Abstract. The DSTO Survivability Integration Laboratory (SIL) is being developed under a collaborative R&D program with US Army CERDEC focussed on Aircraft Survivability Equipment (ASE) and technologies. The SIL seeks to provide a modelling and simulation test-bed to enable cost and operational effectiveness analysis, evaluation of alternatives, pilot training, tactics development and model validation. The primary objective of the SIL is to support both military experimentation and on-going research and development in order to facilitate the transfer of new capability to the Australian Defence Force (ADF).

The SIL architecture integrates human-in-the-loop, hardware-in-the-loop and digital models in a distributed synthetic environment, exploiting industry standard protocols. The SIL will add value to the ADF by providing a multi-function interoperable environment in which to conduct mission rehearsal and Countermeasure Development and Validation (CMD&V) activities, supporting ASE capability development and sustainment. This paper will discuss the objectives of the SIL, its implementation and demonstrate its intended application from an operational perspective.

1. INTRODUCTION

The first-shot, first-kill nature of the modern battle-space necessitates the survivability of our military assets be effectively tested, measured and in a simulation context, appropriately modelled. The Survivability Integration Laboratory aims to provide an interoperable, distributed and scalable architecture to enable Survivability Experimentation. The SIL facility provides the integration point for digital sensor and effecter models with both human-in-the-loop (HIL) and hardware-in-the-loop (HWIL) capability within a synthetic environment. Furthermore, it provides an infrastructure enabling traceable, controlled and validated analysis of the interaction between virtual entities and environments, hardware and human operators. In a broader context, the application of mission rehearsal and CMD&V activities and their outcomes can be evaluated and the results and impacts transitioned to the Australian Defence Force (ADF) for the benefit of the wider defence community. Currently the primary focus is the air domain, however the facility could provide support to multi-domain experimentation.

1.1 Requirements for a Simulation Facility to Assess Aircraft Survivability

The complex nature of the electronic warfare (EW) battle-space in the current climate creates many challenges that need to be considered in the assessment of survivability. The following requirements are considered necessary to form the technological basis for the assessment of aircraft survivability in an EW context:

- Mission-level (moderate fidelity) and engagement-level (high fidelity) modelling of EW sensor, emitter, countermeasure and platform interactions.
- Full-spectrum ASE suite simulation.
- Incorporation of HWIL to provide true system responses and enable the evaluation of ASE suite configurations and integration issues.
- Incorporation of HIL to enable human factors research and training in EW situational awareness and tactics development.
- Ability to support operational mission planning, training, and countermeasures development and validation (CMD&V).
- Provide the means by which digital system models can be validated against system hardware.
- Provision of an integrated logging and analysis capability to enable the collection of simulation experimentation metrics.
- Development of appropriate Measures of Effectiveness/Measures of Performance (MOE/MOP).

To ensure system versatility, industry standard communication interfaces for ASE hardware, digital models and distributed simulation are used where possible. Adopting standard interfaces enables seamless integration and multi-function support to other domains such as land and sea.
A mission-level model refers to a model that has been simplified from an engagement-level model, such that only the critical parameters or engagement effects are retained. Mission-level models are also known as effects-based models. Mission-level models are essential where the architecture involves many complex interacting systems. The level of resolution of mission-level models will vary depending upon the complexity of the interactions, availability of intelligence data and in most circumstances processing resources.

1.2 Requirements for a Hardware-in-the-Loop Capability

The integration of hardware into any simulation facility provides an effective platform for developing and testing real-time embedded systems and does so by adding the complexity of the system under test into the test environment. The hardware targeted for integration into the SIL includes ASE (such as radar warning, laser warning, missile warning capability), associated stimulators, threat systems and EW controllers to provide end-to-end system functionality.

Incorporation of ASE in the SIL will provide valuable insight into the design and development of a future Ground Support Environment (GSE) incorporating full-spectrum ASE stimulation and EW suite re-programming. It will allow pilots to interact with ASE hardware within a virtual controlled environment, and enable the validation of EW system models for further experimentation purposes.

In order to provide the function of a GSE, the SIL must provide the ability to optimize the operation of the various ASE suites targeted for integration. To benefit from the integration of hardware-in-the-loop into the SIL environment, the following functionality is considered necessary:

- ASE suite programming to enhance individual system performance or platform compatibility.
- Full-spectrum ASE suite stimulation.
- Capability to exercise all operating modes of the ASE suite.
- Coordinated transfer of intelligence and data between the digital and electronic domains.
- Common HWIL architecture to accommodate testing for future suite integration.

1.3 SIL Architecture

The SIL is comprised of six functional components, Simulation & Control, HWIL, External Threat Models, HIL, Digital ASE Models and Data Capture & Analysis. Employing distributed simulation protocols and developing specialised interfaces where necessary, enable the interaction of these functional components.

The HIL component provides the virtual (immersive) environment for the human operator and both a rotary and fixed wing aircraft modelling capability using two COTS products, HELISIM and FLIGHTSIM. The flight simulator software connects to console based controls for the platform, forming part of the flight deck used by the human operator, featuring standard PC monitors serving as cockpit screens. The SIL does not aim to provide a realistic physical flight environment for the HIL, however it needs to be sufficient to enable a human operator to navigate the virtual environment. The physical flight console for the HIL comprises representative aircraft flight controls, typical cockpit instrumentation, ASE displays and scene generation of the virtual environment. The SIL is able to link with the Air Operations Support Centre (AOSC) for experimentation requiring high fidelity flight models with realistic physical flight cockpits.

The Digital ASE Models are based on an integrated self-protection capability comprising a Radar Warning Receiver, Radar Jamming, IR Countermeasures, Missile
Warning, Laser Detection, and associated EW situational awareness displays.

The External Threat Model component provides console-based simplified engagement-level models, controlled by a human operator. Threat systems modelled at the engagement level require dedicated computing resources for real-time execution and as such are developed external to the Simulation and Control component.

The Data Capture & Analysis component enables the qualification and quantification of experimental outcomes from the SIL. The primary logging and analysis capability is provided by DSTO developed technology that captures, decodes and stores both DIS and Virtual MIL-STD 1553 data into an SQL database in real-time. The analysis component of the tool extracts specific information from the SQL database, calculates metrics ‘on-the-fly’ and presents it to a human operator. Metrics provided by the tool has enabled the SIL to undertake an evaluation of alternatives experiment to determine the behaviour of varying configurations of ASE kit.

The HWIL component incorporates all HWIL systems intended to interact with the SIL using DIS and MIL-STD 1553 to interface to the other components. This currently includes GPS Simulator, Threat System Simulator and ASE.

A subsystem of the HWIL component is the ASE HWIL (Figure 2), which allows the ASE to operate in a closed-loop environment with both platform and threat simulators. It encompasses specific ASE suites represented by the digital ASE models, and the necessary infrastructure and control mechanisms to accurately measure the ASE suite responses used to test and evaluate these systems.

The hardware targeted for integration includes Laser Warning Receiver, Radar Warning Receiver and Missile Approach Warning Systems and associated stimulators. The HWIL component features the HWIL Interface Controller function which bridges the necessary intelligence and data between the digital and electronic domains, specifically listening to the DIS data traffic and the encapsulation of MIL-STD 1553 messaging into Ethernet frames and vice-versa. The bridging functionality allows the hardware to be responsive to the Simulation & Control component and to feedback the primary and secondary system responses into the simulation to determine the outcome(s).

The architecture of the ASE HWIL provides a generic interface enabling the system hardware under test to interact with the digital models. This allows the testing of future EW suite integration, contributing to the procurement process.

2. INTEROPERABILITY

In providing transparent interoperability between the HIL, HWIL and Digital ASE Models, the SIL can provide an extensible, scalable and reconfigurable environment in which to conduct survivability experimentation. Utilising DIS, MIL-STD 1553, and a common model framework has enabled the interfacing of discrete components into the SIL synthetic environment to interact with other discrete components.

2.1 Distributed Interactive Simulation (DIS)

DIS supports communication between distributed systems or models within a simulation. The SIL utilises the primary Protocol Datagram Unit (PDU) set and has extended the protocol using the Data PDU to allow for the transfer of Electro-Optic Emission information and other customised information, which is not sufficiently represented using the existing Electromagnetic Emission PDU.

Employing DIS allows connectivity with other simulation facilities, which can be used to complement the SIL architecture or replace specific components (i.e. high fidelity flight simulators). High fidelity flight simulators incorporate detailed cockpit layouts, high fidelity flight models, and high-resolution visualisation displays projected onto a large dome. This technology allows the SIL to incorporate ADF pilots in the loop when conducting experiments and exercises involving survivability and/or EW systems assessments.

2.2 MIL-STD 1553

ASE hardware utilises the MIL-STD 1553 protocol for integration into aircraft platforms. MIL-STD 1553 specifies a multiplex data system for systems integration and provides standard digital interfaces for subsystems connected to a 1MHz serial data bus. Whilst this protocol is predominantly used in the aerospace domain, it is not limited to other applications where appropriate. The hardware systems transmit electronic signals on to a data bus, whereas in the digital domain, the data is encapsulated within a DIS Data PDU and transmitted on an Ethernet network. The SIL implements digital models of the ASE hardware, which utilises the MIL-STD 1553 protocol within the digital domain. EW system hardware utilising this protocol simplifies the integration of different MIL-STD 1553 compliant ASE into the mission systems of host platforms by adopting a standardised interface.
2.3 Combined Sensor Modelling Infrastructure

The Combined Sensor Modelling Infrastructure (CSMI) provides a framework for the development and implementation of mission-level EW threat emitter and self-protection models. These are real-time 'effects-based' models that execute in real-time. The framework allows for the definition of EW systems, which reside on simulated platforms within a scenario and therefore relies on platform position information, extracted from a scenario generation tool such as STAGE.

The framework minimises the coupling between itself (and the models contained within it) and scenario generation environments (such as STAGE and OTB) by implementing an Application Programming Interface (API). In conjunction with this, the use of the eXtensible Markup Language (XML) reduces the level of dependency to the entity database of the scenario generation environment toolbox.

3. CAPABILITY DEVELOPMENT AND APPLICATION OF THE SIL

3.1 Capability Development

The development of the SIL will provide a multi-function application, which is easily adapted to satisfy changing requirements and objectives within the ADF.

Figure 3: SIL Capability Development Implementation

The three primary streams of functionality within the SIL can be categorised as human-in-the-loop (HIL), hardware-in-the-loop (HWIL) and digital modelling. The integration of the three streams provides a consolidated capability to investigate operational, human factors and technological based problems in a measurable and controlled environment.

Significant applications of the SIL, which have been identified as relevant capability areas, are the support to the acquisition process, pilot training, tactics development/mission rehearsal, model validation and trials planning. In addition to the operational applications, significant research and development will continue within the SIL alongside the operational deployment of the facility.

3.2 Support to Acquisition

In providing support to acquisition programs, a method of comparing the performance of alternative systems for procurement will be necessary. Systems that provide seemingly similar functionality will require a scientific mechanism of comparison to determine the best alternative based on the acquisition requirements. The conditions under which the ‘systems under test’ may be subjected to might vary or require much iteration to determine the system specific behavioural attributes including system phenomenology. Conditions that would be important to a study of this nature might include atmospheric/climatic, terrain, flight profile, platform configuration and human operation interaction with the simulation.

The SIL is able to provide a repeatable simulation capability as part of its M&S environment and provide for extensive reconfiguration of terrain profiles with varying levels of detail, modification of atmospheric and climatic conditions that would effect the transmission and processing of EW signals and configuration of the physical platform under test.

3.3 Pilot Training/Situational Awareness

Pilots will require familiarisation with new aircraft platforms, different ASE systems and various terrain environments as part of preparedness activities for war. Effectiveness studies into new situational awareness tools and techniques (both visual and audible) will be necessary to evaluate potential enhancements for platforms. Further researches in this area include studies into human interaction and behaviour within the cockpit and associated situational awareness displays. It is essential to understand how the pilots are affected by the visual displays and audible warnings in the field.

Digital ASE suite models within the SIL provide threat information to a generic multi-purpose display, which the human operator has access to during flights. The communication protocol between the display and the discrete models is Virtual MIL-STD 1553, which allows for the existing display to be replaced with alternative displays. The replacement of these modules allow for the comparison of alternatives to assist in determining the affect that visual displays have on a human operator.

3.4 Model Validation using HWIL

The proprietary nature of system processing architectures and algorithms means that perfect emulation is not easily possible and that effects-based modelling is the typical approach used to represent system behaviour. Having access to ASE hardware and being able to stimulate these systems and determine their response allows for comparison between the digital models and that hardware. This in turn allows for digital model validation and the enhancement of these models to reflect system phenomenology in the synthetic environment (such as emitter track break-up, false alarms), inherent in real system hardware. It is
recognised that the hardware is confined to a laboratory environment and hence there is a limited capacity to accurately emulate real-world conditions. Examples of these physical limitations are atmospheric conditions, spatial configuration of the hardware systems, stimulation effects and interaction of the equipment with other systems and platforms. However, the integration of HWIL still significantly increases the fidelity of the simulation by replacing the digital models with hardware.

3.5 Tactics Development/CMD&V
The SIL is able to significantly support CMD&V activities due to the cost effectiveness of M&S over field trials. This is further compounded by the need to perform many runs of a particular scenario in order to obtain sufficient statistical data to produce effective CMD&V outcomes. M&S should therefore form the basis of any CMD&V plans, and should be a key component of field trials planning and subsequent data analysis.

The SIL contributes to the CMD&V program by supporting experimentation in the following areas:

- Assessment of countermeasure techniques
- Integration of tactics with CM
- Rangeless EW training for operators
- Optimisation of operator situational awareness

3.6 Mission Rehearsal/Trials Planning
The SIL can support mission rehearsal by consolidating discrete capability into an end-to-end scenario to determine deficiencies in the mission plan. Scenarios can be used to focus on discrete elements of a mission or the mission as a whole. This has particular benefit to the testing and validation of Mission Data Files used to program ASE hardware before subjecting it to a real threat environment. The integration of HIL, terrain databases, HWIL, EW models and rapid scenario generation provides the mission level environment in which to conduct experiments to support these activities.

Similarly the SIL environment can be used to pre-plan trials based on perceived ambiguities in the trial plans, to ensure maximum coverage is gained from the trial. In the pre-planning stage, the simulation can provide a level of confidence in the design of the trial. Factors inhibiting design and feasibility might be atmospheric condition, flight dynamics, physical terrain attributes and geography.

4. SUMMARY
DSTO has built the Survivability Integration Laboratory to support survivability experimentation from both an operational and research and development perspective. Best practices have been adopted in maintaining generic interfaces providing optimal integration capability and extensibility. The primary function is for air based platforms, however the generic architecture can be applied to both land and maritime experimentation if necessary.

Adopting commercially available technologies provides a cost effective growth path for the SIL without being dependent on proprietary ‘black-box’ capabilities. Having access to commercial software and source code where possible provides maximum value and enhancement capability for the SIL. The development path for the SIL must be accessible and based on practical and extensible technologies and practices to ensure sustainability.

The CSMI has been integrated into the SIL to provide pseudo-segmentation of the EW interactions from the platform behaviour. The modelling framework provided by the CSMI for the representation of threat emitter and self-protection systems allows for greater model sharing with other simulation facilities. The CSMI relies on a scenario generation package for platform location and behavioural characteristics, which can be provided by any commercially (or otherwise) available scenario generation and management software.

Integrating HWIL significantly increases the fidelity of the simulation by replacing the digital model with the real hardware, allowing system phenomenology to be represented in the synthetic environment. This capability has been enabled in the SIL through the use of industry standard interface protocols, providing a greater level of control over enhancements and extensions to the facility.

The SIL has an interesting future as the battle-space becomes increasingly complex. The continually developing life-cycle of the SIL will see it adapt to the changing nature of the battle-space and continue to transition capability to the ADF, initially through the development of a Ground Support Environment. The SIL will provide the basis of further research into self-protection technology and aircraft survivability, while providing critical operational support to capability sustainment within the ADF into the future.