

FCS Signature Modeling SDD Demo

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ABSTRACT

Ensuring Survivability is major thrust of the Future Combat System (FCS) and is one of the key performance parameters (KPP). The lighter vehicle platform mandates that surviving will take an innovative integrated solution between situational awareness and the usual survivability onion approaches of detection, hit, and penetration, and kill avoidance. The FCS Signature Management Science and Technology Objective (STO) has been working for two and a half years to address the technologies and tools to help aid in determining an integrated survivability solution. Specifically, the STO has attempted raise awareness of signature modeling and metric deficiencies and the need for a virtual field test capability, as well as performing R&D to improve existing signature models to address the needs for FCS. As FCS begins the System Design and Development (SDD) phase, this paper reports the demonstration of the virtual field test capability as it stands today and what lies on the horizon.

INTRODUCTION

Signature Management has been in pursuit of its own Holy Grail for over a decade. The sometimes seemingly unattainable goal is the capability to virtually “test” or predict the performance of vehicles and treatments in a virtual world. This goal is desirous because field testing for Signature Management is ripe with frustration and even at its best, yields limited results. This is largely due to the fact that determining whether something has a “good signature” or not is exceptionally challenging, since there is a lack of robust measurable metrics and the conditions under which one would have to test in order to confidently determine goodness is considerably large, yet still undefined.¹ If one could test synthetically, at least there would be the opportunity to control the environment and conduct repeatable tests under numerous conditions.

Progress has been made as computational power and computer science improve, but the community has not yet embraced any simulation as being able to match nature (here defined as “scenes as viewed through human eyes or eyes through sensors”). One might ask “when will we know it is good enough?” and this is a legitimate question. The difficulty in answering this question lies with the understanding that the process (comparing acquisition using synthetic scenes to natural scenes) is nearly impossible to validate under the normal understanding of that word, due to the aforementioned lack of robust or standard metrics of signature management “goodness”. We need metrics to measure in order validate goodness. No standard metrics-no standard validation.

Science is not completely in the dark when it comes to human observation however, and thankfully we always have the ability to use human observers themselves in experimentation to help determine goodness of a virtual field test. This paper

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outlines the development of partnerships and the tools that will help create such a synthetic field test process and offers a proof of principle of using human observers to gather metrics.

THE SCIENCE AND TECHNOLOGY OBJECTIVE

The STO under which this work is being done is the III.GC.2001.01 FCS Signature Management STO. It is divided between improving signature management technology and signature Modeling and Simulation (M&S) in support of that technology. The specific goals of the M&S side of the project can best be described as follows:

1. Goal: Provide FCS vehicle developers with integrated Signature Management virtual prototyping tools to optimize the basic signature of all FCS concepts. (*per ORD and Specs*)
2. Provide capability to develop and determine effectiveness of advanced signature technologies prior to physical prototyping. (*per LSI*)
3. Provide robust scenario specific signature data for operational models and Modeling Architecture for Technology and Research Experimentation (MATREX). (*critical AMSAA and RDECOM identified priority respectively*)

The barriers to carrying these tasks out are:

- Modeling and Simulation has not kept pace with low observable technology
- Current signature management virtual prototyping tools take too long to prepare the model.
- Visual and IR metrics are hard to quantify
- Pervasive mistaken impression that a system has a single “signature” that can be quantified.

These are ambitious tasks requiring expertise in several areas in order to overcome the barriers. No one organization has that expertise (or money). Therefore, the path to success relies on bringing together the knowledgeable organizations and support contractors using principles from the SMART (Simulation and Modeling for Acquisition, Requirements, and Training) community ²and leveraging dollars from multiple sources. The history as outlined in the table below shows that this has started and continues today. In addition to the Survivability Technology Area at TARDEC who is providing the vehicle integration and thermal and visual modeling experience, the Night Vision Electronics and Sensors Directorate Modeling and Simulation group is on board as the sensor modeling and acquisition experts. ARL’s Sensors, Materials, and Computer Science Directorates are on board officially (it is now a joint STO) to add their expertise in each of those areas and the Army Test Center is now involved to cover the testing aspect of the project. AMSAA is engaged to help define the validation of the M&S and data gathering processes. And the Air Force and Navy are aiding in M&S development and procedures in Radar and Thermal respectively. The list of collaboration grows as industry and international partners are brought in to participate in the STO goals and the partners are leveraging program dollars, Small Business Innovation Research (SBIR) Dollars, and Common High Performance Computing Software Support Initiative (CHSSI) dollars.

Table 1 shows a brief history of this effort; from the beginning of the Army Science and Technology Objective (STO) that spawned the effort up to the demonstration.

Oct 99	FCS Signature Modeling program is established by Army under FCS Signature Management Science and Technology Objective (STO).
June 01	ARL/ TARDEC Collaboration begins informally. ARL leads materials, work, HPC utilization, and electromagnetics (EM), TARDEC takes on vehicle integration issues, Visual and IR Modeling. Acoustics is shared.
Aug 01	STO briefed at the Ground Target Modeling and Validation Conference. Outlined top needs as better metrics, better physics (like BRDF) and an overall synthetic field testing ability.
Apr 02	NATO group investigating synthetic scenes for use in Camouflage Concealment and Deception has first meeting. STO begins search for candidate synthetic rendering capability based on info at meeting. STO collaboration with Navy NSWC, ONR, and NRL is discussed in a meeting hosted by ONR.
Apr 02	NVEDS informally enters collaboration with STO (TARDEC/ARL/NVEDS). Will provide sensor modeling and use of Paint the Night to supplement IR modeling capability.
Aug 02	After deliberations, decision made to fully investigate UK Cameo-Sim as a candidate code. Boeing, as part of the FCS Lead System Integrator LSI briefed. Gives endorsement of STO’s definition of M&S needs and plans to address them.
Sep 02	Broad Agency Announcement (BAA) placed by Army Test Center for synthetic field test capability (unknown to Sig Man STO).

Table 1. The History of the Project - table continues on next page

Nov 02	Teresa Gonda, principal investigator for FCS Signature Modeling under the STO, and member of the US/UK AFV Working Party in the signature area, becomes chair of earlier mentioned NATO group. The fact that the goals of the groups overlap leads to a strong US/UK collaboration and discussion begins on a Project Agreement.
Dec 02	First Phase Demo and training of Cameo-Sim proves successful. Begin parallel path of evaluating use of UK Cameo-Sim, while improving portions of it to allow for a final evaluation. Demo for FCS SDD planned for Aug using Cameo-Sim and NVESD's Paint the Night.
Mar 03	ATC and TARDEC meet and discuss work planned for BAA and STO to help reduce redundancy. ARL joins the STO formally and it is now a joint STO. NVESD continues as an informal partner. Navy DDX program decides to use MuSES and funds improvements.
Jun-Aug 03	Concepts developed, CFD analysis run, MuSES runs completed, experimental synthetic scene ported to Cameo-Sim, thermally predicted targets inserted into Cameo-Sim and Paint the Night, observer experiments performed on Paint the Night imagery. Progress review Joint MuSES meeting between TARDEC and Navy. Collaboration between AFRL and STO begins.

Table 1. The History of the Project.- Table begins on previous page.

STO APPROACH

Above, we outlined the goals of the synthetic field test and some of the barriers to achieving those goals. We also mentioned that part of the approach to solving the barriers is to bring together a team of expert organizations to attack different aspects of the problem. Let's look at each of the issues individually.

Modeling and Simulation has not kept pace with LO Technology

Even though we lack exact metrics to tell us what specifically we need out of our modeling and simulation, subject matter experts agree to some extent on the areas, if not the specific level of fidelity³. An example list of areas that still need addressing to some extent in state-of-the-art simulations include the handling of bi-directional reflectance (BRDF), plume modeling (including computational fluid dynamics (CFD)), target-to-background interaction, and path radiance modeling in visual and thermal codes. Parallelization of codes in all signature areas and better fidelity in the 94+ GHz in electromagnetic modeling are also hot issues. To some degree all of these weaknesses are being addressed under the STO, via SBIRs, and through the Army Test Center's (ATC) Broad Agency Announcement (BAA) (see table above). TARDEC, ARL, ATC, and NVESD are working together to enhance thermal models, radar models, and visual models to account for the physics needed to address today's and tomorrow's technology.

Current Signature Management Virtual Prototyping tools take too long to prepare the model.

It is a well known paradigm in this area of modeling that often 80-90% of the time is spent in preparing the model and the remaining time is spent on the actual runs and analysis. The STO developed a capability for those with Pro/Engineer ProMesh to be able to create a MuSES .TDF files from within Pro/E and read the results back in to Pro/E. For those without Pro/E or ProMesh and for those who cannot afford an expensive meshing tool, we developed Eclectic a tool that aids in massaging existing meshes into clean meshes for use in the analysis. A SBIR topic, currently in Phase I status, will be looking at attempting to provide meshless solutions. There are two contractors who will be looking at two separate approaches to this difficult problem. TARDEC has taken on this task and is cost sharing with partners in the auto industry.

Visual and IR Metrics are hard to quantify

For too long, the signature community behaved as if it was a cohesive group with identical needs and viewpoints. In this climate, a metric that was developed to determine goodness of sensors⁴ was assumed to be able to be flipped around and be used to determine something about the sensor's target and signature performance of a system. Allowed to develop, was the idea that for any system, there was a typical or average signature. Even after proof to the contrary^{5,6}, this assumption continued until very recently¹. Approximately two years ago, work began to replace the old Acquire model within CASTFOREM to better predict the performance of specific targets in addition to sensor performance (see below). Additionally, in order to help focus the research even further on target performance specific metrics, ARL hosted a metrics symposium in August 2003 on the topic of Complex targets in Complex Backgrounds. Experts from industry and academia were brought in to listen to the Army's problems and discuss potential ways forward. An edited transcript will be produced from this workshop and several candidate approaches have been identified for initial research. What is needed are a series of experiments designed specifically to address the problems of acquisition that the Army is facing. This work is not funded at this time and continues to be a serious knowledge gap. In the next year, some limited metric work will be funded that can aid in the confidence building of synthetic scenes, which will be useful, but will not

necessarily link to quantifiable “goodness” measures of signature treatments. ARL has taken up the lead in this area and together with NVESD and TARDEC and of course AMSAA will continue to push for funding to address this knowledge shortfall.

As mentioned earlier, work was initiated to improve the acquisition metric within CASTFOREM. Work was completed that replaced the simple Delta-T value (Ttgt-Tbkg) with the Delta-T RSS⁷ metric ($\sqrt{(T_{tgt} - T_{bkg})^2 - \sigma^2}$) to give a more accurate representation of vehicle texture. This approach is still new and is undergoing sensitivity analysis and therefore not widely known or understood. A series of sensitivity experiments need to be run to better understand the impact of differing values on the outcome of scenarios. This work has begun, but is not well defined at this time⁸.

Pervasive mistaken impression that a system has a single “signature” that can be quantified.

There still exists among respected simulationists, the mistaken impression that a vehicle has a representative or even average signature¹. An effort lead by the Army Material Systems Analysis Activity (AMSAA) and supported in part by the STO activity has lead to a report that outlines a new understanding of what needs to occur when populating a database for CASTFOREM runs⁹. In addition, the Lead System Integrator and the PM FCS office have determined that modeling values for specific CASTFOREM scenarios using programs such as the Multi-Service Electro-optical Signature code (MuSES) is how it plans to proceed.¹⁰

THE SYNTHETIC FIELD TEST IDEAL

We have discussed the need for a synthetic testing capability and the status of some of the issues surrounding such a capability. Let us now take a look at an ideal synthetic field test tool. Ideally it would:

- Produce images that would inform us of the fidelity required for specific types of experiments
- Provide data to research the number of different types of scenarios needed to fully understand a vehicle’s vulnerability or a treatment’s full effectiveness
- Provide images for perception experiments

The capability would allow users to take geometry and assign material properties to the geometry (that would affect a given signature), the systems would be placed in predetermined scene locations optimized for overall performance understanding, and the images would then be assessed for goodness in some manner and design iterations could then occur.

The image below depicts a flowchart of the current capability as it stands today in visual and thermal.

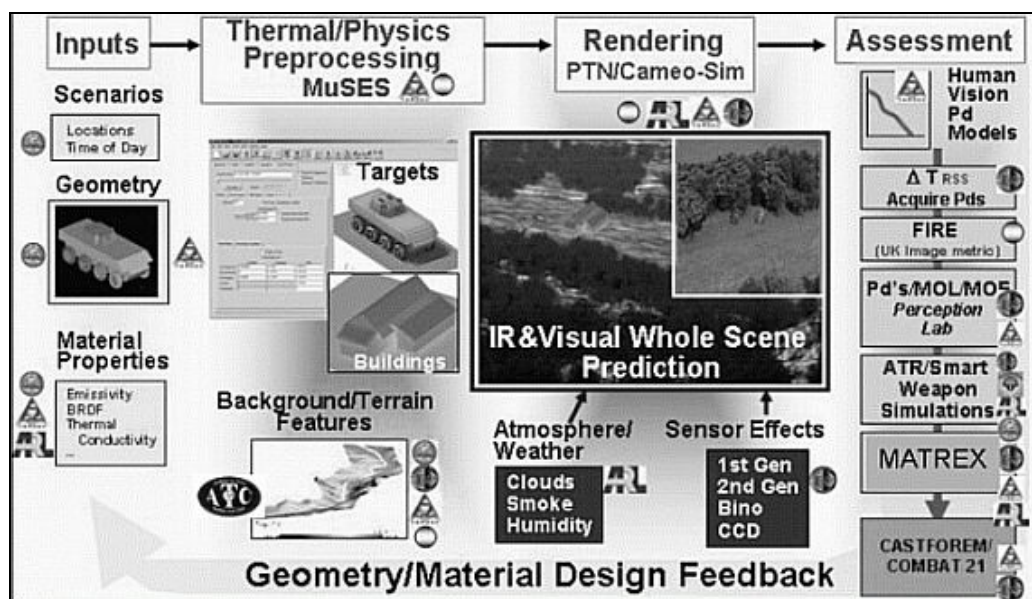


Figure 1 The Synthetic Field Test Capability

We are currently able assign properties to geometry for thermal, visual, and radar models. For thermal we process the file through the MuSES for a detailed thermal analysis. Some design iterations can occur at this point before insertion into a scene. Then in IR and Visual, we have an initial capability that allows us to put vehicles into a scene and then perform assessments on those images. Now, organizations have been doing this in one form or another for some time. The breakthrough of this current process is that the following factors are being addressed.

1. Photo-realism is the goal, not rendering time or real time capability
2. Physics realism is the goal over photorealism that “looks good” (i.e. artistic based commercial rendering tools)
3. The goal is an adjustable level of physics reality. In other words, a simulation can say it is physic’s based because it accounts for sun angle and emissivity and atmosphere. How a model does that and the resolution with which it addresses those aspects can be dramatically different from one to another and depending on what one wishes to achieve with the simulation, one approach can yield correct results while another may not.
4. The simulation is being built with the thought of being able to predict signature performance from a target-centric aspect in addition to sensor-centric. Allowing for adjustable calculations in the prediction make this possible.

DEMO

Since we are in the early stages, the capability as described by the flowchart is only in its initial phase and is not able to achieve every aspect of vehicle terrain interaction (automatic plume heating of the ground and asymmetric BRDF) or atmospheric and sensor effects or assessment. In addition, while one of the current synthetic scene capability Cameo-Sim (by the UK company INSYS) is 3-dimensional and every blade of grass and leaf exists in 3D, the scene is not rendered using fully first principles for every single blade of grass. However, FCS is in need of the capability today and in its current state, there are work-arounds to achieve these many of these effects. Some of the plume elements on the ground can be handled in MuSES and passed along to Cameo-Sim as part of the vehicle prediction. In rendering fidelity, assumptions are made to accommodate the limited rendering capabilities of current computers. One way in which we can address some of these issues today is that when we believe it does matter that first principles need to be used at a certain range, we can allow the model to do so, but make expert judgments on what ranges might be too long for the eye to resolve artifacts that might occur. In the meantime, ATC has funded an effort with Signature Research that is attempting to break this limitation.

In order to demonstrate to FCS the current capability, we developed a mock exhaust study that would walk through each step as it exists today.

- A generic future concept vehicle with the exhaust in 3 different positions developed in Pro/E
- Converted into MuSES.
- Run in MuSES, CFD runs using Fluent. MuSES and CFD runs linked. Final MuSES runs.
- Import the MuSES predictions into Paint the Night (PTN) and Cameo-Sim
- Render in a generic scene in visual and IR
- Leverage existing PTN soldier perception experiment schedule to demonstrate potential metric analysis of systems.
- Show potential analysis of data

Caveat: All data, throughout process, while realistic in concept, has been purposefully steered away from being “real” for security reasons. Also, while plume effects are shown, actual plumes are excluded.

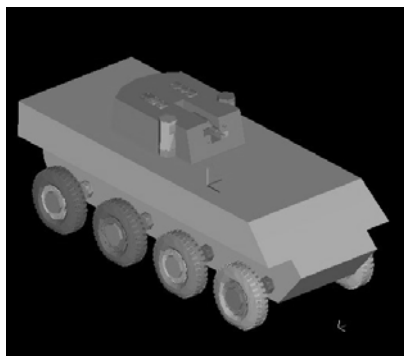


Figure 2 Pro/E model of generic future concept

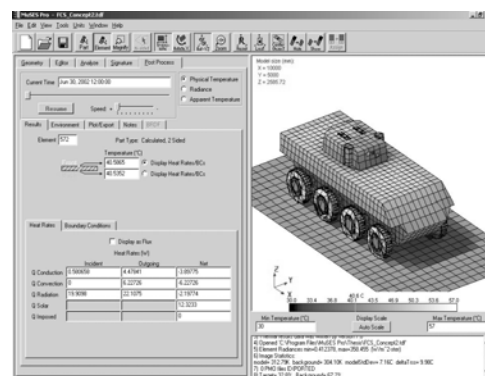


Figure 3 Concept input into MuSES

As figures 2 and 3 show, the concept vehicles successfully transfer into MuSES. The geometry for each of the different exhaust configurations were done in Pro/E so that three concepts were converted into MuSES. Next, Fluent runs were completed and the results were linked back into MuSES (a recent feature) and a final MuSES prediction was completed for a particular time of day, day of year, and location in order to attempt to match the synthetic scene predictions. Figure 4

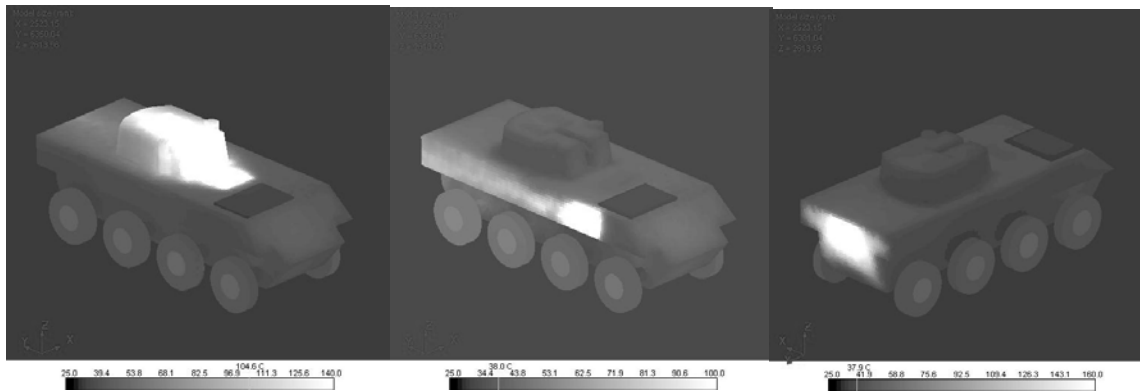


Figure 4 The MuSES predictions of the 3 concepts

shows the results of the MuSES predictions with the Fluent fluid flow effects. Since the scene and target are not linked and the system is not automated. Specific choices were made to determine wind speed, vehicle speed, and direction in order to make a prediction. The usefulness of the tool is already apparent even without the synthetic scene in that it brings full visualization to the impact of exhaust placement in a way that a discussion between engineers cannot. In these particular images the darker square is the cooling air intake grille which was also included in the simulation. Take note that the scales are optimized for each image and are not identical. The low end is 25°C for each but the upper value is 160°C on the left, 100°C in the middle and 180°C on the right.

Next, the MuSES .TDF files were imported into the candidate synthetic scenes. Both scenes are using a generic database created (LaLa land) for these types of analyses. Figure 5 shows some example scenes from this database in Paint the Night

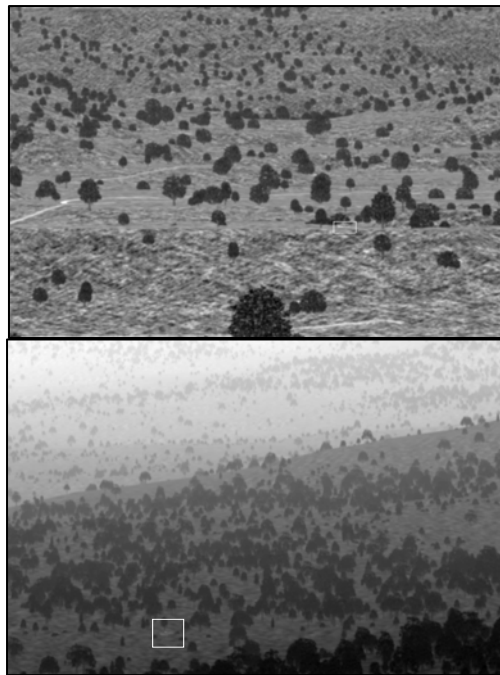


Figure 5. Example PTN imagery used in experiments. Figure 6. PTN image with all three concepts shown.

(PTN) while figure 6 shows the three concepts placed in a spot in the LaLa land in PTN. PTN was developed for sensor model performance studies and is an interactive model (utilizing real time capability). As such, it has optimized its design from a sensor-centric perspective. NVESD and TARDEC are working together to help determine what this type of capability needs to include from each perspective. Future comparisons between Cameo-Sim and PTN and validation experiments will help steer the course in determining what, if any improvements need to be made to these models for their individual clients and tasks. Issues that still need to be addressed with regard to incorporating MuSES targets into PTN are working to ensure the syncing between the background prediction and the target prediction. Most likely, target-ground interactions will be handled via MuSES and input into PTN as one object (i.e. the ground around the target is included as part of the vehicle).

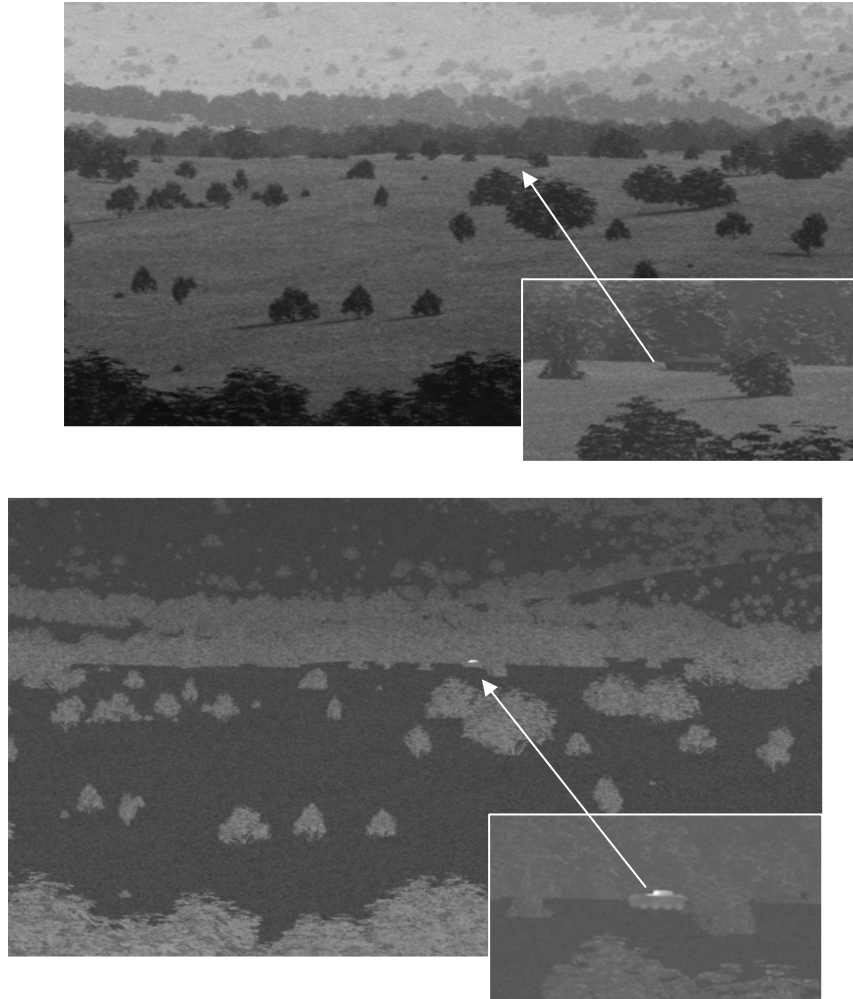
Cameo-sim is a code developed by INSYS of the UK for the UK MoD's Defence Science and Technology Laboratory (DSTL). The U.S. has held two training sessions and a demo session in order to evaluate the usefulness of the code for use in this country. As the history table describes, after evaluation, the decision was made to move forward with integrating MuSES with Cameo-Sim to take the evaluation to the next level. A feasibility study was conducted to determine how best to integrate the two codes and 4 stages were defined¹¹. Currently we have completed the first stage of integration. Users now have the ability to convert MuSES files and have them read by CameoSim. As in this demo, all syncing between environmental parameters must be done manually by the user and there is no thermal connection between the target and the terrain (there is radiometric exchange in the rendering process however). The second stage will have Cameo-Sim drive the environmental parameters for MuSES, the third stage will have the target see the terrain and the fourth will have the terrain be impacted by the target.



Figure 7. Example Cameo-Sim images.

Figure 7 shows some example Cameo-Sim imagery and explains why the U.S. was eager to evaluate its potential. Except for the bottom right image, the others are visual and show strikingly photorealistic images. The left two images are of the same location from different aspect angles to show the 3D nature of the database. After some investigation, it is clear that the even once the capability is available, that considerable resources will have to go into making the databases we desire for our

synthetic field tests. Database generation takes a balanced combination of scientist and artist to know how much detail and what kind of detail is important to convey a convincing scene as well as a physically reasonable one. For instance, numerically random grass generation will create an abnormal looking terrain, there are patterns in nature. An individual who understands the details of this more esoteric aspect of nature is needed, just as much as someone who understands bi-directional reflectance or heat transfer due to transpiration. Clearly, this is a challenging area. To address this, we are beginning the appropriate training now and looking to find the most qualified individuals available for such a task.



The figure on the left shows the concept vehicle inserted into Cameo-Sim in the visual (top) and the IR (bottom). There is a small inset showing an enlargement so that you can see the vehicle placement. Unfortunately in this black and white representation, the visual does not have as much impact, but much can be ascertained by the two images. Cameo-Sim can predict hyperspectrally (render narrow band images) or bands can be grouped as we see here into more common renderings (eyes and thermal camera).

As mentioned above, there is more work to be done on the target-terrain interaction, but if we wished to include part of the terrain as a part of the vehicle, these predictions can be made in MuSES and input into Cameo-Sim. In addition, plume effects are shown, but not plumes. This will not be addressed until the final levels of MuSES-Cameo-Sim integration.

Figure 8 Cameo-Sim images with concept imbedded.

The next phase of the demonstration requires that we apply sensor effects to these images and then assess them in some manner. NVESD has been involved in ongoing experiments using soldiers in perception tests using synthetic and measured imagery. Several images with the concept vehicles in various locations and varying angles were presented to soldiers in a perception laboratory experiment (subjects in front of calibrated monitors). Figure 9 shows some sample results of images shown to observers and some statistics. Given a sensor type, range, and aspect angle, the probability of the image being detected in the study is given. This data can be manipulated to show results by sensor, by angle, by range, and by exhaust placement and plotted using Microsoft Excel.

The next goal is to work with AMSAA to determine a feasible method to determine goodness of the process for comparing one treatment with another. This is a somewhat easier task than trying to determine the absolute merit of a synthetic scene. Validation efforts using image metrics are being performed now as part of the STO and as part of the NATO group efforts

described in the history table. We should at least be able to determine if significant aspects of measured scenes are accounted for in the synthetic scenes and if perception lab performance trends are the same.

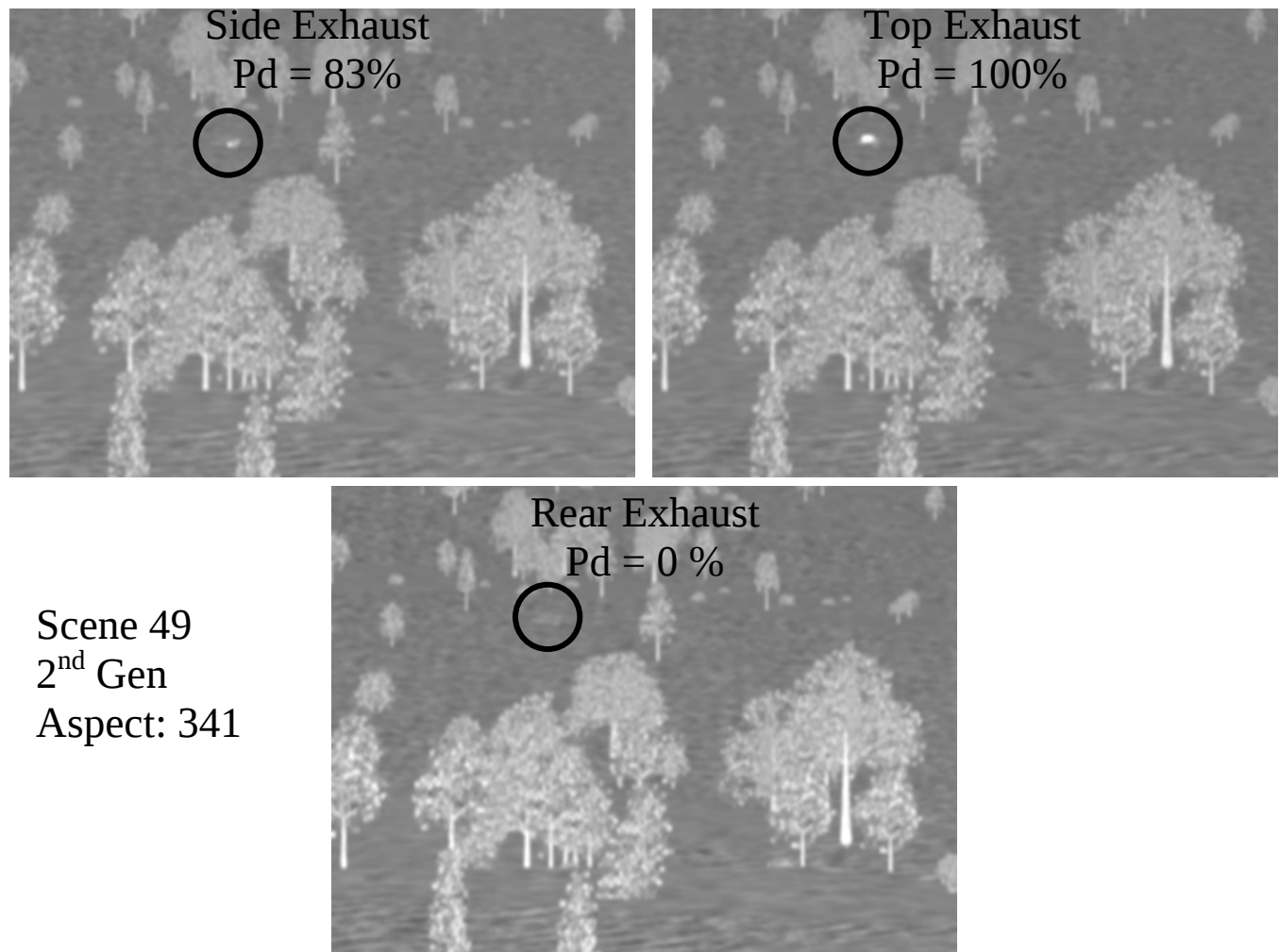


Figure 9. Example results from perception test

SUMMARY

The demonstration has proved out the feasibility of the capability as well as shown the status of the individual pieces and the integration or lack there of at this time. Today, we can take concept vehicles and give a good thermal prediction of their performance, we can then imbed the targets in thermal and visual synthetic scenes and analyze the images with image existing image analysis tools using Delta-T RSS metrics for instance or present the images in experiments to observers. As long as the scientists using the tools understand the current limitations, there is reason to believe the capability has a value even in its current state. The model integration and improvements will continue and are funded through the end of FY05. As identified earlier in the paper however, there is a serious knowledge gap with respect to understanding signature “goodness” and under what conditions it should be tested to give the decision makers the answers they really need. Some basic experiments need to be designed and executed to address these questions specifically.

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