IR Signature Validation Results for Full-Scale Plastic Targets

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ABSTRACT

The Targets Management Office (TMO) manages the development, acquisition, and operation of both aerial and ground target systems for use in destructive and non-destructive testing by the U.S. Army T&E community. A need has been identified for low-cost, full-scale validated targets that can accurately simulate the visual, infrared (IR), and radar signatures of threat systems. To address this need, a program was initiated by TMO to augment an existing full-scale, vacuum-formed plastic target with sufficient signature fidelity to adequately stress U.S. weapon system sensors. This paper discusses the validation of a passive IR signature augmentation system to meet the IR signature requirements. The chosen solution for initial passive IR signature emulation was the addition of water jackets to these plastic targets to replicate the thermal mass of actual thick armor. This technology provides both an affordable approach to improving the passive IR signature of existing plastic and a target that is easily supported on a test site. This program has successfully designed, built, and tested a passive IR signature augmented plastic target for a heavily armored vehicle.

With the design and construction process complete, field tests were conducted to verify the signature fidelity and structural integrity of the surrogate target. The validation test was a side-by-side comparison conducted with the surrogate and an actual threat vehicle in an identical environment. This paper presents IR signature validation procedures and validation results consisting of both long-term thermocouple data and diurnal thermal imagery.

INTRODUCTION

The Targets Management Office (TMO), Project Manager for Instrumentation, Targets, and Threat Simulators (PM-ITTS), U.S. Army Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI), is responsible for the development of ground targets for weapon system testing. Customers testing new weapons that employ intelligent seekers require ground targets that have visual, infrared, acoustic, and radar signatures that accurately emulate the threat. In order to accurately stress a weapon system's sensors, it is crucial to have a ground target that is a correct representation of the intended threat system. TMO manages the development, prototype fabrication, validation, and production of ground target surrogates to meet these requirements.

The Naval Air Warfare Center Atlantic Targets and Marine Operations of Patuxent River Naval Base has developed a variety of plastic, full-scale, vacuum-formed targets. The targets are created from 5/32" thick Acrylonitrile Butadiene Styrene (ABS) plastic sheets. The plastic is available in either olive drab or desert sand and can be painted in camouflage colors. The vehicles are usually mounted on skids and can easily be towed behind a pickup truck. Visually, these targets are an accurate representation of the actual target for which they are modeled after for most applications. The effort described in this paper augmented the T-72 main battle tank plastic target to simulate the passive diurnal IR signature of an actual T-72.

The overall development process of a full-scale plastic target is depicted in Figure 1. The IR signature augmentation process involves the addition of internal water jackets to the plastic shell to replicate the heat capacity of the thick armor of the T-72. If the heat capacity of components of the actual vehicle is replicated properly, the target will have a thermal signature over the diurnal cycle that is close to an actual T-72's thermal signature. A detailed description of the plastic target augmentation process has been previously published[1] as well as the basic design and physics of water jackets[2].

The plastic target design process begins with design trade studies to determine how the water jackets will be designed to meet signature and manufacturability requirements. A structural analysis is then conducted to check that the sub-structure will adequately support the additional weight of the water. Third, to reduce risk a signature analysis is preformed to predict the

signature of the augmented plastic target, and simulated signatures of an actual T-72 and the plastic T-72 are compared. If the predicted signature of the plastic target is sufficiently close to the actual T-72 signature the initial design phase is concluded. If not, the design is refined until the simulations show that the plastic target will meet signature requirements.

After the initial design is complete, limited field-testing is completed to validate the physics of the process. A single part of the plastic target is selected and instrumented with thermocouples and placed next to an instrumented T-72 in a natural environment. Temperature data is collected and design modifications are made to the water jackets based on this initial design evaluation. With all of the modifications implemented, a full target prototype is assembled. The prototype target then goes through an extensive signature validation. The focus of this paper will be on the results of the full vehicle validation test. After close analysis of the validation data, any remaining design modifications can be made before the vehicle is ready for final production.

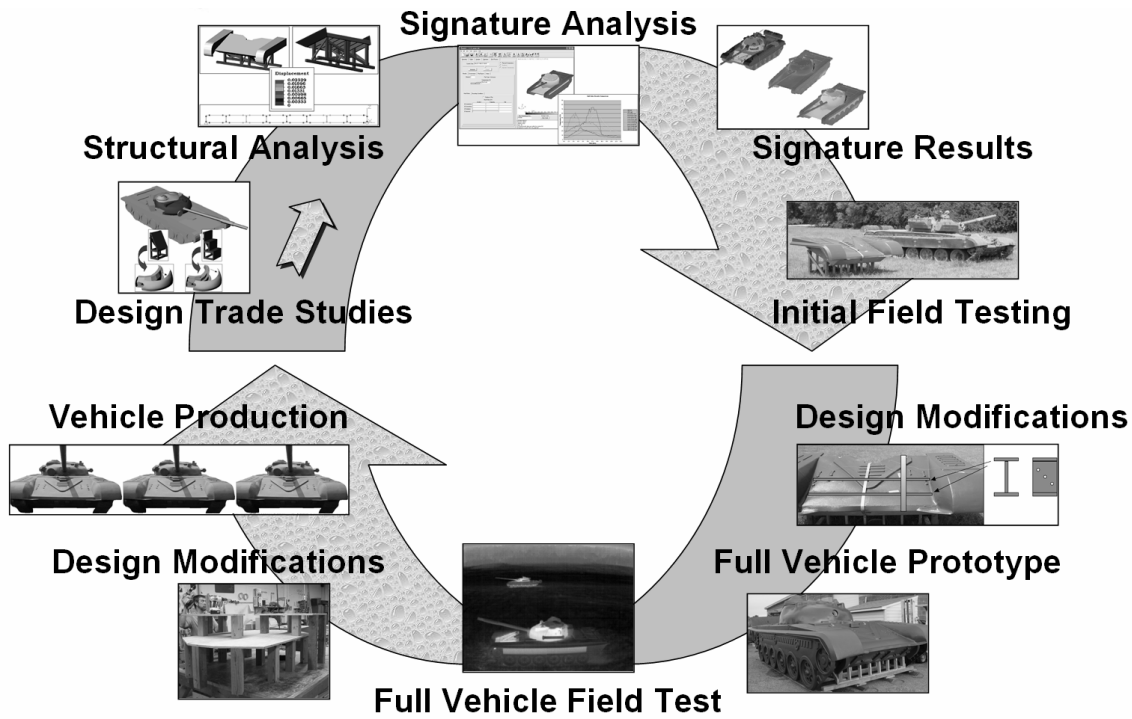

Figure 1: Plastic Targets Development Process Overview

VALIDATION TEST SETUP

The validation test setup consists of a series of steps taken to minimize uncertainties in the validation data and insure the best validation test data possible. The first step of the validation setup is to select an actual T-72 to be used in the test. Since there are numerous variants of the T-72, it is important for validation purposes to select a target similar to the target after which the plastic T-72 was modeled. Unfortunately, the existing plastic T-72 was designed as an early model T-72, with none of the later T-72 modifications such as track skirts and glacis armor modifications. The actual T-72 used in the validation test was a T-72M with accessories and modifications not present on the plastic target. The selected T-72 had similar green paint to the plastic vehicle and the exterior was washed so that any mud obscuring the paint was removed.

The validation test can be divided into two separate components. The first component is the collection of long-term temperature data of particular surfaces of interest using thermocouples. The second component involves the collection of multi-aspect, calibrated IR imagery with cameras in both the 3-5μm and 8-12μm bands. The nature of both the thermocouple and IR testing requires that the targets be measured simultaneously with both targets at thermal equilibrium in the same

natural environment. Figure 2 shows the validation test setup. Both targets were placed in a field with the front of the target facing south. The targets are close enough to each other that they experienced identical weather patterns, but are far enough away so that they didn't cast shadows on each other or have any other conflicting influences. The water jackets of the plastic target were filled and allowed to reach thermal equilibrium with the ambient environment before any testing began.

The thermocouple validation data was collected for multiple weeks so that the long-term diurnal characteristics of the plastic target could be compared to the actual vehicle. The thermocouple testing required a pair of thermocouples to be bonded to the following sections of each target: lower glacis, middle glacis, upper glacis, glacis I-beam (water jacket only), port fender, lower turret front, middle turret front, upper turret front, turret top, turret rear, and gun barrel. The redundant thermocouples in each location provide redundancy and minimize the possibilities for error by checking that the two track each other closely. Once the thermocouples are attached and connected to the data loggers, they are allowed to continuously record data on two-minute intervals for multiple weeks. Weather data is also collected for this period so that the thermocouple data can be compared to the weather trends to see how each vehicle performs in various weather conditions. The lower part of Figure 2 shows the thermocouple placement on each vehicle. No major performance anomalies appeared after initial investigation of the thermocouple data, and therefore the diurnal IR signature collection could then be executed.

Figure 2: Target setup and Thermocouple Locations

The IR testing was conducted over the course of a day to properly characterize the diurnal performance of the plastic target. Testing began before dawn at 05:00 and ended post-sunset at 23:00. Images were collected at multiple aspects on both targets once every hour during this period. Images were collected at elevations of 17° and 30° from the horizontal and azimuths of 0°, 90°, 180°, 270°, with 0° looking at the front of the target and progressing clockwise around. Data was collected using an Amber 3-5µm and an Indigo Merlin 8-12µm and both cameras were calibrated with external blackbodies prior to each collection.

VALIDATION RESULTS

Once the data from the field tests is collected, the next step is reduction and analysis of the data. The outputs from each pair of thermocouples are compared to make sure the two tracked together. This helps to insure the temperature readings are valid and that one individual thermocouple didn't experience technical problems. Once it is confirmed that the thermocouple pair tracks together, one of the data sets from each pair is used in the comparison between vehicles, and the data from each of the corresponding locations on both of the targets is plotted. Figure 3 shows thermocouple data for the fender and the glacis of both the plastic and actual T-72. The fender data in Figure 3 demonstrates how 5/32" ABS plastic is a good thermal surrogate for the three millimeter steel sheet metal, which is commonly used for fenders and storage boxes on armored vehicles.

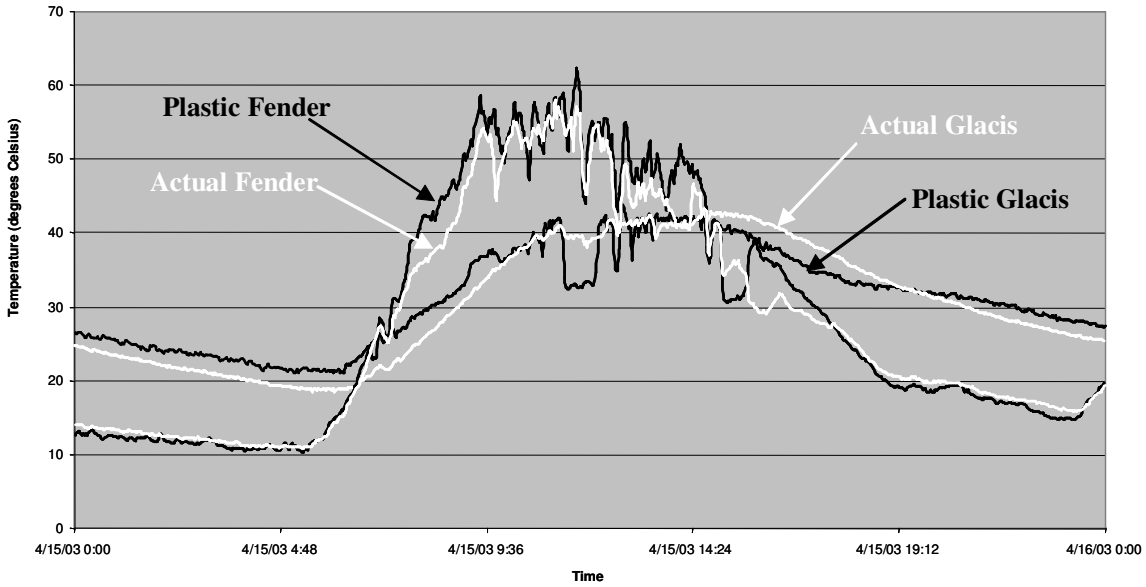

Figure 3: Plastic and Actual T-72 Fender and Glacis Thermocouple Data

The initial analysis of the IR signature data consists of calculating the plastic and actual T-72 mean temperature throughout the day to provide information about total target signature and target to background delta-T. Figure 4 shows the mean temperatures for both targets throughout the day from a frontal aspect. To generate the data, each target is outlined and the mean temperature is calculated for the selected area. This comparison process is completed for each aspect and time of day throughout the entire collected data set. As can be seen in the figure, the plastic target has the same general size and shape of the actual T-72 as well as the same general thermal contrast throughout the day. The top image pair demonstrates how the water jackets retain significant amounts of heat from the previous day all the way until dawn of the following day. The second image pair demonstrates the thermal lag of the water jackets as the thinner target components heat up due to solar loading in the morning, and the third image pair shows the washout of the vehicle signatures as the thermal crossover point is approached later in the day. The final image pair once again shows how the water jackets retain heat after the sun goes down while the thin fenders cool off rapidly.

Target mean temperature vs. time of day data is presented in Figures 5 and 6 for frontal and right side aspects. As can be seen in the figures, the mean target temperatures are very close at nighttime, early in the morning, and late in the afternoon. This result was expected in that previous work has shown that the thicker the water jacket, the poorer its performance in late morning and early afternoon[2]. This phenomenon is due to the lower thermal conductivity of water as compared to steel in that water cannot conduct heat away from the solar-loaded front surface of an object as well as steel. This causes the outer

surface of a plastic water jacket to have higher temperatures that thick steel during periods when the solar loading is rapidly changing. While the water jackets perform less well during the day than at night, they still provide the correct thermal contrast inversion during the day and greatly enhance the passive IR signature of the plastic T-72.

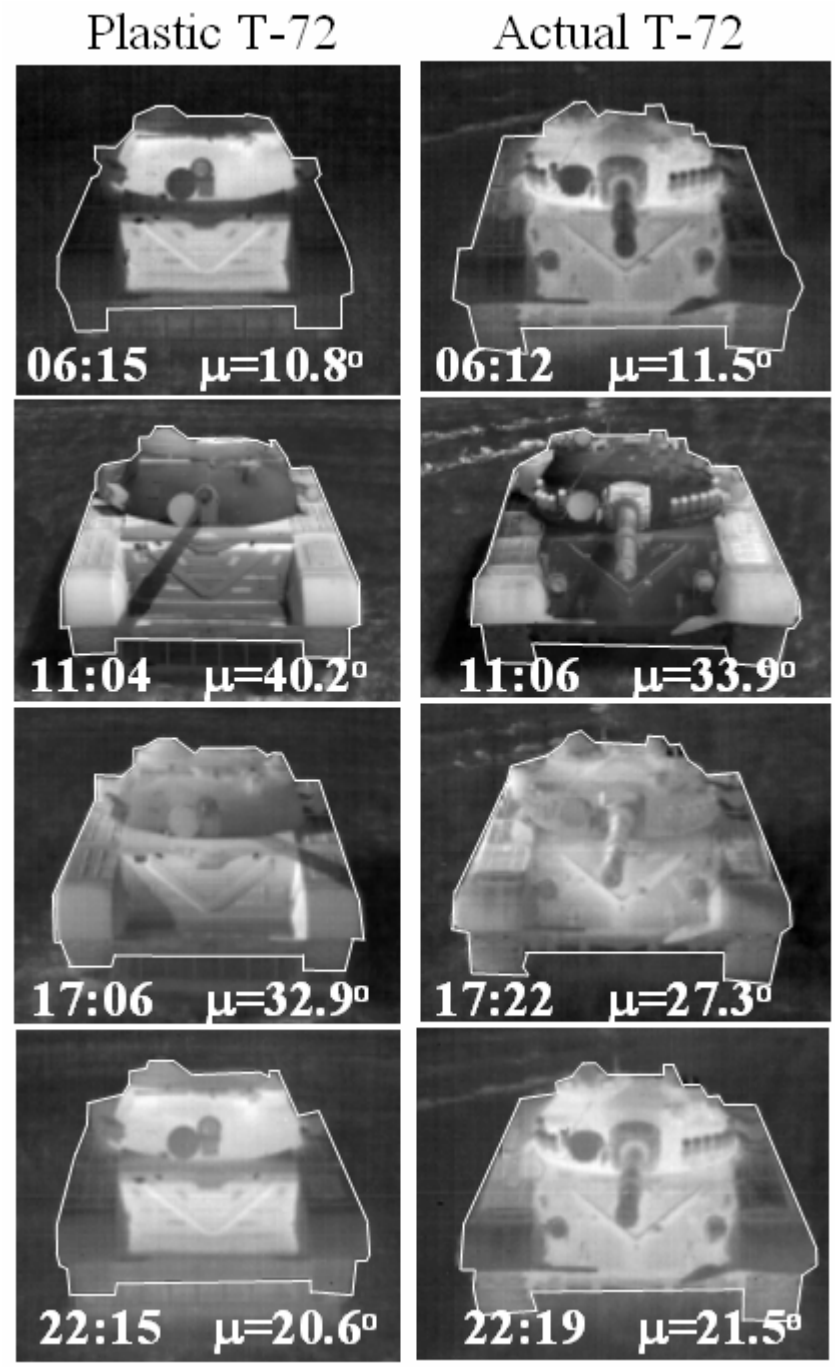

Figure 4: Target to Background ΔT Comparisons

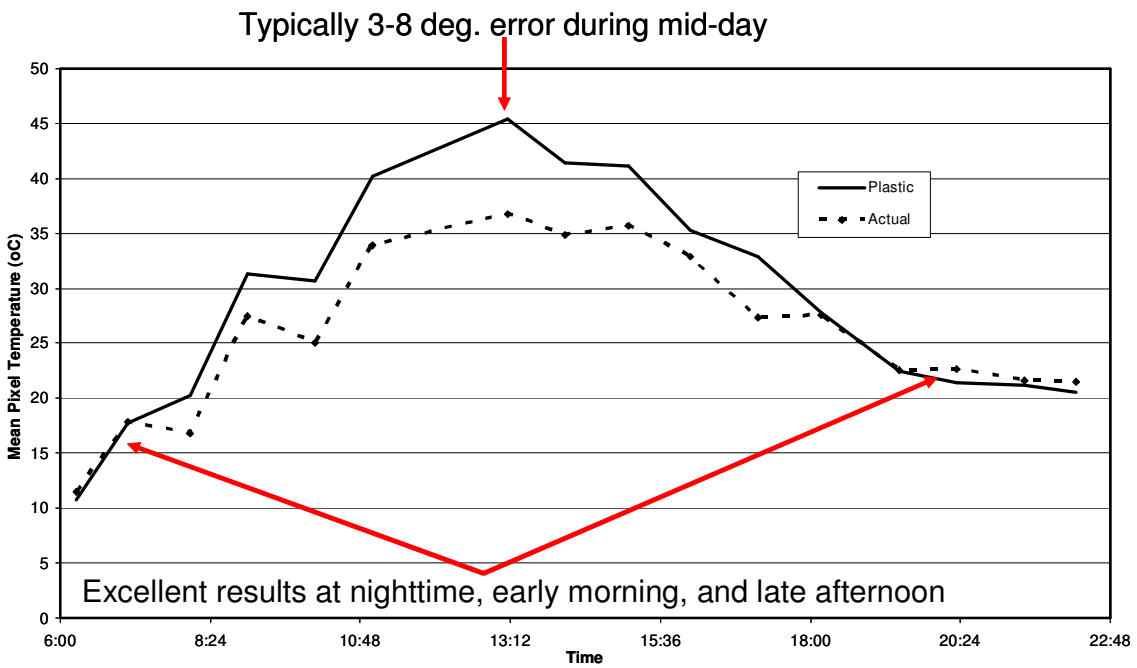

Figure 5: Plastic vs. Actual T-72 Diurnal ΔT Data, 0 degrees Azimuth (Front), 17 Degrees Elevation

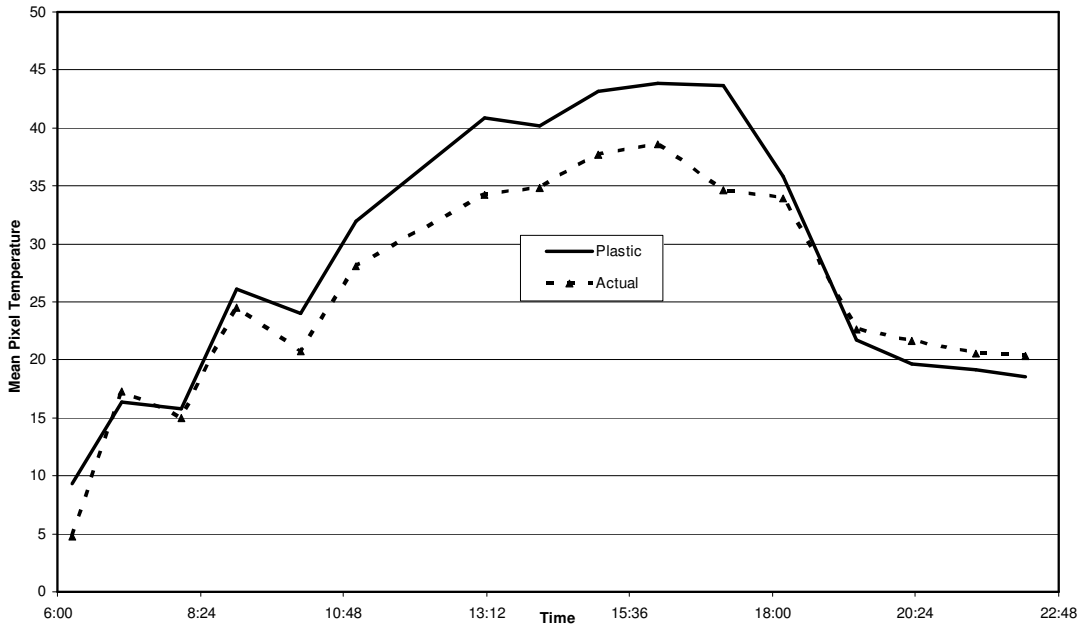

Figure 6: Plastic vs. Actual T-72 Diurnal ΔT Data, 90 degrees Azimuth (Right Side), 17 Degrees Elevation

In addition to the target mean temperature analysis, a detailed region of interest (ROI) analysis will be completed that compares specific plastic target components to the corresponding components on the actual T-72. A numbered parts tree is generated categorizing these areas of interest and the target surfaces are divided into approximately 20 ROIs. Each area is

labeled and the mean temperature of that area is recorded. This process is completed for both vehicles for every ROI at each time step. The left side of Figure 7 shows how the areas are defined and labeled and the right side of Figure 7 shows an example of how the ROIs are selected from the thermal imagery.

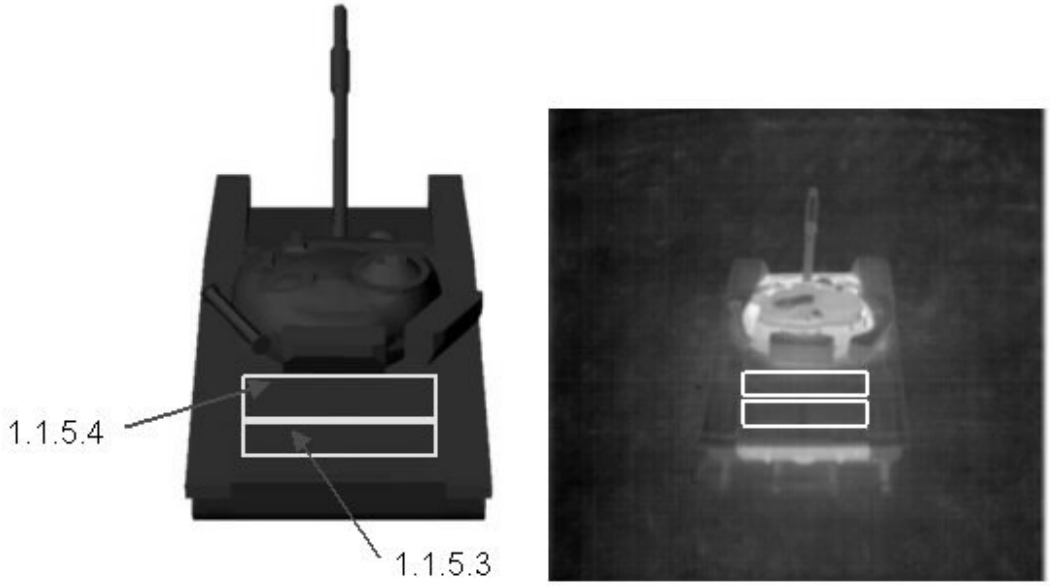

Figure 7: Region of Interest Example

In order to discuss thermal signature fidelity in the proper context, the reader must be reminded that the purpose of the augmented T-72 plastic target is to provide an inexpensive, easily maintained surrogate target for use on test ranges. The plastic target is designed to be both visually and thermally representative of the actual threat system when viewed from tactical ranges. One of the inherent benefits of using the water jacket approach is that the plastic target will simulate the passive thermal signature of the actual vehicle in all weather conditions at all times of the day and night without any operator control required. However, it is important to note that when viewed at very close range such as in the validation imagery, there are many apparent differences between the plastic target and actual vehicle that would not be apparent for its intended use. Figure 8 shows a thermal image of both targets from approximately 500 feet that was collected with a wide field of view thermal sensor. The target on the far left is a plastic ZSU-23-4 manufactured using the same process as the T-72 plastic target. The plastic ZSU-23-4 is 5/32" ABS but with no water jacket augmentation. The middle target is the actual T-72and the right target in Figure 8 is the plastic T-72 target with complete water jacket augmentation. As seen in the figure, the plastic ZSU-23-4 heats up uniformly during the day with no contrast indicating thin and thick armor. During a clear day, the ZSU-23-4 plastic target could be identified as a target-shaped object, but after sunset or in inclement weather it is a dark object that thermally blends into the background in a manner not representative of an actual armored vehicle. The plastic T-72 with water jackets both visually represents an actual T-72 and possesses the thermal signature of an actual T-72 at all times of the day as was seen in Figure 4. Figure 8 demonstrates that the addition of water jackets has enhanced the passive thermal signature of the T-72 plastic target to the point where it can be considered for use in testing thermal sensors. The final assessment of the signature fidelity of the augmented T-72 plastic target will have to be done by each potential user and a signature validation report will be available with sufficient data for potential users to perform an evaluation.

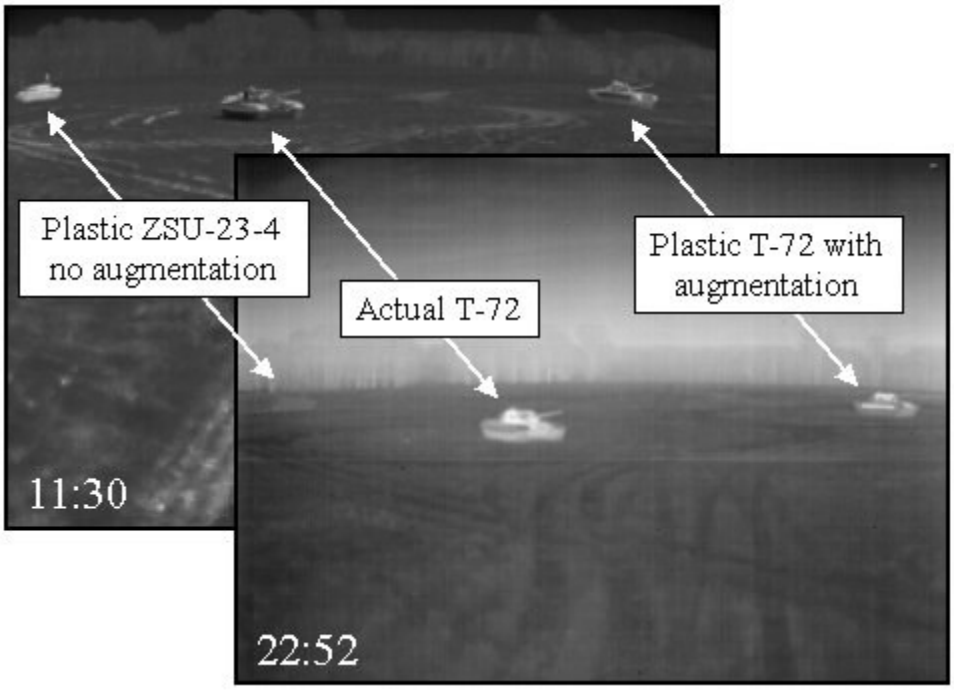

Figure 8: Day and Night distance comparison

CONCLUSIONS

This paper presented IR signature validation procedures and validation results for the T-72 plastic target with passive IR signature augmentation. Initial analyses have shown that the process of augmenting the plastic T-72 with water jackets was successful in greatly enhancing the diurnal IR signature of the plastic T-72. The augmentation was most successful at nighttime as expected from previous results, but even the worst diurnal results with the water jackets demonstrated a significant enhancement of the passive IR signature of the plastic T-72. Detailed validation results and analyses will be included in a formal validation report. The validation report will be available for potential users to access whether the T-72 augmented plastic target meets their particular sensor testing needs.

REFERENCES

[1] Gebus, L.M., and Sanders, J.S., "Passive Infrared Signature Augmentation of Full-Scale Plastic Targets", *Proceedings of the Thirteenth Annual Ground Target Modeling & Validation Conference*, Houghton, MI, August 2002.

[2] Sanders, J.S., and Wible, W., "A Novel Method for Enhancing the Passive Infrared Signature of Target Surrogates", *Proceedings of the Sixth Annual Ground Target Modeling & Validation Conference*, Houghton, MI, August 1995.