
Integration of the CAT Crewstation with the Ride Motion Simulator (RMS)

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ABSTRACT

Members from the National Automotive Center (NAC) TARDEC-RDECOM are involved in a Power Budget Model and Duty Cycle Experimentation Project that is part of an Army Technology Objective (ATO). The main goal of this program is to develop models and simulations that will help engineers evaluate conceptual designs for use in propulsion and power delivery for the Army's Future Combat System (FCS). The initial phase comprises mounting a Crew integration and Automation Test bed (CAT) Crewstation onto the Ride Motion Simulator (RMS) and then integrating a dynamics model. This paper will discuss the various components that were used in the integration, which consists of the Vehicle Dynamics Mobility Server (VDMS), a Combat Hybrid Power System (CHPS) Powertain, a SimCreator dynamics model, a Soldier-Machine Interface (SMI), and an Embedded Simulation System (ESS). This paper will also present the numerous challenges involving the system and software integration.

INTRODUCTION

The U.S. Army is transforming its fleet by modernizing its assets through the development of the Future Combat System (FCS), which includes a family of manned and unmanned systems that are networked to support air and ground-based systems. The FCS fleet will be multi-functional and will have the capabilities to do reconnaissance, surveillance, target acquisition, and command, control, and communication [1]. Furthermore, the vehicles will be strategically deployable, tactically superior, and rapidly responsive. In addition to having these capabilities, the FCS vehicles will be hybrid-electric.

The U.S. Army is developing and designing alternative vehicle power by researching hybrid-electric vehicles to reduce the cost for the Army by conserving fuel in its future military vehicles. Military vehicles utilizing a hybrid-electric power system are more fuel-efficient than

conventional gas-driven vehicles. Hybrid-electric power also reduces the weight of the vehicle since it uses smaller power and electronics components. It centralizes all the power distribution in the vehicle, allows for flexibility in placing the components, and provides power for advanced weapon and protection systems that are not feasible in older, conventional, mechanical systems. However, the hybrid-electric power system must be able to provide enough power to the vehicle so that it is still versatile, lethal and most importantly, protects the soldiers. Some main-weapon and protection systems that will be considered, which also consume power, are an electro-magnetic (EM) gun, an electro-thermal chemical (ETC) gun, and electric armor [2]. To accomplish the Army's goal, and facilitate the design process, researchers and engineers from the RDECOM Tank Automotive Research Development Engineering Center's National Automotive Center (TARDEC NAC) are involved in a Power-Budget Model and Duty-cycle experimentation project that is part of an Army Technology Objective (ATO).

The purpose of this ATO is to design and develop technologically advanced military vehicles for the Army through the development of hybrid-electric power systems. However, to design efficient and effective hybrid-electric vehicles, engineers need to measure the power consumed by the vehicle. To acquire the necessary measurements, a sophisticated high-fidelity simulated environment was implemented to collect and calculate the power system's duty cycles. This is achieved by developing an Army Power Budget Model [2]. The model consists of components such as transient loads, steady loads, and projected duty cycle. The transient load consumes a significant amount of power that depletes quickly when a power hungry system is in use such as electric armor. The steady load is power that is always on even in minimum-load conditions, such as a computer or communication systems.

Researchers are aware that there are trade-offs when using power, thus they need to devise a method to

manage the power consumed by the system. To manage power consumption, they need to develop ways to calculate the power duty cycles. The power duty cycle describes how power is consumed within the system, since power needs to be channeled from one system to another depending on the priority of the system at a particular moment in time. For instance, if a vehicle is under attack, should all the power be given to the protection system or should some of the power be diverted to the engine so that the crew can move and shoot at the same time? These issues are challenges that engineers need to resolve early on in the development of the vehicles. Fortunately, these scenarios can be created via a simulated warfighting environment using physics based vehicle models, terrain databases, and Army Power Budget Model.

To analyze these challenges, a project was established to develop models and simulations that will help engineers evaluate conceptual designs for vehicles, such as hybrid-electric vehicles, in the area of propulsion and power delivery for the Army's FCS. To achieve this endeavor, the program is broken into three phases. The initial phase, which is the focus of this paper, involves numerous integration components. These components consist of the Vehicle Dynamics Mobility Server (VDMS), a Combat Hybrid Power System (CHPS) power train, a SimCreator dynamic model, a Soldier-Machine Interface (SMI), and an Embedded Simulation System (ESS). The second phase will involve driving the simulated vehicle model in a war-fighting scenario and integrating software components. The final phase will consist of linking the RMS at the Ground Vehicle Simulation Lab (GVSL) in Warren, Michigan to the CHPS System Integration Lab (SIL) in Santa Clara, California. The CHPS SIL is a hybrid-powertrain, systems-integration lab, through a combination of both actual hardware components and software models that can simulate vehicle operation.

Figure 1 shows a high-level interaction of the high-fidelity, physics-based vehicle dynamics model, the RMS, and the CHPS SIL. It shows the high-fidelity vehicle model integrated with the RMS, the CAT Crewstation, and a power systems model. The power systems model not only calculates mobility power loads but also takes into account the non-mobility load models such as ETC gun or communication system loads that are consumed during the simulated warfighting scenario. The information gathered during the experiment will be transmitted to the CHPS SIL, which stimulates actual power system hardware and calculates the power load consumption in a closed-loop environment.

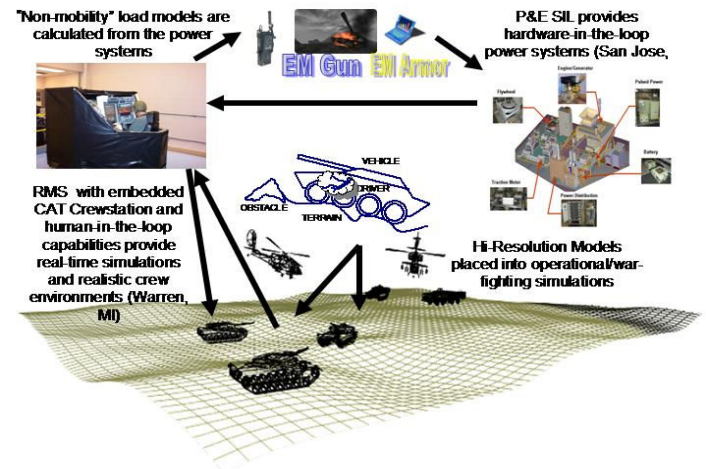


Figure 1: Interaction of High-Fidelity model, RMS and CHPS SIL

RIDE MOTION SIMULATOR AND CAT CREWSTATION

The initial phase involves integrating the various software components such as the VDMS, the CHPS power train, the SimCreator dynamics model, and the embedded simulation system. However, these components also need to interact with both the RMS and the CAT Crewstation.

RIDE MOTION SIMULATOR

The Ride Motion Simulator (RMS) is a high-performance, single occupant, six degree-of-freedom (3 translational, 3 angular) motion base designed to recreate the "ride" of nearly any ground vehicle with high precision and accuracy. The simulator has two vehicle cabs that are essentially space frames that allow for a variety of vehicle configurations to include accommodating a single CAT crewstation. The RMS is utilized to assess soldier performance in moving vehicle environments, to identify areas of concern early in vehicle design and development processes, and to perform real-time human/hardware-in-the-loop simulation.

To enhance the driver's perception of being in a realistic environment while driving the RMS over a virtual terrain, visual rendering of a scene and motion dynamics is used. Previous GVSL projects utilizing the RMS include: comparing the effect that visual field of view (FOV) (2 fixed, 40° FOV 120° FOV and a head slaved movable, i.e. Head Mounted Display) has on driving [3], driving a vehicle dynamics model of a High Mobility Multi-purpose Wheeled Vehicle (HMMWV) over a virtual proving ground such as the Aberdeen Proving Grounds to

validate the authenticity of the terrain [4], studying the effect of motion on accuracy and time to reach control buttons and touch-screen panel displays [5], and doing tele-operational experiments to test performance of drivers in a sensory-mismatch environment. In addition to utilizing the RMS for use in a simulated environment, the RMS was used to study loading and shock on the crew of simulated guns firing including the Non-Line-of-Sight Cannon (NLOS-C) and Mounted Combat System (MCS), and testing different types of seat belts for the HMMWV.

Integration of the CAT Crewstation onto the RMS (Figure 2) and into the GVSL real-time environment required several of the crewstation's subsystems (Embedded Simulation System (ESS), Soldier Machine Interface (SMI) and the X-IG Visualization system) to communicate with GVSL's subsystems (RMS, Vehicle Dynamics and Mobility Server (VDMS), and SimCreator Vehicle Dynamics Model). These components and their interactions are shown in Figure 3.



Figure 2: CAT Crewstation on the RMS

CAT CREWSTATION

The Army needs smaller vehicles and the ability to easily control its unmanned assets for its FCS fleet. One of the ways to accomplish this goal is to design a crew cockpit that allows for a reduced crew size while providing the soldiers the capability to control unmanned aerial and ground vehicles while increasing operational effectiveness. To evaluate possible reduction in the crew size, a CAT Crewstation was built. The CAT Crewstation provides engineers the opportunity to develop, integrate, and demonstrate technologies for reduced crew operations and unmanned vehicle control.

The focus of the CAT Crewstation is to improve soldiers' performance and situational awareness, while minimizing workload to support reduced crew size. It also provides

soldiers with the capability to perform tele-operations such as command and remote control of unmanned systems from a single, common crewstation; beneficial in FCS vehicles. The crewstation presents soldiers with the opportunities to rehearse mission planning and to coordinate, route, and plan logistics re-supply via the use of tactical Embedded Simulation System (ESS) [6].

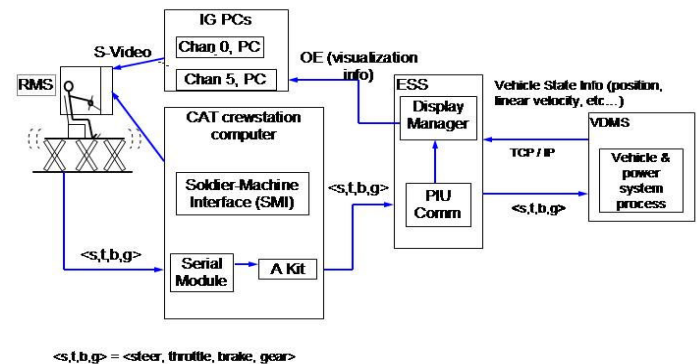


Figure 3: Crewstation's System Components

EMBEDDED SIMULATION SYSTEM (ESS)

The CAT Crewstation is a multi-role crewstation that is equipped with an Embedded Simulation System (ESS), which allows for intelligent driving, commander's decision aid, route planning, deployed training, and mission rehearsal. ESS is the control center for the whole system since it ties together all of the individual components and acts as a messenger service for transferring information from one component to another. It has a world model, which displays the terrain database to create a particular area of the warfighting theater, a high-fidelity maneuverability model, which simulates the vehicle's movement, and battlefield visualization, which provides a bird's-eye view of the warfighting scenario [7]. It also has the capability to do vehicle simulations of mobility, survivability, virtual Opposing Forces (OPFOR), and allies.

SOLDIER-MACHINE INTERFACE (SMI)

The Soldier-Machine Interface (SMI) is the front-end of the crewstation that is utilized by the end-user to interact with the simulated environment. The SMI consists of three touch screens, multi-functional flat panel displays (MFDs) with panel buttons for subsystem control and crewstation mode selections. In addition, a multi-functional yoke is used for driving, target acquisition, tele-operation, and weapons firing. The SMI also has a

graphical user-interface (GUI) that allows the user to control the CAT via a tactical interface. The SMI provides the operator with many display combinations that are required by the operator to complete the mission. The information displayed on the CAT Crewstation includes the setup, map, warning, cautions and advisories queue, target acquisition, report data and information, target queue, indirect vision display, and driving gauges. In addition, the SMI provides engineers many different options for configuring the CAT Crewstation such as a driver, an operator, or a gunner station.

X-IMAGE GENERATOR (X-IG)

To render the simulated terrain and warfighter scenario on the three touch screens, the CAT Crewstation has an X-Image Generator (X-IG). The X-IG creates a realistic environment for firing and moving since it displays a virtual environment from a database; for the experiment, a database of the Caspian Sea region was used. The visual display of the database includes a surface terrain, roads, and buildings, along with vehicle and personnel models. The image generated by X-IG is overlaid on top of the SMI screen.

VEHICLE DYNAMICS AND MOBILITY SERVER (VDMS)

The three elements, ESS, SMI, and X-IG, from the CAT Crewstation need to communicate with the Ride Motion Simulator to provide the occupant with the feeling that he/she is driving in a real environment. When a driver sees that he/she is going over a bump, the driver must also feel that he/she is also going over a bump. One of the software components that is utilized to achieve this correlation of both the visual and motion cues is the Vehicle Dynamics and Mobility Server (VDMS). The VDMS is a server that allows clients to use a collection of multi-body, real-time vehicle dynamics models to simulate the motion of a vehicle in a virtual environment. VDMS uses Real-time Technologies Inc.'s Ground Vehicle Dynamics System (GVDS), a system that allows VDMS to access a variety of vehicle models along with digital elevation terrain. VDMS interfaces with OpenFlight[®] terrain databases, which can be tailored to include specific terrain/soil information and physics-based object collision data. VDMS provides very high-resolution, physics based, three-dimensional representations that simulate a vehicle's interaction with the environment to reproduce its performance, including its ground mobility, stability, handling, and vibration [8]. VDMS also serves as an interface to the RMS via SCRAMNet[®] fiber-optic shared memory. SCRAMNet[®] allows multiple computers to share data, thus giving VDMS the ability to transmit in real-time the dynamic model's position, velocity, acceleration, and orientation

data to the shared memory. The RMS controller is able to read this information and moves the motion base to recreate the "ride" of the vehicle as it traverses the virtual terrain.

The simulated vehicles are dynamic, multi-body models constructed in a graphical real-time simulation and modeling system called SimCreator[®] [9]. Several vehicle models have been tested with the CAT Crewstation, namely, the Stryker, the Bradley, a notional Armed Robotic Vehicle (ARV), and a FCS vehicle with a Combat Hybrid Power System (CHPS).

COMBAT HYBRID POWER SYSTEM (CHPS)

Since the engineers were interested in a projected duty cycle and power consumption of the vehicle, the Combat Hybrid Power System (CHPS) was implemented to address hybrid electric power and its sub-components, such as pulsed power and continuous power that must function cohesively without interference. Pulsed power needs to supply a large amount of power in a short period of time such as delivering power to the vehicle's ETC gun and/or EM armor. Continuous power is the necessary power that is needed to mobilize the vehicle and behaves as the auxiliary power unit for the other electric components and loads. The CHPS powertrain was integrated into the vehicle dynamics model and will later be used as a component to connect the vehicle dynamics at the GVSL in Warren, MI to the CHPS SIL in Santa Clara, CA.

CHALLENGES OVERCOME

CHPS, VDMS, and the components from the CAT Crewstation were successfully integrated for the first phase of the project. However, to accomplish the integration some obstacles were encountered and resolved. These issues involved mounting the CAT Crewstation onto the RMS, cable connections, video outputs and driver views that were not correctly displayed, vehicle models that did not respond to driver input, and a database terrain that did not interface with the dynamics model.

MOUNTING THE CAT CREWSTATION

One of the obstacles faced during this integration effort was the physical coupling of the CAT Crewstation to the RMS. To solve this problem, a set of three custom mounting brackets were manufactured, each weighing 50 lbs. The brackets were manufactured out of steel and each was fastened to the the RMS seat attachment plate using two Grade 8 bolts. The CAT Crewstation was then fastened to the mounting brackets in the middle of its frame. While testing the CAT on the RMS, using this

mounting solution, it was noticed that undesired vibrations were being transmitted into both the crewstation screens and the enclosure that is holding the SMI embedded computers on top of the crewstation. To reduce this vibration, two additional bolts were added to the front of the crewstation frame at the corners. Due to lessons learned from this integration effort, future mounting solutions will involve aluminum mounting brackets instead of steel to reduce the weight burden on the motion simulator. In addition, brackets will be designed to fasten to the corners of the crewstation to reduce the amount of vibration during the simulation.

CABLES

The CAT Crewstation was mounted on the RMS, but the computers controlling most of the software components, ESS and XIG, were located in a separate rack, ESS rack, which was placed next to the simulator. Four cables, each 50 feet long, were required to connect these computers to the crewstation – power, s-video, RS-232, and Ethernet (Category 5 cable). The ESS rack was approximately 30 feet from the RMS, and additional length was needed to account for the motion envelope of the RMS. Because of this distance, the power cables required additional shielding to prevent them from acting as antennas and introducing undesired noise into the system. The s-video, RS-232, and Ethernet cables were all within their recommended maximum lengths so no additional amplification was required. Future programs may require greater stand off distances of the ESS rack and thus longer cable runs. For these such runs, amplification will be required for both the s-video and RS-232 signals to minimize signal degradation.

DYNAMICS MODEL

The ESS comes with its own low-fidelity dynamics model. While this model is more than adequate for static driving, it is neither easily extendable nor sufficient for dynamic simulations. One of the goals of this integration effort was to replace the ESS dynamics model with a high-fidelity, physics-based, multi-body dynamics model developed by the GVSL. The high-fidelity model was executed inside VDMS and its interfaces are exposed via a TCP/IP socket. The high-fidelity model updates its dynamics at 400 Hz, updates the vehicle state information that is sent to ESS (which updates the visuals) at 60 Hz, and drives the RMS controller, which runs at 1KHz, at 400 Hz.

In this exercise, a notional 24-ton tracked FCS model was developed in SimCreator[®] [9] and embedded inside VDMS. VDMS received tele-operation controls from the ESS (steer, throttle, break, and gear) and forwarded this information to the dynamics model. The dynamics model

used the tele-operation controls to update its state (velocity, position, acceleration, and orientation) and return this information to VDMS. VDMS used the vehicle state information to send new motion commands (six accelerations, six velocities, and six positions) to the RMS motion controller. The controller transmitted the vehicle state information to the ESS, which in turn updated the visuals on the CAT Crewstation. Thus the state information generated by the vehicle model was used to synchronize both motion and visuals in the simulation.

VEHICLE TERRAIN INTERFACE

In addition to the real-time dynamics model, a Vehicle Terrain Interface (VTI) was also used. VTI is a set of terrain interrogation routines that allow for more realistic modeling of the effects of vehicle motion on the terrain [10]. The VTI allows modeling of persistent soil deformation that is dependent on the soil codes of the terrain over which the vehicle is traversing. Currently, the VTI exists only on wheeled vehicles. An effort is under way to introduce VTI capabilities to tracked vehicles. VTI consists of two components, where one component is embedded inside the vehicle dynamics in the vehicle tire/track and is used to increase the fidelity of the simulation by communicating with the second component that is embedded inside VDMS. The second component is used to perform terrain queries and return the resultant forces to the first component.

NON-MOBILITY LOADS DATA COLLECTION

One of the goals of the Power Budget Model and Duty Cycle Experimentation Project is to collect non-mobility power-load data from the CAT Crewstation during a simulation exercise. The interfaces between ESS and the non-mobility data analyzer were established during the integration. The data collection done by the non-mobility modules was accomplished via a TCP/IP socket interface that receives power consumption events from the ESS, such as gear shifts and EM armor activation.

PREVENTING ROLL-OVERS

During trial runs of driving the CAT Crewstation on the RMS, the driver would occasionally roll over the simulated vehicle. This action would cause the RMS to rapidly accelerate and hit one of the limits. While this behavior is not hazardous to the driver, it can be jarring. Moreover, it brings the simulation to a halt, which is an inconvenience since the RMS needs to be reset, and the simulation needs to be completely restarted. This was resolved by putting software limits on the vehicle's roll and pitch directions in VDMS. The software checks if the roll and pitch angles are greater than 60 degrees, and

stops writing vehicle state information to SCRAMNet[®] if it is. Since the vehicle state is no longer updated, the RMS comes to a stop, and the driver is not subjected to undue stresses. Therefore, only the dynamics model needs to be restarted in order for the simulation to continue.

CONCLUSION

The Army is researching and developing state-of-the-art vehicle components and systems that rely heavily on electrical power consumption. To accomplish the Army's goals, engineers from TARDEC are facilitating this research as part of the Army Power Budget Model. The initial phase of the RMS's role is to have the CAT Crewstation and its various hardware and software components, such as Soldier-Machine Interface and Embedded Simulation System (ESS), mounted and integrated with the RMS, Vehicle Dynamics Mobility Server (VDMS), Combat Hybrid Power System (CHPS), and SimCreator dynamics model. The CAT Crewstation was successfully tested and evaluated during the first phase integration effort. The CAT was mounted onto a motion base platform and used to perform testing of all the components that will be used during the Power Budget Model and Duty Cycle Experiment. Several key problems were identified during this process and these issues were addressed during the first phase of the integration.

The integration of these subsystems into a real-time motion base environment will allow designers of FCS power and energy systems to determine loading requirements and evaluate preliminary designs in a operational scenario. This will ultimately lead to a much more robust, capable power system to meet the needs of the Army's future force.

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