LST,M,KA,K2

SUBROUTINE LEAF CALCULATES THE HEAT TRANSFER TO THE LEAF OR
MATERIAL SURFACE BY EVAPORATION AND CONVECTION AND THE HEAT LOST
BY THE LEAF DUE TO RADIATION.

IF (RL.LT.0.0) GO TO 3

CALCULATION OF RATE OF HEAT TRANSFER BY EVAPORATION (WE)
BOUNDARY LAYER EVAP RESISTANCE

RBI=60.0*V/VI
RBI=K2*RBI

TOTAL EVAP RESISTANCE

KT=KL+RB

DENSITIES FOR Q EVAPORATION

RHU=1.0/VG( TL)
RHO=1.0/VG(TA)
QE=RHDL-KH*RHO
QE=(2.*G.*380.0*QE)/RT
IF (QE.LT.0.0)QE=0.0
GO TO 4

3 QE=0.0
4 CONTINUE

CALCULATION OF THE RATE OF HEAT TRANSFER BY CONVECTION (CC)

TFM=(TA+TL)/2.0
ANU=B.032+.8422E-2*TFM
CP=ANU+1.06E-5*TFM
REP=V0/ANU
UK=G**U*ABS(TL-TA)/(ANU*ANU*TFM)
IF (GR/RE**2.0*LT+1.0)GO TO 1

CALCULATION OF FREE CONVECTION COEF. (HC).

HC1=(0.447*KA*GP**0.25)/D
HC2=HC1/2.
HC=HC1+HC2
QL=HC*(TL-TA)
GO TO 2
1 CONTINUE
LEAF

C CALCULATION OF FORCED CONVECTION COEF. (HC)
C
0033  HC=0.599*KA*SQRT(RE)/D
0034  HC=2.0*HC
0035  UC=HC*(TL-TA)
C
C ENERGY RADIATED FROM THE LEAF (QR)
C
0036  QR=2.0**SIG*TLK**4.*
0037
0038  RETURN
0039  END
SUBROUTINE DETECT

C DIMENSION B(50), FV(50), WAVE(50)

C COMMON/ DATA1N/P1, C2, SIG, TL, EPS, G, K2, CP, Z

C COMMON OT, M, LAT, DEC, M, LST, L, QA, QR, TA, V, TMAX, TVAR

C COMMON U8, O8, CL, QAT, WG, KG, GK, H, T, SC, COSH

C COMMON QC, HC, ASU, ASL, EA, RG, EG, ASU, KS, AG, GST, QSU, QSL, QDF, C4

C COMMON RH, d, K, RE, GR, KL, DFS, CD, DEL, TE, G

C COMMON S, COSD, SINL, COSL, SINA, CMS, SIM, COSS, SINH, COSH, COSZ

REAL LAT, LST, M, KA, F2

C

C THIS SUBROUTINE CALCULATES THE RADIANT ENERGY WHICH WILL BE
C DETECTED ABOVE THE RADIATING SURFACE IN THE 3-5 AND THE 8-14
C MICRON RANGE

C

C WAVE(1)=1.
C WAVE(2)=5.
C WAVE(3)=8.
C WAVE(4)=14.
C TL=TL+273.
C UO 3 I=1.4
C UO I=1.4
C BL=BL+BL(1)*TLK
C IF(u(I), L, 2, 3)GOTO 4
C FV(I)=0.0
C UO 5 N=1.9
C UO 29
C FV(I)=FV(I)+.15*(((EXP(-N*B(I)))/N**4.)*((N*B(I)+3.)*N*B(I)+6.))
C FV(I)=FV(I)+.15*(((EXP(-N*B(I)))/N**4.)*((N*B(I)+3.)*N*B(I)+6.))
C
C 5 CONTINUE
C GOTO 3
C 4 FV(I)=FV(I)-((1.5*B(I)**3.)*((1.3-6(I)-l(I)/8.+(6(I)**2.)/60.-(B(I)**4.)/5
C 140.+(B(I)**6.)/272160.-l(I)**8.)/13305600.))
C 3 CONTINUE
C F1=FV(2)-FV(1)
C F2=FV(4)-FV(3)
C F3=.016
C F4=.032
C UO 29
C W8=(F1*SIG*(TLK**4.))+(F3*RU*1.94*COSH)+(F3*TP*SG
C 11.94*COSZ)
C UO 30
C W8=(F2*SIG*(TLK**4.))+(F4*RU*1.94*COSH)+(F4*TP*SG
C 11.94*COSZ)
C UO 31
C RETURN
C END
FUNCTION VG(T)

FUNCTION SUBROUTINE VG(T) CALCULATES THE SPECIFIC VOLUME OF SAT. WATER AS A FUNCTION OF TEMPERATURE.

T=T*273.16
X=647.27-T
Y=X*13.2437+(5.8863E-3*T-1.17024E-6*X**2)*X
Y=Y/T*(1.0+2.18785E-3*X)
PSL=216.167/(10.0**Y)
B1=(2.64162*10.0**((0.0725)/(Y+1)))/T
B2=1.69-81
B3=2.546
T=62460.0/T
B4=0.21828*T
B5=126470.0/T
B6=80*PSL/(T*T)
B7=80*(1.0+2*162-B3+Z*(B4-B5)*B0*PSL)
VG=4.35504*T/PSL+B
T=1-273.16
RETURN
END
SUBROUTINE GTEMP

DIMENSION TG(200)
COMMON/DATAIN/Pi,C2,SIG,TL,EPSC,K2,CP,Z
COMMON DT,M,LAT,DELCH,LST,LQA,TA,TMAX,TVAR
COMMON QB3,088,C1,WATM,WG,GE,RT,T,SC,COSTH
COMMON QC,HC,ASU,ASL,AL,AC,EG,AS,RS,AG,WST,USUS,WDS,OD,CG
COMMON RH,D,K,KE,UR,LR,DFS,CONU,DELT,TGR
COMMON SIN1,COS1,COSL,SIN1,CUS1,CUS2,SINH,COSH,CUS2
REAL LAT,LST,M,K,TA,K2

SUBROUTINE GTEMP CALCULATES THE GROUND SURFACE TEMPERATURE
BY AN EXPLICIT FINITE DIFFERENCE METHOD.

N IS THE NUMBER OF NODES USED IN CALCULATING THE TEMPERATURE
GRADIENT IN THE SOIL.
DELTX IS THE DISTANCE BETWEEN NODES, IN CM.

1
N=20
TIME=0.0
DELTX=SQRT(2.*DFS*DELT)
C=0.559*T*CO2
C1=COS2
C2=0.559*DFS
I=LIN(0,0) GO TO 2
J=N+1
L=3 L=L+N
3 TG(I)=TMAX-TVAR/2.0
2 CONTINUE
4 TG(1)=T1
5 C5=DFS*DELT/(DELTX*DELT)
6 C6=CG/DFS/DELTX
7 T1K=TG(I)/273.0
8 T1S=DELTX
9 QU=0.05*TGR*TK*2
10 TFLM=TG(I)+TA)/0.5
11 ANU=0.082*4.5*22E-2*TFLM
12 ANU=ANU+0.065*TFLM/TFLM
13 RHDA=0.333/(TA+273.0)
14 PH=1.0/(CP*KHA*KHA)*0.066
15 CH=1.*J/(2.5*ALUG(160.0/2)+5.0)**2
16 HG=PR*CF*KH)*CP*V
17 QUAN=WS1*ASG+WATM*AG-WG
18 TG(I)=(HG+TA+G5+T6(2)+QAN)/HG+C6
19 DG 1=2,4
20 4 1 TG(I)=TG(I)+C5*(TG(I+1)-2.0*TG(I)+TG(I-1))
21 J=1,4,5
22 5 IF(L.GT.0) GO TO 4
23 GO TO 1
24 CONTINUE
25 CL TIME=TIME+DELT
26 IF(TIME.LT.0) GO TO 2
27 L=L+1
28 RETURN
29 END
SUBROUTINE BLOCK DATA allows variables in COMMON to initialized in a DATA statement. The following data is initialized as block data.

- C2 is a constant used in Planck's spectral energy distribution in microns-degrees K.
- SIG is the Stefan-Boltzman constant, in CAL/CM**2-K**4.
- TL is the arbitrary initial temperature of the leaf or material surface.
- EPS is the precision with which the temperature of the leaf or material surface is calculated. Note: if EPS is set too small a divide check will occur in the main program due to the small change of RES1 and RES2.
- G is the gravitational constant, in CM/MIN**2.
- K2 is a proportionality constant.
- CP is the specific heat of air, in CAL/GM-DEGREE C.
- Z is the ground cover vegetation height, in CM.

END
APPENDIX B

Evaluation of Various Surface Coatings on Camouflage Material Temperatures
Introduction

As shown in Table 1, camouflage material temperatures are several degrees higher than foliage when exposed to solar radiation and slightly lower during the evening hours when no solar insolation is present. This information leads us to the conclusion that the radiative characteristics of the camouflage material must be altered if it is to emulate foliated backgrounds. To accomplish this end, two basic approaches were considered: (1) change the radiative characteristics of the top surface of the material by using a clear spray coating or a transparent acetate cover as previously discussed and; (2) alter the solar and I.R. energy absorbed and emitted from the lower side of the material in order to control its temperature.

Two types of surface configurations were used to evaluate the second approach. The first consisted of bonding a sheet of aluminum foil to the lower surface of the camouflage material. The foil has the effect of lowering material temperatures when large amounts of solar radiation are reflected from the ground and has little or no effect when no reflected solar radiation is present. This is due, in part, to the fact that the foil effectively eliminates the absorbed short wavelength radiation which is reflected from the ground, and eliminates the long wavelength exchange between the lower surface and the ground. In addition, another piece of camouflage material was coated on the lower surface with white lacquer.
The lacquer has the effect of reducing the solar radiation absorbed on the lower side of the material while the long wavelength emittance remains unchanged. Thus the white paint effectively lowers the temperature during periods when solar radiation is present and has little effect at night.

**Experimental Procedure, Results and Conclusions**

Temperatures of the plain camouflage material and four variations thereof were made and compared to a Botanical Wonder plant (Fatsia Japonica). The measurements were made with Barnes PRT-5 and PRT-10 radiometers and were carried out with varying atmospheric conditions in order to properly evaluate the effect of the coatings. The results of these measurements are presented in Tables B-1 and B-2. In addition the air temperature, plant temperature, plain camouflage material temperature and one variation of the plain material temperature were plotted using data from the PRT-5 and are shown in Figures B-1 through B-4.

No concrete conclusions can be drawn from the preliminary data obtained thus far; however, certain trends are evident. The white lacquer coating lowered the material temperature below that of the plant and plain material during daylight and evening hours (Figure B-3). Both transparent coatings effectively lowered the material temperature during daylight hours, however the spray coating increased the temperature at night, while the acetate cover tended to lower the apparent temperature at night. Unfortunately, the acetate cover reflects large amounts of short wavelength radiation thus producing glare (Figures B-1 and B-4).
Table B-1. Comparison of the effect of various surface coatings on camouflage material temperatures in the 8 - 14. micrometer range.

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<th>Air Temperature in °C</th>
<th>Plant Temperature in °C</th>
<th>MATERIAL TEMPERATURE °C</th>
<th>Comments</th>
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Table B-2. Comparison of the effect of various surface coatings on camouflage material temperatures in the 6.5-20. micrometer range.

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Figure B-1
MEASURED PLANT AND CAMOUFLAGE MATERIAL TEMPERATURES
PRT-5 RADIOMETER
DECEMBER 29, 1976
OKLAHOMA STATE UNIVERSITY
STILLWATER, OKLA.

Figure B-2
MEASURED PLANT AND CAMOUFLAGE
MATERIAL TEMPERATURES
PRT-5 RADIOMETER
DECEMBER 29, 1976
OKLAHOMA STATE UNIVERSITY
STILLWATER, OKLA.

MID-MORNING

PLAIN MAT'L

MID-AFTERNOON

MAT'L W/WHITE PAINT

PLANT

EVENING

AIR

TEMPERATURE °C

DATA POINT

Figure 3-3
MEASURED PLANT AND CAMOUFLAGE MATERIAL TEMPERATURES
PRT-5 RADIOMETER
DECEMBER 29, 1976
OKLAHOMA STATE UNIVERSITY
STILLWATER, OKLA.

MID-MORNING

PLAIN MAT'L

MID-AFTERNOON

PLANT

EVENING

MAT'L W/ACETATE

TEMPERATURE °C

DATA POINT

Figure B-4
The foil cover produced the most promising trends. It effectively lowered temperatures during the mid-morning, and mid-afternoon hours and slightly raised temperatures during the evening hours. In addition, it followed the plant temperature more closely than the other variations (Figure B-2). This configuration holds the added advantage that most of the radiation emitted from a hot object placed under the material would be reflected off the lower side.

The measurements made thus far are only preliminary and were designed to establish various trends by altering certain radiative properties. It is not known if the materials tested could be used under field conditions, however it is evident that progress can be made towards emulating foliated backgrounds with continued research in this area.