How to avoid using stupid agents to train intelligent people

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ABSTRACT

Team training is increasingly conducted as distributed exercises blending live, virtual, and constructive players. But the benefits that distributed team training affords could be significantly extended if training were made available to individuals or teams on an as-needed basis. For individual and team training to be truly “on-demand”, three important requirements must be met: the training must be accessible when and where the user needs it; the presence of an instructor must be optional; and the presence of human teammates and adversaries must be optional.

In order to meet the challenges presented by on-demand team training, robust, verbally-interactive synthetic agents are required with capabilities that extend well beyond conventional computer-generated forces (CGFs), semi-automated forces (SAFs), and game-based “AI”s – largely scripted entities with limited abilities to respond to events beyond a predefined range of simple behaviors. These “AI”s, or any task- or frame-based agents, cannot model the real-world complexities necessary to provide training value.

Despite these limitations, new training initiatives driven by desktop gaming engines increasingly feature AIs, which can deliver eye-catching demos but fail to provide comprehensive training across a spectrum of required situations and behaviors. Training warfighters to be better decision-makers requires simulations that present the user with realistic problem-solving experiences; for promoting team coordination, simulations must present realistic dialogue and interaction. Cognitive agents provide more training value because of their ability to interact in realistic ways across a broad range of tactical situations and to verbally engage in dialogue with users (and with each other).

In this paper we present a systematic approach to creating agents of sufficient cognitive fidelity to provide training benefits that extend well beyond what is capable with limited, scripted agents, and present three example demonstrations of this approach in different training domains.

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THE ROLE OF AGENTS IN TEAM TRAINING

Software agents that emulate human performers increase the ability of simulation-based training to address team training requirements. Yet, these agents have historically played only limited roles in simulation-based training. Emerging technologies that help accelerate the engineering of human performance models make this approach ready for broader attention.

Conventional simulation-based training has received steady support from the military as a tool for providing opportunities to acquire and practice mission skills in a safe environment. The use of simulation has won broad support because of its ability to create specific environments and to present situations to users that may otherwise remain inaccessible, or at best infrequently accessible. The emphasis on the simulation training devices themselves has been on creating the best physical simulation of the actual environment as possible – focusing on the feel of the controls, layout of the instruments, and appearance of the external environment - factors that collectively we will refer to as *physical* fidelity. Simulation acquisitions are competed largely on the basis of how close a vendor can come to the “real thing” as measured by physical fidelity. The cost of these systems is balanced against the expected training benefit for mission-critical skills that can be effectively practiced utilizing such devices.

What has this discussion got to do with agents? For some kinds of training, criteria other than physical fidelity are needed to assess what aspects of the “real thing” are most relevant to skill acquisition and mastery. For instance, training warfighters to be better decision-makers requires simulations that present the user with realistic problem-solving experiences; for promoting team coordination, simulations must present realistic dialogue and interaction. Skills associated with the areas of decision-making, team coordination, and communication collectively demand what we will call *cognitive* fidelity. Such skills are assuming heightened importance as the military increasingly emphasizes teamwork as well as joint and coalition operations.

The role of agents is thus linked to the need for cognitively-realistic individual and team training. Joint and distributed exercises illustrate the military’s awareness of the importance of cognitive fidelity. Assembling teams of operators (co-located or distributed) in concert with an adequate supply of technical controllers, instructor/evaluators, and human role-playing confederates allows simulated engagements to be fought in synthetic battlespaces. Vendors of conventional high-fidelity simulators now offer networked, or linked trainers that multiple users can operate simultaneously in a shared synthetic battlespace, enabling the possibility of team training. Unfortunately, the potential reach of this powerful technology is severely constrained by cost, geography, and scheduling. The ability of high-fidelity simulators to provide on-demand team training, as defined below, is thus limited without the help of complementary technologies.

Intelligent, conversational agents thus support a central tenet of our work: the benefits that distributed team training affords could be significantly extended if training were made available to individuals or teams on an as-needed basis. For individual and team training to be truly “on-demand”, three important requirements must be met. First, the training must be accessible when and where the user needs it. For deployed forces, training must therefore be portable and readily accessible. Second, the presence of an instructor must be optional. Even for remote, networked training, arranging common meeting times between user and trainer establishes systemic barriers to on-demand training. Third, the presence of human teammates and adversaries must be optional. Providing team training to individuals currently requires that all teammates participate synchronously; even individual training exercises employ human confederates to act in OPFOR roles such as aggressor squadrons in tactical aircrew training exercises.

These three characteristics have important implications for how simulation-based training must be designed. For fully-accessible training environments, training should be deployable on low-cost, low-footprint computational hardware with minimal specialized equipment, carefully balancing the training requirements with the desired levels of physical, visual, cognitive and social fidelity. Instructor-optional training requires robust performance measurement, mission replay, and AAR, as well as learning management tools to help instructors define, catalog, and select scenarios. To accomplish team-optional training, the environment must provide training of communication and coordination skills through realistic interaction with other entities, such as other strike elements, command and control (C2) assets, or tactical air-ground controllers.

THE COGNITIVE FIDELITY GAP

For any given set of training objectives, there exists a range of acceptable simulation fidelities (Isdale, Fencott, Heim & Daly, 2002; NRC, 1997). Simulation-based training must be designed so that training objectives are carefully aligned with the level of fidelity needed to practice and master those objectives (Salas, Bowers & Rhodenizer, 1998; Hays & Singer, 1999; NAVAIR Orlando TSD, 2002). A focus on communication, coordination and decision-making implies a strong need for cognitive fidelity, meaning users should be immersed in environments that elicit decision-making and team behaviors that closely match the mental processes they apply in actual practice.

Flight training devices commonly used for military training offer high-fidelity simulation, complete with wide field-of-view projection, detailed terrain, and actual flight controls and instrument panels. It should come as no surprise that such devices are very costly to acquire and maintain and require dedicated hardware and personnel. The supply of these devices is therefore severely constrained. As a result, users can train only in specific locales and during assigned time slots. Moreover, these devices are designed principally as simulators, not as training devices, and so offer very little training support, leaving instruction to human instructors. Nonetheless, instructors and students accept these devices as an effective tool for practicing a range of flying skills (Koonce & Bramble, 1998).

Desktop flight simulators offer an obvious solution to cost and access barriers by providing greater numbers of trainers and by reducing reliance on instructor pilots. In many cases, desktop flight simulation has proved to be an effective training tool (Dennis & Harris, 1998; Lintern, et al., 1997; Ortiz, 1994; Talleur, et al., 2003; Taylor, et al., 1999).

Commercial-off-the-shelf (COTS) simulation technologies, though, currently lack the sophisticated tutoring and assessment required to address real-time decision making in complex situations such as overhead pattern operations. In fact, using simulations in the absence of appropriate instructional feedback, such as could be provided by an intelligent tutor, can have a negative impact on performance (Means, Salas, Crandall & Jacobs, 1993). Simulators devoid of speech understanding capabilities are unable to train skills related to communications, such as radio procedures with tower or en-route controllers. Finally, current COTS flight simulators lack the cognitive and pedagogical infrastructure to perform training management tasks such as presenting scenarios that optimally expose the trainee to skills in greatest need of practice, or reporting student performance.

Cognitive and physical fidelity are not at all exclusive and are in fact complementary. There are two factors that have nonetheless placed these approaches in competition with one another. One factor is money. The dollars spent on simulation-based training are devoted largely to transition and acquisition, with only modest investment in basic and applied research. Since large, high-fidelity simulators and visualization systems are mature technologies they can be paid for with procurement funding. Cognitive fidelity, while comparatively less costly, is supported with a much smaller pool of research dollars and has yielded products and technologies that have largely failed to cross the chasm into the acquisitions world.

The second factor is more one of perception, or “mindshare”. Educating and persuading end-user communities as to the utility and training value of cognitive fidelity is made more difficult when such discussions are juxtaposed with parallel conversations of high physical fidelity simulators. Decision-makers and end-users are subjected to a continuous barrage of site visits, teleconferences, trade shows, and slide presentations. Against the cluttered backdrop of this informational assault, a converted tractor-trailer containing a pod of full-fidelity helicopter cockpits and high-resolution wrap-around displays is likely to enjoy greater impact than a laptop-based demonstration of cognitively-realistic simulation-based training.

Low-cost, portable training technologies that achieve high-levels of cognitive fidelity are urgently needed. In particular, intelligent tutoring is needed in order to offer interactive, adaptive, instructor-less training. Simulation featuring entities appropriate to a scenario (e.g., controllers, other pilots) that interact in spoken language, and that exhibit realistic, responsive, adaptive behaviors, is another need, particularly in training communications.

TRAINING WITH (UN)INTELLIGENT AGENTS

The challenges presented by on-demand team training cannot be adequately addressed by the use of conventional computer-generated forces (CGFs), semi-automated forces (SAFs), and game-based AIs – largely scripted entities with limited abilities to respond to events beyond a predefined range of simple behaviors. These "AI"s, or any task- or frame-based agents, simply cannot model the real-world complexities necessary to provide training value. The deficiencies suffered by such approaches include:

- Heavy reliance on deterministic, close-world assumptions;
- Inability to manage multiple simultaneous, interruptible tasks;
- Little or no ability to engage in cooperative and collaborative behaviors;
- Deterministic, not dynamic behaviors;
- Infallible performance – no principled approach to realistic error behaviors;
- General lack of mixed-initiative dialogue capabilities.

Cognitive agents that overcome these limitations provide more training value because of their ability to interact in realistic ways across a broad range of tactical situations and to verbally engage in dialogue with users (and with each other). Wide-scale use of advanced cognitive agent technology in training applications has been hampered by the cost of creating such models, and new training initiatives driven by desktop gaming engines have been forced to rely on AIs, which can deliver persuasive demos but which fail to provide comprehensive training across a spectrum of required situations and behaviors

STRIKING THE RIGHT BALANCE

In order to overcome the challenges introduced by on-demand team training, robust, verbally-interactive synthetic agents are required. However, our emphasis on cognitive fidelity for simulation-based training and our use of cognitive agents for synthetic teammates calls for careful deliberations about "how cognitive" these agents must be. For training purposes it is not relevant that, for example, a synthetic wingman perceive the world through sensory processes that model how real pilots process environmental stimuli. Cognitive agents deployed in a training simulation are there for one purpose only: to provide a training benefit, not to offer computational accounts of human cognition. Such agents must exhibit behaviors that suitably replicate the decision-making, coordination, and communications dimensions of the synthetic environment. In particular, a synthetic teammate must possess capabilities that include:

- Taskwork (flying the strike aircraft, performing the terminal controller role);
- Teamwork (coordinating with and supporting the user and other controllers);
- Instruction (providing assessment and feedback on the user's actions);
- Interaction via spoken language (required for team training in verbal environments);
- Behaviors to replicate various error modes (important in team training).

The process of constructing agents can be accelerated using a commercially available cognitive modeling tool such as iGEN®. The goal is to create agents with sufficient sophistication to act as team members, interacting in natural spoken language and exhibiting human-like variability. Unlike simple role-playing entities, which are scripted to exhibit a pre-defined sequence of behaviors, cognitive agents should function effectively in a team-training environment, where team interactions must be non-deterministic, responsive to scenario dynamics, collaborative and imperfect. Moreover, for training teamwork skills, the models' behavioral imperfections need to be strategically controlled, to optimize training opportunities.

SMART PEOPLE DESERVE SMART AGENTS

An emphasis on cognitive fidelity does not mean that other forms of simulation fidelity are unimportant. Aspects of the user's experience must still be replicated in tactically-plausible ways. A useful heuristic is to match the right tool to the right job. For instance, airmanship "stickwork" training requires an emphasis on physical fidelity whereas training situational awareness and decision making demands greater cognitive fidelity. Practicing team coordination calls for synthetic teammates and communications training introduces an additional need for speech-interactive teammates.

The principle of cognitive fidelity can be further refined to address specific training needs. Below we discuss three such refinements: workload fidelity, dialogue fidelity, and cultural fidelity.

An important dimension of cognitive fidelity is workload and multitasking. Teaching skills, even cognitive skills, in isolation or "part-task" training offers little assurance that those skills will be successfully integrated in practice. Training must thus immerse the user in an environment that presents a realistic array of stimuli and tasking. While it is important that these additional factors induce the right measure of cognitive load and task interdependencies, it is less important that these ancillary tasks are themselves presented in the highest possible fidelity. This issue is illustrated below in our discussion of STRATA.

Dialogue fidelity addresses training where spoken interaction is an important objective. Consider the example of radio communications training for aircrew. As part of a high-cognitive fidelity training environment for practicing radio comms, we would want the simulation environment to require the user to exhibit mastery of the required communications skills while attending to the other tasks he or she will be required to perform in concert with communicating, such as flying a prescribed ground track, reducing airspeed and altitude, and visually clearing the area prior to entering a turn. Our position is that this flying task need not meet the same standards of fidelity that actual flying training must meet for simulation events. That is, the flight simulation component of a radio comms trainer must faithfully replicate the cognitive demands of flying the airplane but need not be rated for training flying skills. More discussion of this example appears below under VIPERS.

Cultural fidelity has emerged in the face of unprecedented troop strength in areas where disregard of local custom can lead to friction and violent confrontation as well as inhibit effective collection of intelligence. Simulation-based cultural training has only recently become feasible due to the emergence of first-person gaming environments, and so competition for mindshare between legacy, high-fidelity simulators and their lower-fidelity but more agile contemporaries is noticeably absent. A handful of demonstration projects have received attention and publicity, not because these simulations provide high levels of physical fidelity, but because the way players interact in such environments is realistic and, presumably, of some training benefit. We explore this case below in our discussion of VECTOR.

COGNITIVE AGENT CASE STUDIES

Computational cognitive agents can be applied in support of various dimensions of cognitive fidelity. Below, each of three brief case studies illustrates a training need addressed by adhering to the principle of cognitive fidelity.

STRATA

The principles of cognitive fidelity for on-demand team training are illustrated in a training application that features synthetic entities interacting with a user during simulated Close Air Support (CAS) missions. Synthetic Teammates for Realtime Anywhere Training and Assessment (STRATA) (Bell, Johnston, Freeman & Rody, 2004) provides training opportunities for effective team coordination and communications for users flying a CAS mission. Although the training takes place via desktop flight simulation, airmanship ("stickwork") is not emphasized. Creating opportunities to measure user performance in teamwork and effective communications requires a simulation that provides high degrees of cognitive fidelity with less stringent requirements on replicating visual and physical stimuli.

In CAS the objective is to deliver ordnance on the right target at the right time without endangering friendly ground forces or civilians. To achieve this objective, aircrew must ensure that they have full Situational Awareness (SA) of the target area. While visual information, and thus visual fidelity, is important to this task, SA is primarily built through sophisticated verbal interactions with team members. Therefore, it is the fidelity of the cognitive environment that is paramount to training the CAS mission in STRATA. The pilot's ability to manage the mission, adapt to en-route re-tasking, coordinate with the forward air controller (FAC), and maintain SA are all trained and measured with an emphasis on creating a realistic task loading for the user. The dimension of cognitive fidelity that STRATA illustrates here is therefore workload fidelity.

STRATA creates an environment with realistic task saturation through the use of advanced, voice-enabled cognitive agents. Based on extensive cognitive task analyses with subject matter experts, these agents interact with STRATA users in spoken language and maintain a rich knowledge of the environment and context. Principal among them is the FAC agent, who is responsible for guiding the pilot's eyes onto the assigned target. The FAC accomplishes this task with a rapid exchange of succinct verbal interactions. The FAC uses its knowledge of the layout and features of the target area to generate descriptive communications which it transmits to the user. If the user reports that the ground features referenced by the FAC are in sight, the FAC repeats this "talk-on" process with finer granularity until the pilot visually identifies the target. The talk-on is an integral part of the CAS mission and it is a key example of why cognitive fidelity is essential for complete CAS training.

A key aspect of on-demand training is that it must be instructor optional. STRATA satisfies this need by using automated performance metrics, dynamic selection of scenarios based on training needs, and systematic modulation of behavior, or error induction, by the cognitive agents. Training objectives are associated with automated performance metrics that evaluate the user on data collected during the mission. These metrics evaluate the user on cognitive and social metrics by analyzing spoken communications as well as physical interactions with the simulation environment. As the user trains, this information is used to create a profile that reflects the strengths and weaknesses of the user with regard to training objectives. This profile is then used to dynamically select future scenarios that provide training in the areas where the user is most deficient and to direct the cognitive agents to adjust their behavior to focus on the user's deficiencies.

Cognitive fidelity also calls for agents whose behaviors can be modulated to create experiences in the scenario that serve specific training needs. For example, providing training for error detection and compensatory action requires cognitive agents that can exhibit realistic error behaviors when called for by the user's training profile. Because the FAC was created from cognitive task analysis of human FAC behavior, it possesses the cognitive fidelity to systematically introduce human-like error. For instance, the FAC could provide an unrealistic time-on-target (TOT) to the user and steer the dialogue into a series of interactions where the user must remedy the situation and agree on a more suitable TOT.

VIPERS

The notion of "team training" can be broadly interpreted to include distributed, heterogeneous actors working cooperatively. For pattern operations at an airfield, the notion of a team includes the aircrew and controllers who together maintain pattern safety and traffic separation.

Undergraduate Pilot Training (UPT) is an intensive program that trains military pilots prior to their being assigned to an advanced training track. During the program, student pilots are presented with an array of complex skills to acquire and integrate in a dynamic, time-sensitive performance context. Since most of a student's hours in UPT are spent on the ground, training could be fundamentally improved if students had on-demand access to flight or part-task training devices that were sophisticated enough to provide automated instruction in complex, interactive flight regimes. In a study of undergraduate pilot training (UPT), the Air Force Research Lab (AFRL) identified two urgent training needs: the improvement of radio communication training and practice in overhead pattern operations (AFRL, 2002).

The need for augmenting formal UPT classroom and flight instruction with portable, simulation-based training is driven in part by the limited flight time UPT students have. The training benefit from time in the airplane is compromised whenever an instructor is obliged to review skills and concepts that might have been mastered if appropriate simulation technology were available. Training will be fundamentally improved when students can receive on-demand access to flight training devices that are sophisticated enough to provide automated instruction in complex, highly interactive flight regimes, yet simple enough for students to operate alone, on low-cost, portable personal computers (PCs). The Virtual Interactive Pattern Environment and Radio Communications Simulator (VIPERS) (Bell, Ryder & Cain, 2004) is a tool aimed to complement current UPT ground-based training.

VIPERS extends COTS simulation with intelligent tutoring to provide effective, instructor-less training opportunities, and synthetic agents that can assume key roles within training scenarios and which can interact in spoken language with the trainee. VIPERS emphasizes situation awareness of pattern procedures and radio communications and is an example of a high cognitive-fidelity training application. Moreover, its emphasis on radio communications makes it an effective illustration of the dimension of dialogue fidelity.

Agents in VIPERS play the roles of air traffic controller (called a Runway Supervisory Unit or RSU), Instructor Pilot (IP), and other student traffic in the pattern. The RSU agent provides air and ground control of the UPT pattern, including deconfliction and some guidance to student pilots (SP). The RSU agent is therefore designed to maintain SA of all the aircraft in the pattern, recognize and correct possible conflicts, and responds to pilot requests. The IP agent, which provides guidance and feedback to the SP, maintains SA of the flight - including awareness of other aircraft in the pattern - and responds to errors in airmanship and radio communications. Additionally, both the RSU and IP agent record performance measures throughout the simulation that are used during the mission debrief.

Each SP model controls an aircraft in the pattern not flown by the human student pilot. As in real training environment, the SP agents are fallible and contribute to situations that require the human pilot to adjust in order to avoid conflicts.

VECTOR

The number of military activities classified as "operations other than war" is on the increase. These activities may include such things as counter-insurgency campaigns, hostage rescue operations, low intensity conflicts, military operations in urban terrain, and peacekeeping operations. Such activities will require a vastly different set of tactics, equipment, training and skills than conventional military engagements of the past. To address these changes in war-fighting, CHI Systems has built the Virtual Environment Cultural Training for Operational Readiness (VECTOR) training system (Santarelli, et al., 2004).

VECTOR immerses a user in situations where problem-solving relies in part on displaying culturally-appropriate behaviors, and thus illustrates a dimension of cognitive fidelity we label cultural fidelity. VECTOR provides a new technology for training in cultural familiarization through the application of highly experiential, scenario-based training in virtual environments. VECTOR can be used to develop specific skills for interacting with members of a culture of interest utilizing the iGEN® cognitive modeling toolset to create synthetic members of that culture. This kind of cultural familiarization helps to provide the context for mission-specific training on procedures, tactics and techniques, and rules of engagement.

In observing the goal of cultural fidelity, VECTOR provides:

- Agents that generate spoken utterances, move through the virtual environment, and display emotional state through gestures, body-posture, and affectively-attenuated speech;
- A computational model of emotion in the agents that drives interactions with the user and provides feedback on the propriety of user actions as reflected in emotional states;
- Adaptive scenarios that accommodate trainee actions without compromising the pedagogical goals of the training;
- Automated performance assessment and dynamic updating of the scenario goals.

VECTOR utilizes two specific classes of cognitive agent: a non-player character agent (NPC) and an instructor agent (IA) – both implemented as cognitive models. The NPC agent is used to drive the behaviors of the in-game characters and possess the ability to generate verbal utterances, physically navigate through the virtual environment, and respond to trainee actions based on their emotional state (which is, in turn, modified and influenced by trainee actions). The instructor model contains both cultural knowledge and pedagogical expertise, can provide real-time and post-exercise performance feedback, can follow the trainee and 'course-correct' them as needed to maintain the viability of the unfolding scenario, and offer cultural advice if needed.

One important feature of the NPCs relevant to cultural fidelity that resulted from the training requirements in the particular culture of interest (i.e., Kurdish) was the need to allow the trainee to interrupt the speech of an NPC. For instance, a user may need or want to obtain information from an NPC in a timely manner. The user must, however, balance this urgency with the particular [Kurdish] cultural norms that avoid interrupting another's speech. Through the principled use of interruptible speech within the cognitive agents used to drive the NPCs, VECTOR can asses the trainee's knowledge of these types of culturally-relevant dialog interactions.

Another important determinant of the success of the VECTOR training system is the representation of significant aspects of NPCs' affective processes, as well as their cultural background, in the scenario. VECTOR adopts an ontology of culture (see Triandis, 1994; Strauss & Quinn, 1997) under which interactions between individuals are governed by implicit norms and procedures, which are organized in individuals' minds as shared cognitive schemas. These schemas provide members of a culture with a complex and interactive set of principles and procedures (e.g., "cultural rules") ranging from coherent verbal interactions to acceptable social behaviors. It is this fundamental principle of culture/emotion that underlies all actions of synthetic actors toward the trainee. Emotional modeling is, therefore, a linchpin in the integration of cultural factors into synthetic actors.

Cultural fidelity is aided through VECTOR's implementation of a computational model of emotion based on the work of Ortony, Clore, and Collins (1988). They categorize over 20 emotional variables with respect to a valanced mapping of reaction to objects, events, and actors. The emotional variables within the NPCs are controlled by a set of (culture-specific) mappings that take output from the dialog manager, and from events in the environment and apply corresponding adjustments to one or more of these variables. The mechanism can be elaborated to include excitatory and inhibitory effects between emotional variables, as well as saturation levels and a decay curve.

CONCLUSIONS

Cognitive fidelity is an important touchstone for training intended to provide users with enhanced decision-making, problem-solving, SA, coordination, or communication skills, to name a few. Cognitive fidelity can thus be decomposed into specific dimensions, of which we have illustrated three in this paper: Workload, Dialogue, and Cultural fidelity. Current projects demonstrate these principles in practice: STRATA, VIPERS, and VECTOR, respectively.

Legacy simulators will continue to provide warfighters with effective training but must be supplemented with devices that address emerging needs. Devices with high physical fidelity are heavily task-work focused in an increasingly teamwork-focused world, where social behaviors of simulation entities are critical to training effectiveness. Physical fidelity also incurs cost and portability penalties during a period when training transformation calls for a departure from the centralized training center model as the sole means for distributing simulation-based training. Cognitive fidelity places fewer demands on hardware and display technologies and enjoys low-footprint advantages for deployability.

ACKNOWLEDGEMENTS

STRATA is supported by DARPA through an Office of Naval Research Contract: N00014-03-C-0300. The authors gratefully acknowledge the support and guidance of Dr. Ralph Chatham of DARPA, Dr. Harold Hawkins of ONR, and LCDR Jim Patrey of NAVAIR PMA205. VIPERS is supported by the Air Force Research Laboratory under contract number F33615-03-M-6347. The authors wish to thank Capt Stefanie Williams, AFRL, Major Alex Darosa, 84th FTS, and Major Eric Fisk of the Air Education and Training Command, for their invaluable contributions to this project. VECTOR was sponsored by the U. S. Army Research Institute under contract number DASW01-03-C-0023. The authors would like to acknowledge the support of Dr. Bruce Knerr.

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