Methods for Evaluating Thermal Camouflage

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ABSTRACT

This paper discusses different methods for formulating specifications for thermal camouflage materials or systems. The discussed methods range from full-scale realistic combat-like military exercises to laboratory measurements of material properties and computer simulations. As an introduction to the discussion, a brief overview of the physical processes governing the temperature of outdoors surfaces is given as well as a basic introduction to the formalism and methods used in thermal imaging systems performance prediction.

1.0 THE PROBLEM

The task for all camouflage is to reduce the contrast between the target and the background as much as possible. In the visual the contrast is caused by differences in the reflective properties of the target and the background. Light surfaces reflect much of the incoming light, darker surfaces less. The differences in reflective properties are properties of the *surfaces* that stay constant independent of the lighting conditions. Of course, there exist seasonal variations in the colours found in the nature, but except for a short period during autumn, healthy vegetation is green and withered vegetation is brown. This makes it possible to define a limited set of colours that are representative of the colours found in a particular area or type of biotope. These colours give good camouflage independent of time of the day and weather conditions.

For observation with thermal imagers it is the difference in target and background temperature that causes the contrast. Different from visual (reflective) contrast the difference in temperature is not caused by the properties of the surfaces alone, but rather a number of properties of the *bulk material* as well as the influences from the environment, i.e. the weather conditions. The temperatures in the nature vary fast with the weather conditions and time of day, and different materials like rock and grass changes temperature differently. This causes the temperature differences (the contrast) also to change fast. For a camouflage material to have the same temperature as the surroundings, its temperature has to change in the same way. The camouflage material has to show the same temperature response to changes in the environment as the natural materials in the background. This makes it much more complicated to formulate requirements for thermal camouflage than for traditional, optical, camouflage.

Prior to procurement of military materiel detailed requirement are formulated with respect to almost every aspect of the items involved. For camouflage materials, requirements are put on properties like water absorption, durability, tear strength, and flame resistance among others. For all these properties there exist some form of standardized methods of measurement that makes it possible for the procurer and the industry to relate to the requirements. The industry can use the measurements methods in their research and development. The procurer can test if the supplier meets their demands and make an objective

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judgment of two competitive suppliers based on objective measurement methods. For the performance of thermal camouflage materials or systems, there exist no such standardized methods of measurements. In fact, it does not even exist a consensus regarding what parameters such methods should concern.

2.0 SURFACE TEMPERATURE – ELEMENTARY PHYSICS

The purpose of thermal camouflage is to minimize the chance of being detected, or put in another way, to reduce the range at which a camouflaged object with a given probability is detected. The objective for thermal camouflage is therefore to alter the actual or apparent temperature of a target so that it appears to have the same temperature as its background. This makes it imperative to understand the physical processes that are influencing the surface temperatures outdoors.

An outdoors surface absorbs radiation from and emits heat radiation to the sun, the sky and the surroundings (Figure 1). In addition the surface exchanges heat with the air close to the surface either by free or forced convection. Forced convection occurs when the air moves due to wind and free convection is due to air movements caused by local differences in the surface and air temperatures. A wet surface cools when the water evaporates, and if water condenses on a surface the condensation contributes to a heating of the surface. For massive objects, for instance a rock, internal heat conduction gives an important contribution to the surface heat flux. How quickly the surface temperature changes, depends on the net heat flow to the surface and its effective heat capacity.

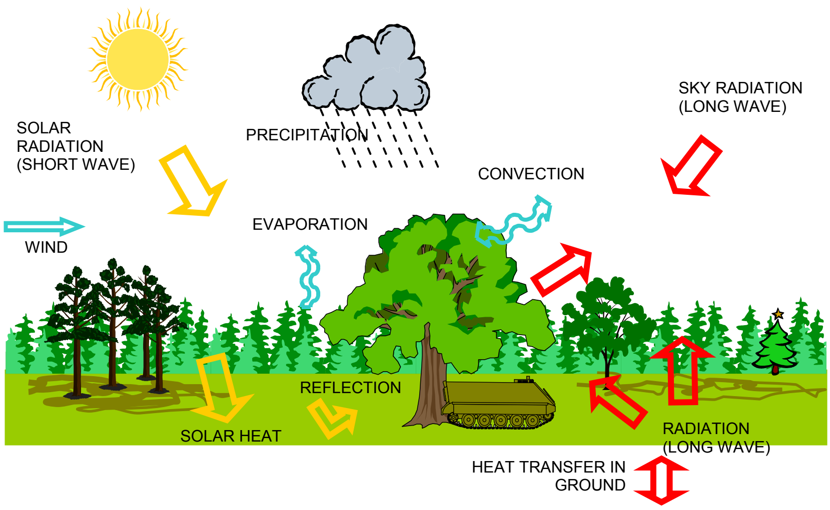

Figure 1 Heat transport processes for outdoors surfaces

Internal heat conduction in a vehicle will cause a heat flow from for instance a warm engine to the outer surfaces of the vehicle. The heat will also spread over the outer surface, and the rate at which the temperature changes with the net heat flow to the surface is determined by the surface's heat capacity, heat conductivity and the thickness of the materials. It is the interaction of all the heat transport processes that governs the amount of heat flowing to and from a surface, and it is the material properties that govern how the surface temperature changes in response to the net heat flow to the surface. Elements found in the background, e.g. trees, grass, heather and rock, have different material properties and hence their surface temperatures are influenced differently by the weather conditions.

In Mid-Europe trees are common background elements, and it would be a good thing if camouflage nets could mimic the thermal behaviour of trees. In arid environments rocks is a more likely background and a good camouflage would mimic the thermal behaviour of rocks. Since rocks and trees have distinctively different material properties, the two types of nets are not compatible. Thermal camouflage materials suited for Mid-European conditions cannot perform well in arid terrain and vice versa.

3.0 THE SENSOR SYSTEM

Intuitively we understand that the probability of detecting an object in a background decreases when the sensor moves further away from the target or if the contrast between the target and the background is reduced. The probability of detection depends on both the sensor system's capacity to depict the target and the observer's ability to interpret the image that the imaging system gives out. This section briefly discusses how the sensor system performance can be predicted, while the next section treats the observer's ability to extract information from the images, and how detection probabilities and ranges can be estimated.

The thermal radiation from the target and the background propagates through the atmosphere to the sensor system. On its way the intensity decreases due to absorption and scattering processes, and this causes the apparent temperature difference between target and background to reduce. This is illustrated in Figure 2.

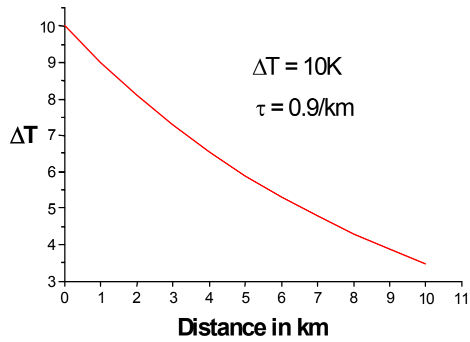

Figure 2 Apparent temperature difference, ΔT_R, as function of distance.

Often the air between the target and the sensor is turbulent and this causes blurring of the image. In the sensor system's optics the radiation is focused and forms an image on the sensor, and the image is divided into pixels. How well the target is depicted depends on the field of view of the sensor and the sensor's number of pixels. The quality of the final image also depends on the sensor's sensibility and the system's noise.

Figure 3 illustrates what an image of a vehicle (a) can look like at different distances: The contrast between target and background is reduced due to noise (b) and the vehicle is represented by a number of pixels (c). By observation from greater distances the apparent contrast reduces due to atmospheric absorption and scattering. Also the number of pixels covering the target reduces. In image (d) it is not longer possible to identify the vehicle, and in (e) it can only be detected as a blob. If confusing objects are introduced to the background it becomes very difficult and in many cases impossible to discern the real target. In a realistic scenario the confusing objects can be other vehicles or parts of the natural background like boulders, rock, trees or bushes. This is illustrated in (f). For a more thorough discussion of thermal imaging systems see Holst (1).

There exist a number of models for sensor systems performance prediction (e.g. Acquire, NVTherm, and TRM3) but it is beyond the scope of this paper to discuss in depth the theoretical foundation for these models. Instead a very brief introduction to the theoretical framework, which is the starting point for the most common models, is given.

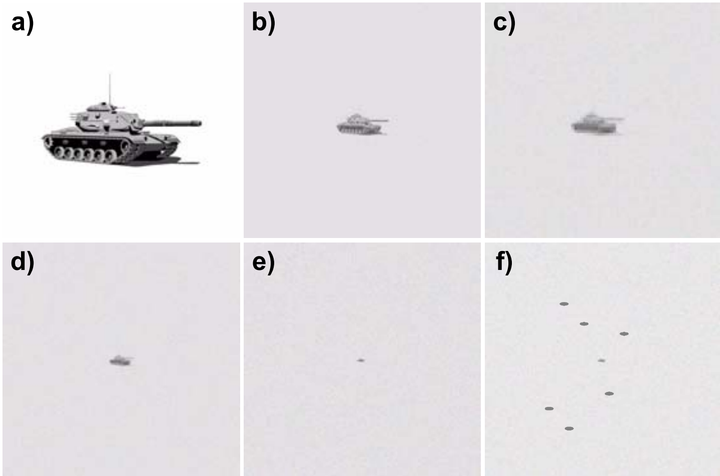

Figure 3 Image of vehicle simulated at different ranges.

In the commonly used models the contrast between target and background is represented by a single number, the temperature difference ΔT. As mentioned above the radiation from both target and background is absorbed and scattered as the radiation propagates through the atmosphere between the target and the sensor. Often the absorption and scattering processes are assumed to be independent of wavelength and an average value for the atmospheric transmission, τ, is used. Apparent temperature difference between target and background at a distance R from the target, ΔT_R, is then $\Delta T_R = \tau^R \Delta T$. For conditions with good visibility the value $\tau = 0.9/km$ is often used. That is, the temperature difference decreases to 90% for every kilometre distance to the target.

Infrared imaging systems are often characterized by a function called the MRT (Minimum Resolvable Temperature). This function gives the systems minimum resolvable temperature as a function of the targets spatial frequency. For a given target size spatial frequency can be converted into distance. The MRT function increases with decreasing spatial frequency, which means that the system can resolve smaller temperature differences for a large target than for a small target. Or related to distance: The systems temperature resolution is better when the target is closer to the sensor. The largest possible detection range for a target is therefore the distance where the systems effective temperature resolution (MRT) equals the apparent temperature difference between the target and the background. This is illustrated in Figure 4.

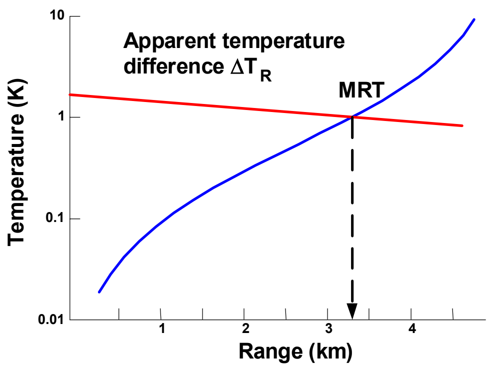

Figure 4 Detection range for a typical infrared imaging system.Apparent temperature difference, $\Delta T_R = \tau^R \Delta T$, describes a straight line in a semi-logarithmic coordinate system.

An obvious problem with this method is that the conspicuity of the target against the background is represented by a single number, namely the temperature difference ΔT. Normally the temperature of the target is calculated as an area weighted average temperature, and the temperature of the background is taken to be the average temperature of the targets immediate background. ΔT then simply becomes the difference between the average target and background temperature. This simplistic method disregards most of the features that are commonly supposed to be important to the conspicuity of a target, features like shape, shadow and texture.

4.0 THE OBSERVER

Whereas the response of an infrared imaging system, the MRT function, can be measured directly, the observer's ability to discriminate targets in a background has to be deduced from visual psychological experiments. Normally, the experiments are designed to measure the probability of an average or typical observer's probability of successfully completing different discrimination tasks. In the context of camouflage evaluation the levels or tasks are usually detection, orientation, recognition and identification of a target.

In the literature also other levels are used, and it is not always intuitively obvious what the different levels mean. The simplest task, detection, is normally meant to be the ability to discern something in an image that stands out from the background. A typical example is detecting an airplane against a blue sky. Less clear is what is meant by detection of for example a battle tank standing in a more complex background with trees, bushes, stones, rocks etc. In this case it might be necessary to recognize the vehicle as a battle tank in order to say that it is detected. Identification is a higher level of discrimination and is the last step in a complex process. The first step is to search in the field of view to find the object. The search can be random or systematic, and the approach varies with the observer's level of training and education. After the object is found, information about size and shape is used as clues for detection, recognition and identification.

Johnson (2) performed visual psychological experiments in the 50's investigating the relation between discrimination levels for a bar pattern and discrimination levels for images of vehicles. In these experiments he established what today is known as the Johnson criterion. They are stating the number of equivalent bar pattern cycles that is needed across a targets minimum dimension in order to give 50% probability of detection. Even though Johnson's original work was done for visual imagery, the method is used today also for thermal imagery. Table 1 gives today's industry criteria for thermal imaging systems.

Table 1 Current industry criteria for thermal imaging systems (after Holst (1))

Task	Description	# Cycles
Detection	The blob has a reasonable probability of being an object being sought	1,0
Aim	Aiming cross hairs on a target with sufficient accuracy to fire a missile.	2,5
Classical recognition	Object discerned with sufficient clarity that its specific class could be differentiated.	4,0
Identification	Object discerned with sufficient clarity to specify the type within the class.	8,0

Pursuing Johnson's methods even further it is possible to experimentally deduce the probability of successfully performing a discrimination task as function of the number of equivalent bar pattern cycles across a target. These functions are known as the target transfer probability functions (TTPF), and examples of functions are given in Figure 5. It is important to notice that the probability given by the TTPF refers to a population and not to a single observer. 80% probability of recognition means that 80%

of a population is expected to recognize the target. It does not mean that a specific individual wil recognize the target 80% of the time.

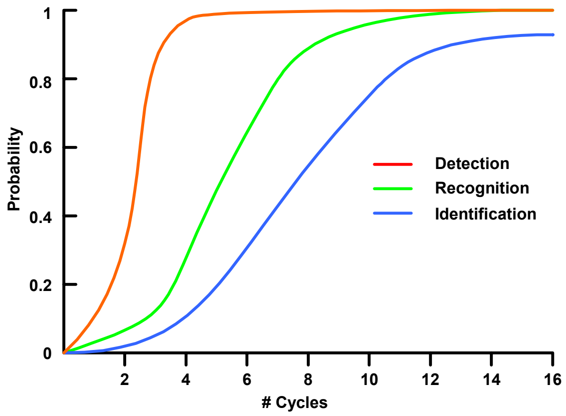

Figure 5 Examples of target transper probability functions (TTPF) for detection, recognition and identification tasks.

TTPF can be used to calculate the probability of a discrimination task as a function of the distance to the target. Then a range R is chosen and $\Delta T_R = \tau^R \Delta T$ is calculated. This value intercepts the MRT-curve at what is called the critical frequency. When the target's size is known the number of equivalent bar pattern cycles across the target can be calculated, and the TTPF gives the probability of for instance detection at the distance R. Then a new distance R is chosen and the process is repeated until the probability of detection is calculated for all ranges of interest. This method is illustrated in Figure 6. For a more comprehensive discussion of the Johnson criterion and the associated methods see e.g. Holst (1).

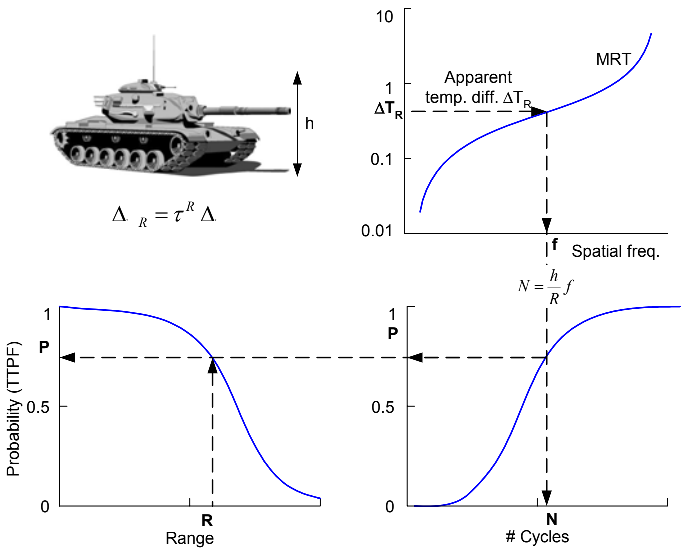

Figure 6 Method for calculation of the probability of detection as functin of range.

The method described above has weaknesses, and perhaps in the context of camouflage assessment the most important are the ability to account for cluttered backgrounds and limited search times. Obviously, the probability of discerning a target in a background increases with the time available. Even though an observer is unable to detect a target after lets say 30 seconds, it does not mean that the probability of detection is zero after one minute. Also, it is apparent that the probability of detection is related to the difficulty of the task. The probability decreases in a cluttered background. The way to cope with this is to adjust the TTPF to the difficulty of the task. The usual way of doing this is to adjust the number of cycles required for 50% probability, N_{50}. The choice of a new value for N_{50} has to be based on the analyst's judgement, his prior experience or with reference to analogue results. The predicted range performance based upon a particular N_{50} should be considered as representative and not as an absolute value.

5.0 THE FORMULATION OF CAMOUFLAGE SPECIFICATIONS

5.1 Problem complex

The dictionary explanation of the word *requirement* is something you must have or do in order to do what you want. In our context camouflage requirements are formulated by the user of camouflage systems or materials; he expresses what camouflage he needs in order to perform the military tasks he is assigned to do. A typical requirement is that the camouflage should keep e.g. a battle tank undetected by an enemy at least until the enemy comes into range of the battle tanks weapon. For the user of camouflage this is a perfectly sensible way of formulating the requirements.

The procurement system or the industry however needs not requirements but *specifications* that can be evaluated using standardized or at least well defined methods. Using our example, it is very difficult for the supplier or procurer to test if a camouflage system keeps a battle tank undetected within the range of its own weapon. This clearly shows that a transition from military requirements to industry specifications is needed.

The discussion in the previous chapters has shown that there exists a theoretical framework and methods for estimating the performance of thermal imagers or imaging systems. These methods are, simply stated, based on the detection of a bar pattern in a homogenous background, and it has been shown that the methods have severe weaknesses when used to estimate detection in more realistic situations. As an attempt for a summary, it may be stated that the methods are suited for the characterization of a sensor system under idealized conditions, but not suited for estimating different levels of discrimination under realistic conditions. The standardized methods for the optimisation and evaluation of sensor systems are therefore less suited for the evaluation of camouflage systems and other starting point have to be found.

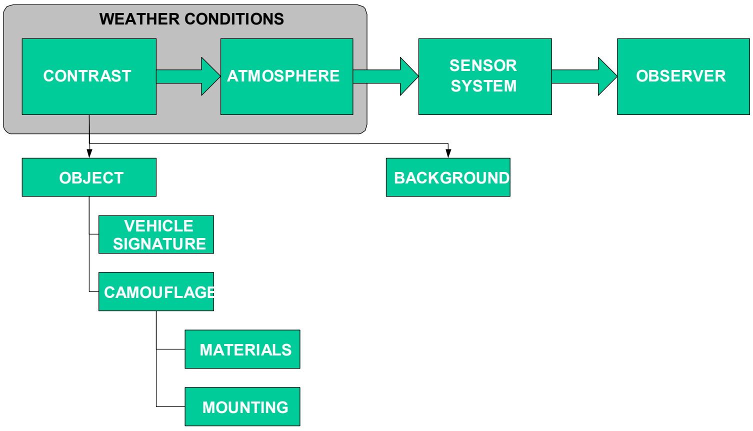

Figure 7 Elements relevant to camouflage evaluation.

Figure 7 shows an illustration of the problem complex concerning detection and camouflage. The ultimate measure of camouflage effectiveness is how difficult it is for an observer to detect and recognize a target in a realistic scenario. This involves the chain starting with the contrast between target and background, through transmission in the intervening atmosphere, the sensor system and finally the observer. But since it is the camouflage effectiveness that is the measure we want to optimise it is the contrast between target and background that is of interest. The target signature can be separated into two components, the intrinsic object signature and the camouflage system itself. The performance of the camouflage system is determined by the material properties of the camouflage materials, the construction of the system, how the system is applied to the object and how the camouflage system and the object interact.

In the following different methods for evaluating camouflage systems or materials are discussed. Each of the methods takes different starting points in the detection and camouflage problem complex in Figure 7.

5.2 In the field

5.2.1 Combat exercises

The most realistic measure of the effectiveness of a camouflage system is achieved in realistic combat-like exercises where units on ground and in air operate realistically. For ground units this means among other things to take advantage of the terrain to hide against observation. A pilot in an attacking fighter jet or combat helicopter has to search a relatively large area depending on the information he has in advance, and the target he is searching for may be fully or partly covered by the terrain or by vegetation. At what range he is able to detect the target is thereby not determined by the effectiveness of the camouflage system alone, but rather mainly by the targets accidental location and cover.

However, the method gives a realistic impression of how difficult it may be to detect the target, and this insight is very useful for the unit itself to possess for instance as a basis for further exercises and the formulation of combat strategies. The information is also valuable as input to war games and other simulations.

The method is less suited for test and evaluation of camouflage effectiveness since it is difficult to separate the effect of the camouflage system from the total result. Also, the method is very costly since it involves a large number of soldiers and much equipment both on ground and in the air.

5.2.2 Detection range

To the scientific community the most prominent measure of camouflage effectiveness is the detection range. The shorter the detection range, the more difficult the target is to reveal. In a duel situation the chance of winning depends on the ability to get the opponent within the range of the weapon before being detected.

When measuring detection range, the experiment is often done by dispersing targets in an open field so that line of sight is achieved for distances larger than the expected detection range. Normally, the imager is mounted on an aircraft. This way the imager can be moved along a straight path towards the target. The target position has to be known to the pilot and the operator of the imager. Video or digital thermal imagery is recorded to enable observer experiments at a later time. Figure 8 shows examples of dispersion of vehicles on an open field.

In this type of experiments, the measured detection range is depending on a number of parameters like the current weather condition, the sun position, the visibility, the sensor system and platform used, and not the least the observer’s level of experience and training. By increasing the number of observers the uncertainty associated with observers can be reduced, but experiments have shown that the local background of the targets plays an evenly important role (3). No matter how carefully the experiment is conducted it will always be possible to argue that the results are not generally valid, but valid for this single experiment or class of experiments only. Even though the method has weaknesses with regard to producing statistically representative detection ranges, the method is well suited for comparative experiments.

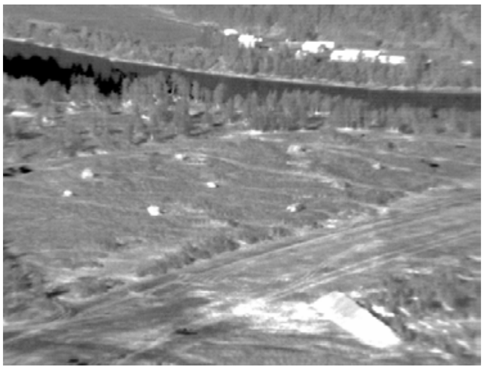

Figure 8 Thermal image of vehicles dispersed on an open field.

By comparing the detection ranges for identical vehicles with different types of camouflage, the camouflage effectiveness of the candidates can by ranked. If the experiment is repeated for different weather conditions the ranking of competing camouflage systems can be based on statistically representative data. But also when the method is used like this it is important to consider the uncertainties in the experiment to prevent that conclusions are drawn that are not supported by the underlying data. Figure 9 shows that one single observer ranks the conspicuity of a target different at different distances (right), and that the averaged ranking by a number of observers vary with the target position in the field and the orientation relative to the sensor (left).

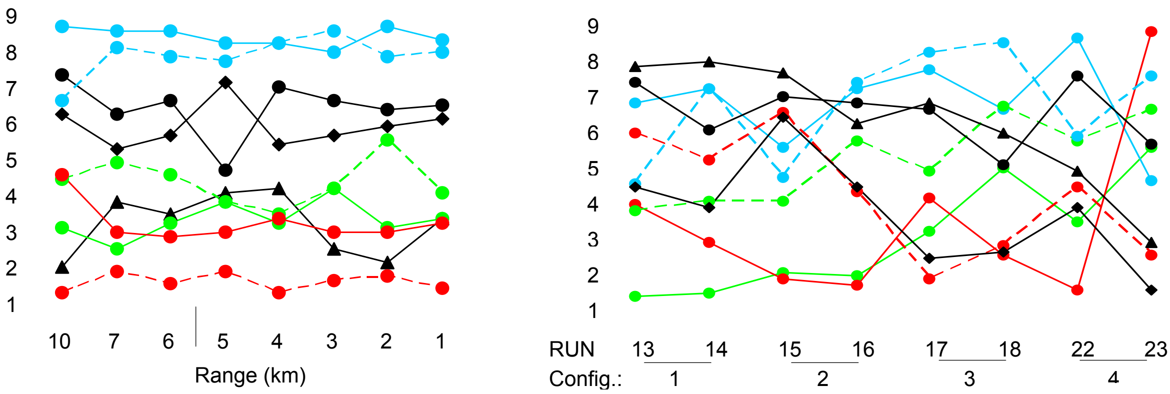

Figure 9 Examples of ranking of object conspicuity (4).
Left: Average ranking for 8 observers for 8 different distances in the same run.
Right: Average ranking for a single observer for all ranges in each of the indicated runs.

An alternative method to using observers to rank the conspicuity of the targets is to use automatic computer based algorithms. A simple approach can be that an operator identifies the position of every target and that the algorithm computes the average temperature of the target. But it is not guarantied that average temperature is a measure that gives results comparable to a human observer because a human observer also takes into account features like shape, contrast and the texture of the target. Therefore it has to be considered if such features should be included in the computations. The advantage of computer-based methods is that the results are objective and reproducible, while the disadvantage is that the results strongly depends on the algorithm applied.

Several authors have reported experiments with automatic detection algorithms of varying complexity. In this case the algorithms themselves find the targets, give their detection range and a number describing each target's conspicuity. Presently it is uncertain if the results from such methods correlate with results from human observers, and an effort must be put into research in this field in the years to come. However, recent work by Müller (5) has shown promising results .

5.2.3 Temperature difference

As discussed above the temperature difference between target and background, ΔT, is an important parameter when calculating expected detection ranges for thermal imaging systems. A small temperature difference gives a small probability of detection, alternatively a short detection range. By using ΔT as a measure of camouflage efficiency many of the uncertainties related to the calculation of detection range are omitted because it is no longer necessary to take into account effects caused by atmospheric propagation, the sensor system and the observer. But also the temperature difference depends on the weather conditions, and to achieve a statistically robust data basis the temperature difference has to be measured for a variety of weather situations. In practice this is achieved by performing long time experiments (Figure 10).

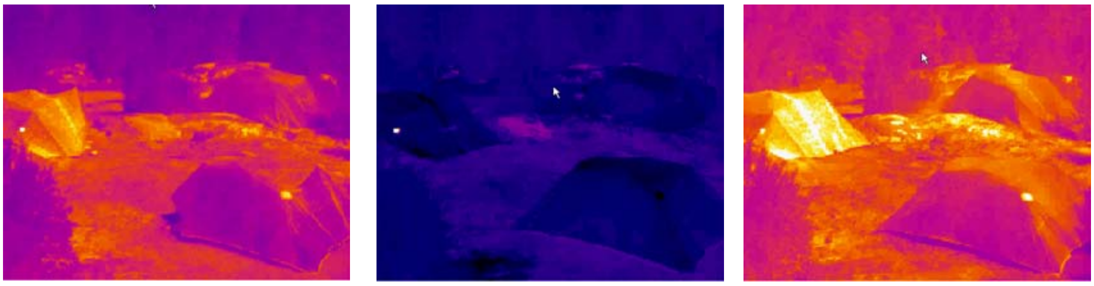

Figure 10 The figure shows examples of thermal images of three different camouflage nets. The images are recorded at different times of day and have the same temperature scale.

Simply put, this can be done by mounting a thermal imager on a mast, and programming it to record imagery of the target and the background regularly, e.g. every hour, over a long period of time. The imagery can be used to calculate the temperature difference for a variety of meteorological conditions. Such long time measurements are difficult to carry out for a large number of backgrounds, and an alternative to measuring the background temperatures is to use numerical models.

Such models exist, and have proven to calculate the temperature of different background elements with the required accuracy. Measurements of the surface temperature of a camouflaged object can be compared to calculated background temperatures. A measure of camouflage effectiveness can be the average difference in temperature between target and background over a period of time, or the fraction of time the temperature difference is below a threshold value. Figure 11 shows an example of the temporal variation of the temperature of target and background.

An important issue here is how the temperature variation of the background should be calculated. It may be that the temperature of a target is within the temperature band for trees at some times and within the temperature band of heather at other times. It may also be clutter elements in the scene such as boulders or rocks. Event though the idea of using the temperature difference between target and background is intriguingly simple, it is problems associated with the method that have to be solved.

It may also be argued against the temperature contrast-method that it only gives results for a fixed, most likely close-up, observation distance. But an effective temperature contrast for other distances may be calculated if the visibility is known. Also speaking against the argument is that if the temperature contrast is a good measure of camouflage effectiveness, the distance to the target is no longer of interest. Then, the temperature difference at close range is the most relevant parameter, and apparent or effective temperature difference at other distances only of interest if the method is used to predict detection range or probability.

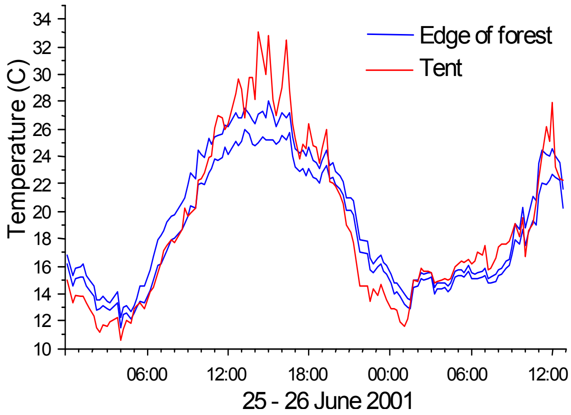

Figure 11 Example of temperature variation in target and background. The background temperature varies between an upper and lower value describing a "temperature band".

When a camouflage material or system is applied to a vehicle it can be difficult to control how much of the internal generated heat that contributes to the surface temperature of the camouflage. This difficulty can be omitted if a standardized target with controllable internally generated heat replaces the vehicle. But this also makes the task of to relating the measurements or results to an operative vehicle more difficult. However, the method is suited for a comparative measurement of the thermal behaviour of camouflage materials. An example of a standardized target is the L-shaped "CUBI" originally used to evaluate the software "PRISM", and later also used as a model for a reference target proposed by AC225/LG6-SG7, Counter-surveillance.

Shortly stated, it might be said that the method of using the temperature difference between target and background is a promising alternative to using detection range as a measure of camouflage effectiveness. FFI and other institutes possess the knowledge of parts of what might evolve to be a method for evaluating camouflage effectiveness based on temperature differences, but to my knowledge no systematic attempts have been made to establish a quantitative correlation between the two methods. Such systematic investigations should be performed before the advantages and disadvantages of the temperature difference approach can be clarified.

5.3 In the laboratory

In the preceding sections the discussion has moved from exercises with military units operating realistically to measurements on camouflage materials applied to standardized targets. These methods are based on measurements outdoors, making it difficult or costly to perform measurements under desired weather conditions or under a wide range of weather conditions. The following sections concern measurements indoors, in the controlled environment of a laboratory.

5.3.1 Climatic chamber

An alternative to experiments outdoors is to simulate realistic weather conditions indoors in a climatic chamber or climatically controlled laboratory. A key element in a climatic laboratory is the simulation of a cold sky with varying temperature. The (apparent) sky temperature is close to air temperature by overcast and can be as cold as -60°C by clear sky. Also, it is important to be able to mimic the sun radiation with respect to both spectral properties and intensity. In addition, parameters like air temperature, humidity and wind speed must be controllable. A laboratory with these features has been built by FGAN-FOM, and has proved to be an important tool in the study of how camouflage materials respond to different climatic conditions.

Ideally a climatic laboratory should be spacious enough to room a vehicle, e.g. a battle tank, but this is difficult to achieve in practice. Therefore it is more realistic to use a climatic chamber to test camouflage materials. One way to perform such experiments is to put the material in front of a hot surface and record the apparent temperature of the surface with a thermal imager. By using a pedestal the viewing direction, the incident angle of the sun radiation and the directions relative to the cold sky and the wind field can be varied.

If the temperature of different background elements like edge of forest, grass, rock etc. are known for different weather conditions (by measurement or calculation) the temperature of the camouflage material measured in the laboratory can be compared to the temperature of background elements. Thereby an assessment of the camouflage effectiveness can be made. FGAN-FOM, FFI and others have developed computer models calculating the surface temperature of a variety of background elements as function of weather conditions (6,7,8,9).

5.3.2 Material parameters

The purpose of thermal camouflage is to adapt the surface temperature of an object to the temperature of the background. The most likely background, at least in Europe, is vegetation, and the perfect camouflage material would have the same temperature as the vegetation in the surroundings for all weather conditions. To achieve this without actively regulating the temperature the material properties of the camouflage material must be carefully selected. In other types of terrain rock or sand may be the most likely background, and the optimal camouflage materials would have the same temperature as those background elements. Since rock and vegetation have very different thermal characteristics, the thermal properties of the camouflage materials have to be different depending on the type of background they should mimic. Table 2 lists the most relevant material properties together with a short, informal description.

Table 2 Relevant material parameters characterizing the thermal properties of a material.

Thermal insulation:	The ability to hinder heat flow through a material or a surface.
Heat capacity:	The amount of heat needed to change the temperature of a surface or material.
Short-wave absorption/reflection coefficient:	The fraction of the solar radiation absorbed/reflected. Absorbed energy contributes to heating of the surface.
Free and forced convection parameters:	The amount of heat exchanged with the surrounding air.
Thermal emissivity:	The relative ability of a surface to radiate energy as compared with that of an ideally black surface under the same conditions. The emissivity is related to thermal reflection coefficient such that a surface with low emissivity has a high reflectivity. A low-emissive surface acts like a mirror for thermal radiation. For an opaque surface, the emissivity equals the thermal absorption coefficient.

All these material properties can be measured in the laboratory; the material can be characterized with regard to thermal properties. However, the key issue here is how to relate the thermal characteristics of a camouflage material to the original military operational requirements. This is still an open question, and is to be investigated by the ongoing NATO task group SCI-117/TG-35 *"Correlation between Laboratory Measurements and Field Trials of Multispectral Camouflage Materials"*.

5.4 Simulations

As discussed above the surface temperature is determined through an interaction of the heat transport processes and the properties of the surface and the underlying material(s). Therefore the surface temperature can be calculated if all heat sources and thermal characteristics of the materials are known. Rønning (10), among others, has described simple mathematical models for the calculation of the temperature of buildings and camouflage nets under different weather conditions. These models where developed in the 70s and are based on very simple assumptions about the surface geometry. They are of course still valid as long as their assumptions are valid, but today's models that are based on a 3-dimensional description of the surfaces. In these geometric representations every surface element is assigned a set of material properties, and the elements are thermally connected to account for transversal heat conduction.

Some examples of tools for simulation of the thermal signature of vehicles and terrain are RadTherm/MuSES [1] and NTCS/ShipIR[2]. These tools can also simulate internal heat sources like engines, and are now so sophisticated that they generate "photo realistic" thermal imagery if the underlying representation (3D model, material parameters etc.) of the objects is sufficiently accurate.

But important problems have to be overcome in order to be able to use the tools in the evaluation of camouflage means. Camouflage materials are difficult to characterize, and hence simulate, because the surfaces are normally fringed. The 3-dimesional structures contribute to increased convection, and the effect depends on the size and shape of the "leafs". This makes the convection parameters difficult to calculate. Further, the camouflage nets are normally placed at a distance from the surface, and the movements of the air between the object and the camouflage net influence the temperature. Both the local temperature differences between air and the surfaces and the wind field enclosing the vehicle drive the movements of the air. All this makes it difficult to simulate the convection effects with the necessary accuracy for 3-dimensional structures.

A discussion of the different simulation tools and their application to the estimation of camouflage effectiveness is analogues to the discussion of the different experimental methods: The photo realistic tools can give results with good accuracy for a given scene, but a generalization of the results must be made with caution.

6.0 SUMMARY

In the previous chapter some examples of methods for the evaluation of camouflage materials or systems have been discussed. The methods range from realistic combat-like military exercises to measurements of material properties in the laboratory and computer simulations. Each method has advantages and disadvantages: Some are closely connected to the formulation of military requirements; some are coupled to the physical properties of the materials. The methods can also be ranked according to criteria like realism, costliness or reproducibility of the results. To what extent the different methods correlates to camouflage effectiveness or detection ranges has not yet been thoroughly investigated.

Figure 12 shows some camouflage assessment methods ranked according to different criteria. As the figure illustrates, the choice of method is a trade-off between several parameters. The balancing of benefit and cost is well known and simple to clarify and relate to. Far more difficult is the appreciation of a method's correlation to camouflage effectiveness. Which method that is to recommend is not only a question of purely scientific considerations, but also subject to pragmatic circumstances: A small nation like Norway buys camouflage materials relatively seldom, and the best method could be to perform combat-like exercises to evaluate competing camouflage systems. For nations that procure camouflage on

[1] RadTherm/MuSES are registered trademarks of ThermoAnalytics, Inc.
[2] NTCS/ShipIR are registered trademarks of W. R. Davis Engineering, Ltd.

a larger scale and more regularly the most cost-effective solution might be to invest in a camouflage assessment laboratory.

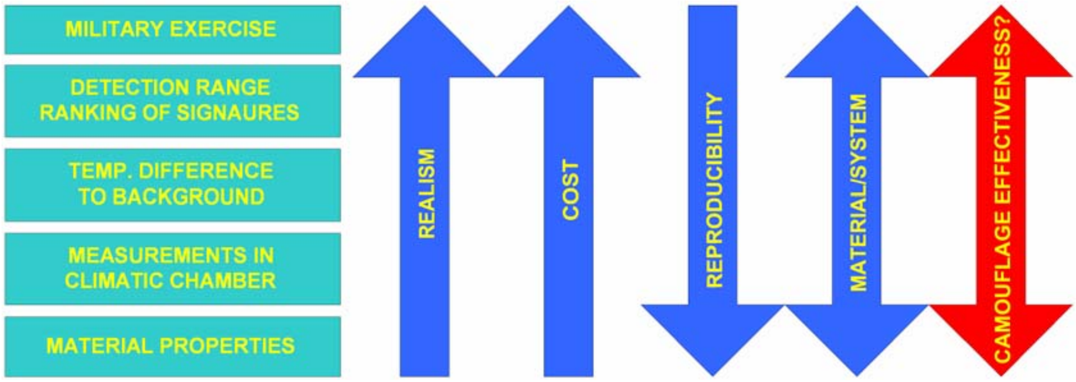

Figure 12 Camouflage assessment methods ranked according to different criteria.

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