More than the sum of its parts: Building a fighter operations concept demonstrator

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Abstract

How do we employ simulation devices effectively for training and concept development? This is a crucial research question, given the increasing importance of simulation in these domains. In this paper, we discuss how NLR is developing a concept demonstrator for air-to-air missions, using available project results and facilities.

The demonstrator is based on the Fighter 4-Ship simulator, consisting of four interoperable fighter aircraft mock-ups. The simulator was extended with four components:

(1) an operational fighter controller workstation,
(2) standard debriefing software,
(3) the Weapon Engagement Simulation Tool (WEST) for high fidelity weapon performance
(4) Smart Bandits, a behaviour modelling tool for the computer-generated opponents.

Combined, these components form a battlelab-like environment that is suitable for training, effectiveness analysis and concept development. This demonstrator has been used for activities such as:

(1) validate the use of machine learning in Smart Bandits
(2) assess the potential of new air-to-air weapons

Introduction

Training and concept development for fighter operations are becoming more reliant on simulation environments. Given the additional capabilities of future systems this trend is expected to continue. Not only are simulation devices a safer and more cost effective way to train certain aspects of fighter operations, simulation devices also allow the representations of conditions and scenarios that are very hard to replicate with live training only.

However, the reliance on simulation devices means that the requirements on these simulation devices are increasing as well. After having been used traditionally and primarily for procedure training, they now need to support tactical training as well. This puts different demands on the simulation systems.

NLR is supporting the Royal Netherlands Air Force (RNLAF) in this topic, by means of research projects that assist the air force in preparing to use simulation devices more and with better results in their operations. For example, by letting pilots experience the capabilities of simulation in the research facilities of NLR, so that they are (1) better prepared for future simulation devices and (2) can already anticipate on efficiently using such capabilities.

The many results of these research activities have been integrated into a concept demonstrator for simulating fighter operations. This article describes how this concept demonstrator has been built. Furthermore, we provide two examples that illustrate the value that can be generated with such a concept demonstrator.

Creating a fighter operations concept demonstrator

At NLR, a concept demonstrator for simulating fighter operations has been built that combines (1) existing research facilities, (2) tools and models that have been developed in research projects with (3) operational tools. Starting with the Fighter 4-Ship research simulator, various other components have been integrated. Below, we describe each of the main components of this concept demonstrator and how each component has been integrated in the Fighter 4-Ship simulation environment.

Fighter 4-Ship simulator

The Fighter 4-Ship is a research simulator that consists of 4 fighter cockpit mock-ups. It allows research in various fighter aircraft related topics. The simulator combines (1) high fidelity flight dynamics and avionics simulation software that together represent an F-16 fighter aircraft, with (2) a flexible touch screen for the display of the cockpit instrumentation, allowing easy adaption of the display to the research demands. The cockpit mock-ups and display system are compact and transportable, allowing the simulator to be deployed easily to different locations. This way, s NLR brings the research to airbases and to the pilots.

Figure 1: Fighter 4-Ship simulator

Over the years the simulator has been used for research into human machine interactions, training effectiveness and distributed simulation technologies. Examples of the research are:

- Studying different cockpit layouts, with the touch screen allowing easy prototyping of different cockpit concepts.
- Research with helmet mounted displays (HMDs), made possible by the HMD with colour display that the simulator is equipped with.
- Participants in NATO exercises into Mission Training through Distributed Simulation (MTDS), where the simulator has been connected with other NATO simulators to perform simulated exercises to research how to employ MTDS effectively [3].

Later in this paper, we describe in detail two additional examples of research that was conducted in the Fighter 4-Ship simulator: (1) the validation of behaviour models for virtual opponents that are generated by means of machine learning, and (2) the assessment of the potential of air-to-air weapons.

Smart Bandits

Smart Bandits is a software package that provides a graphical user interface for the creation and execution of behaviour models for computer generated forces (CGFs). Modelling behaviour for CGFs has typically been the domain of computer programmers. Smart Bandits was developed by the NLR in an effort to make behaviour modelling more accessible to other specialists (e.g., training instructors and simulator operators).

Traditionally, behaviour models take the form of scripts, i.e., collections of *if-then* rules that specify what actions a CGF should take under which conditions. Such scripts are constructed in fully-fledged programming languages, or limited specific scripting languages. An example of the latter is the scripting functionality as provided by Presagis Stage, which provides the CGFs to the Fighter 4-Ship. However, the use of scripts means that the person who develops the scripts needs knowledge not only of (1) the desired behaviour of the CGFs, but also (2) how to express this behaviour in the programming language or scripting language.

In Smart Bandits, behaviour models take the form of hierarchical state machines (HSMs). HSMs are a form of automation which is easily visualized. Blocks of behaviour (viz., the states) can be placed together by means of drag-and-drop. In the simulation, the CGF executes the behaviour that is specified in one of these blocks. The developer can specify links between the blocks and include a condition in these links. Once the condition is met in the simulation, the CGF transitions its behaviour from its current block to the linked block. The HSMs in Smart Bandits can be combined with more complex artificial intelligence models, such as goal-based behaviour [7] and cognitive models [8].

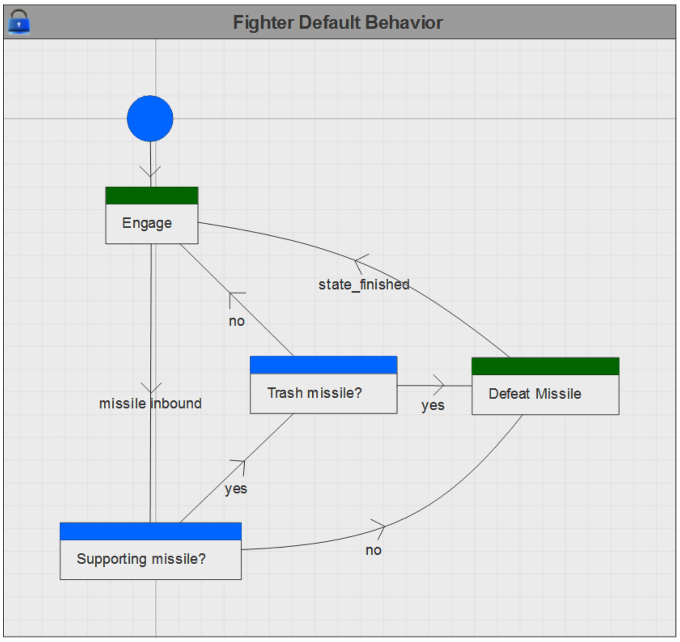

Figure 2: An example of an HSM as it is represented in Smart Bandits (actual partial screenshot).

Figure 2 shows an example of an HSM as it is represented in Smart Bandits. This particular HSM describes the behaviour of a single fighter jet CGF that is attacking an opponent, when it discovers that it is being attacked itself. The model starts executing at the blue circle (top), and then immediately transitions to the *Engage* state (top block). The *Engage* state comprises an additional layer (not shown) in which more specific behaviour is described (viz., it is hierarchical). When the CGF is in the *Engage* state and it believes that a missile is heading towards it, it considers its best course of action. If the CGF is supporting its own missile (bottom block), it proceeds to decide whether it should trash that missile (centre block) based on the expectation of that missile's success. If the CGF decides to trash its own missile, the CGF proceeds to defeat the inbound missile (right block). Then, when the inbound missile is defeated, the CGF reverts back to the *Engage* state. However, if the CGF decides not to trash its own missile, it simply continues to support that missile in the *Engage* state.

The use of a visual paradigm for behaviour modelling allows non-programmers to (1) develop behaviour models rapidly, but also (2) inspect and manipulate the behaviour of CGFs while the behaviour models are being executed. During simulations, Smart Bandits highlights the blocks of behaviour that each CGF is currently executing. By manipulating e.g., the conditions of links between blocks, a training instructor can change the behaviour of CGFs on-the-fly. This way, the instructor can quickly react to emerging training demands, and tailor the behaviour of CGFs to the participants flying in the Fighter 4-Ship.

WEST

The Weapon Engagement Simulation Tool (WEST) is NLR's prime asset for modelling weapon system behaviour and their interaction with targets. It is a modular tool that contains (1) high-fidelity models of projectiles such as guided bombs and missiles, (2) shooter and target models, and (3) sensors including e.g., radars and electro-optical seekers. It is used to (1) evaluate engagements, (2) generate kinematic and acquisition boundaries and (3) calculate Weapon Engagement Zone (WEZ) numbers. When returning from actual training missions, RNLAF F-16 pilots evaluate the missile shots taken by both blue and red air using WEST.

Because of their efficiency and validated accuracy, the WEST weapon model has been integrated into the Fighter 4-Ship simulator, in order to calculate the fly-outs of the weapons that pilots deploy. Furthermore, the model is also used in a faster-than-realtime simulation to calculate the dynamic launch zone displayed to the pilots. Additionally, the model has been integrated into Stage, so as to simulate opponent weapons accurately as well.

Operational tools

NAVAIR's Personal Computer Debriefing System (PCDS) is a Windows-based flight debriefing system that is used by several F-16 operators world-wide, including the RNLAF. It is utilised on a daily basis to debrief actual training missions. Furthermore, its live monitor capability is employed during large scale exercises such as Frisian Flag. PCDS provides a god's eye view of the mission, showing all relevant players over a map of the theatre. PCDS is able to display radar lock lines and shots of missiles, which is done routinely using WEST missile fly-outs.

To be able to simulate the total cycle of typical fighter operations you need more than a flight simulator and good simulation models. It is important that the aspects of planning, briefing and debriefing are also included in the simulated mission. Partly because (1) this ensures that the pilots are performing the simulation mission with a similar mind-set as their real missions, and also (2) to ensure that lessons can be learned from the simulated exercise. To enable pilots to perform the planning and debriefing efficiently at the simulator, it is desired that they can perform these tasks with the operational tools they are used to. Consequently, the simulation system should be able to consume the output of the normal planning software. Furthermore, the recorded simulation missions should be debriefed in the operational debriefing software.

Therefore, the mission files that are generated by the PFPS and Joint Mission Planning System (JMPS) planning software can be used to set up the mission routes in the Fighter 4-Ship simulator. For debriefing, the capability of PCDS to listen to DIS simulation data is used. This allows the simulated mission to be recorded in PCDS. The combination of this recording with a (1) video recording of the displays in the simulated cockpits and (2) the audio communication during the mission allows the pilots to perform a debriefing in the same fashion as after live flights.

Another critical component in fighter operations is the fighter controller that can provide the team of fighter pilots with information and Link 16 tracks about their opponents. To allow fighter controllers to perform their task realistically it is best to let them use the software they also use operationally. Therefore, a Multi –AEGIS Site Emulator (MASE) station [6] has been connected to the Fighter 4-Ship simulator. The capability of MASE to interoperate using the DIS [4] and SIMPLE [5] protocols allows this operational software to be connected with a simulation environment. Furthermore, by adding a DIS radio to the fighter controller workstation they can perform all their interactions with the virtual team of fighter pilots . The inclusion of fighter controllers to the setup not only provides a more realistic environment to the pilots, but also gives the fighter controllers the opportunity to train realistic or unusual scenarios and debrief directly with the pilots.

Example usage 1: Experimental validation of machine-generated behaviour models

Recently, the NLR has been investigating the use of machine learning for the automatic generation of CGF behaviour models ('enemy models'). We identify two major benefits to the use of machine learning here: (1) subject matter experts (SMEs) are no longer required to create new behaviour models, thereby saving time and resources, and (2) the use of machine learning provides the prospect of CGFs that adapt their behaviour to that of the participants in the simulator.

So far, we have focused on the use of machine learning to specifically generate air combat behaviour models (see, e.g., [1][2]). However, an important step in the use of machine learning is determining whether the generated behaviour models provide training value in actual simulations. In other words, the generated behaviour models need to be validated.

To date, there are few (if any) formal specifications for CGF behaviour by which we can validate newly generated models. The reason for the lack of specifications is that behaviour models must produce correct behaviour at all times, viz., in response to any behaviour that is displayed by the human participants in a simulation. As a remedy, we employed the knowledge of SMEs in our validation. We did so in two forms: (1) we used behaviour models that were designed by SMEs in Smart Bandits as a reference point for the newly generated models, and (2) a group of other SMEs assessed the behaviour that was produced by both the manually designed models and the generated models in simulated engagements between CGFs and human participants.

In order to obtain a sample of the behaviour produced by the two kinds of models, we used the models to control the behaviour of a *red air* four-ship of CGFs in the Fighter 4-Ship. Six groups of four Royal Netherlands Air Force (RNLAF) F-16 pilots engaged the CGFs in a predefined scenario. The engagements were recorded by means of PCDS, and later shown to the aforementioned group of SMEs. The SMEs assessed the behaviour of *red air* in these recordings using a newly developed questionnaire.

As the measure of validity of the generated models, we required that the assessment scores obtained by the generated models were equivalent to those obtained by the manually designed models. This measure is based on the assumption that the manually designed models produce behaviour that is *good enough* for training simulations, and that we therefore desire behaviour that is *at least as good* from the generated models. The results of the validation will be reported at a later date. In the future, the assessment scores provided by questionnaires as we have used in our validation may reveal insight into (1) the desirable features of CGF behaviour, and (2) methods for computationally detecting the presence of such features in the behaviour of CGFs.

The use of the Fighter 4-Ship aided the validation in three different ways. First, the use of protocols such as DIS allowed us to easily connect new software packages, such as a custom package that implemented our machine learning algorithm. Second, because the Fighter 4-Ship uses COTS software packages, the software stack is easily replicated at other locations for local development purposes. Third, the use of familiar, industry standard tools (e.g., PCDS) made it easy to incorporate the help of SMEs in (1) the development of the behaviour models and (2) the validation procedure.

Example usage 2: Assess potential of A/A weapons

The set-up as described above, which integrates the Fighter 4-Ship, the MASE fighter controller station, WEST missile models, Stage, Smart Bandits and PCDS can be used to realistically simulate Beyond Visual Range (BVR) Air-to-Air (A/A) combat. Human pilots occupy the Fighter 4-Ship cockpits while the Smart Bandit CGFs act as their opponents. In this set-up, WEST not only provides missile fly-outs, but is also used to display the so-called Dynamic Launch Zone (DLZ) in the F-16 cockpits.

When making a radar lock on a potential target with a missile selected, the F-16 shows a DLZ on the Head-Up Display (HUD) and radar Multi-Functional Display (MFD). The DLZ indicates five important kinematic ranges based on (1) the missile performance and (2) the relative geometry of the F-16 and its target. One of the five ranges that is shown is, for example, the maximum range at which the selected missile can be shot effectively if the target continues to fly with its present heading and airspeed. Another, shorter, range which is indicated on the DLZ is the maximum range at which the missile still intercepts its target when the target immediately starts a high-g turn towards tail aspect with respect to the missile at missile launch. The DLZ is an extremely important tool for tactical decision making in A/A engagements.

The ranges in the DLZ are dependent on a large number of variables: not only the missile performance itself is important, but also parameters such as shooter airspeed and pitch angle and target aspect, angle off, airspeed, etc. The number of variables is of such magnitude that it is virtually impossible to populate tables that cover all conditions. These tables would simply become too large to remain manageable. Additionally, such tables are very time-consuming to pre-compute. Instead, WEST calculates the DLZ in a manner that is faster than real-time. In order to determine all ranges in the DLZ, more than 50 complete fly-outs of the missile against the target are calculated. This procedure is repeated several times per second in order to display a smoothly transitioning DLZ.

The A/A missile models of WEST are characterised by several parameters. These consist e.g., of (1) the thrust of the rocket motor as a function of time and (2) the drag coefficient as a function of the Mach number. It is possible to model another type of missile by changing these parameters. In the present set-up, this not only affects the fly-out of missiles shot in the scenarios, but, because of the construction described above, immediately changes the DLZ as well.

The RNLAF has been using the AIM-120B as their medium range A/A missile for the F-16 fleet for a number of years. With the introduction of the F-35 however, it is impossible to continue to use this missile type, since this missile will not physically fit into the F-35's internal weapon bays. The RNLAF is therefore acquiring a new medium range A/A missile for its F-35 fleet, where it is considering several candidates.

In order to compare these missile candidates in a tactically relevant environment, they were modelled in WEST and implemented in the battlelab-like set-up described above. As a special feature, the indications in the cockpit were changed, allowing the simultaneous display of two DLZs (see Figure 3). Although the left and right DLZ can be selected at will, the usual setup was to have the left DLZ as the AIM-120B and the right DLZ as the candidate missile. This would give a good reference for comparison with the candidate missile, since the performance and characteristics of the AIM-120B are well-known to experienced RNLAF F-16 pilots. In some instances, however, the DLZs of two different candidates were shown next to each other, so as to mutually compare the performance of two candidate missiles.

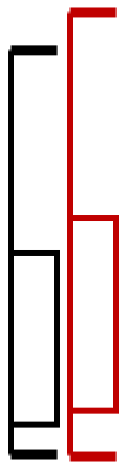

Figure 3: Schematic representation of dual DLZ

A mix of both operational and staff F-16 pilots was invited to experience this set-up and evaluate several candidate missiles. During the evaluation, it was generally agreed upon was that this is a suitable environment to compare the capabilities of missiles. The great benefit of the present approach is that it provides (1) a dynamic and tactically relevant environment and (2) a direct mutual comparison between two missiles. It was also felt that the same set-up is suitable for Concept Development and Evaluation (CD&E) when specifying or developing new missiles. Finally, it was considered beneficial to adopt the two DLZ display in actual fighter cockpits, when flying with a mixed loadout of more than one A/A missile type.

Conclusions

In this paper, we have described the creation of a fighter operations concept demonstrator. This demonstrator consists of (1) the results of research projects, and (2) operational, industry-standard tools. The demonstrator allows rapid CD&E in an environment that is familiar to the intended operators, such as fighter pilots and fighter controllers. We reviewed two examples of CD&E in the demonstrator: (1) the validation of behaviour models for CGF that have been generated by means of machine learning, and (2) the assessment of the potential of A/A weapons.

We conclude that by smart integration of existing parts, we are able to take important steps in simulation research in a manner that is operationally relevant, yet highly cost-effective.

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