Analysis of Military Aircrew Training Systems

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Abstract. The essential characteristics of a detailed functional model that can be employed to analyse a broad range of aviation training systems in the commercial and military worlds is examined. The requirements for the model have been developed with two key drivers: firstly, it must be general enough to model training systems that cater for different trainees (from cockpit crew including pilots, air combat officers and flight engines to aircrewmen, loadmasters and systems operators) from different organisations (including defence aviation, police and emergency services, commercial airlines and charter flight agencies) using a variety of training media (including aircraft, synthetic devices and academic instruction) and a variety of aircraft types (Cessna 152, Pilatus PC-9/A or PC-21, PAC CT/4 or T-6 Texan, Augusta Westland AW-109, Eurocopter EC-135, Bell 429, etc) at different levels of competency (from ab-initio trainees to qualified instructors) and who will go on to assume roles on different operational aircraft (from helicopters and passenger aircraft to transport aircraft and fast jets). Secondly, the requirements must be independent of the particular simulation application that may be chosen to model the training system. We demonstrate that this approach to the modelling and analysis of training systems produces results that can be verified against real-world training data at every stage of the approach.

1. INTRODUCTION
The design of a flight training programme is a challenge comparable to the twelve labours of Hercules. While the actual provision of training services on a day-by-day basis may be uncomplicated, the development and management of new training programmes for pilots and other aircrew is a highly complex endeavour.

With performance-based contracting becoming the norm in the commercial and military aviation worlds, decisions relating to the composition of the training curriculum and resourcing levels (aircraft fleet size, instructors, flight simulators, etc) need to be made and agreed upon prior to the actual roll-out of training programmes. Minor variations in resource planning estimates could mean the difference between profitability and not meeting performance benchmarks.

Thus, it is critical to have confidence in your resourcing decisions in the design phase of a training programme’s lifecycle. At the Systems Analysis Laboratory (SAL) in Boeing Defence Australia, we have developed a robust, high-fidelity and user-friendly decision support tool that allows for the rapid modelling of a training programme and the simulation of ‘what if’ scenarios to determine the effectiveness of the programme and the optimal resourcing mix needed to implement it.

The rest of this paper is organised as follows: Section 2 spells out in detail the essential requirements of an aviation training programme. Not all of the stated requirements in the next section have the same influence on the answer to any one particular question that a training system model is employed to investigate. Some requirements may prove superfluous, depending on the question being analysed. However, our experience has been that during the design phase of a training programme, a model is expected to support decision-makers across a very broad range of queries. (An example question is the number of Full Flight Simulators needed in a pilot training programme to produce X pilots in Y months where N intakes of M pilot trainees are scheduled per year.) As such, the greater the fidelity of the model, the more versatile it is and the greater its utility to training solution designers. Hence, all of the essential requirements detailed in Section 2 warrant inclusion in a useful model.

Section 3 outlines our approach to mapping the requirements to functional blocks that can then be simulated. The approach is general in two ways:
firstly, it can be readily adopted for modelling solutions to proposed defence projects such as AIR 9000 Phase 7 (Helicopter Aircrew Training System), AIR 5428 (Fixed Wing Pilot Training System) and AIR 5232 (Air Combat Officer Training System) or changes to existing training programmes. Secondly, it is independent of the simulation application that is chosen to analyse solutions to a training programme.

Section 4 describes the Generic Aircrew Training (GAT) Model that we have developed in the SAL as a decision support tool for the business. It is ‘generic’ in the sense that it can be applied to model a wide variety of training programmes. Thus, it is purely data driven. We also present some limitations of the underlying commercial-off-the-shelf simulation application upon which we have developed the GAT Model.

Section 5 presents the actions we have taken to overcome such simulation tool-based limitations in analysis and visualization by integrating the GAT Model with BASE, a software product developed in-house that provides a richer environment for the rapid ‘mining’ of the output data generated by the GAT Model.

2. REQUIREMENTS

The key characteristics of an aviation training programme are listed below.

2.1 Training Curriculum

A training curriculum includes a list of events that a trainee must successfully complete. An event could be classroom-based academic instruction, flying sessions in a training aircraft or simulated flying sessions in simulators. Classroom-based academic events are usually done in groups. Under exceptional circumstances, a trainee may receive such an instruction on a one-to-one basis from the instructor. Actual flying or simulated flying events are generally undertaken individually. Again, there are some exceptions when two trainees may be required to complete such an event.

All events associated with a trainee mastering a particular competency are grouped into a module (or phase). Hence, depending on what role a trainee aspires to upon completion, a curriculum needs to be developed for each role such as pilots, navigators, loadmasters, etc. The training curriculum tailored to that role will be referred to as a course.

For example, a pilot training course may contain eight modules. The first module may be largely devoted to learning the basics of flying. As such, it will be mostly classroom-based academic instruction. Subsequent modules may focus on instrument flying or night flying. These will be undertaken mainly in the aircraft or simulator.

The above example can be generalised: a curriculum is defined as a hierarchy, consisting of a course, a handful of modules within a course and several events (of varying types) within each module.

Within a curriculum, the modules and events must be ‘ordered’ in some way so that trainees will be able to do their training in some sequence. This prescription for order arises due to the requisite level of competence needed to undertake certain modules or events. So, by and large, all trainees in a class doing the same course will do their events in the same sequence. However, some latitude should be provided for trainees to be able to do their events out of order – especially for events where no such pre-requisites exist.

Another reason for requiring flexibility in a curriculum is to smooth out demand on training resources that are in short supply. For example, if two back-to-back simulator events are scheduled for air combat officer trainees, it may be prudent to have half of them do those in reverse order to the other half so that simulator usage by that student class is less uneven over time. Such flexibility not only results in better utilization of resources that are responsible for ‘bottle-necks’ in a training system, it also reduces waiting times for trainees – and thus course completion times in general.

Any process model developed to investigate aviation training programmes must provide for the capture of the above details. The depth of a curriculum is a key driver of course completion times. A compact curriculum may afford a greater throughput of trainees graduating in a year - but perhaps at the expense of compromising the level of competency that they individually need to demonstrate. On the other hand, an in-depth curriculum may churn out trainees who are highly skilled; but too few of them in a year. Finding the right balance between the number of trainees and the quality of trainees is one question that training system models should be capable of analysing in detail.

2.2 Trainee Arrivals

Scheduling trainee intakes at the right time of the year is important. If trainees from different courses find themselves requiring completion of simulated flying on the FFS in the same week, then their waiting times to get through that bottle-neck may be lessened if the start dates for the different courses could be staggered by a week. Where possible, adjusting the starting dates for the intakes permits training course designers to smooth
out the peaks and troughs in demand for scarce resources.

Furthermore, trainee numbers in a class also can be a variable that can be analysed for its impact. For example, is it better to split a class of 20 Army pilots into two smaller classes of 10 and have them start one week apart? Is it better still to further split them into four classes of 5 trainees each and stagger their start dates by a week? A model should provide for the analysis of such questions in order to arrive at an optimal decision within the constraints of what is permissible (or sensible) in a real training environment.

### 2.3 Resources

Training resource are any personnel or items needed by the trainees to undertake their training. For example, flight training programmes require flight instructors (at different category levels), training aircraft, simulators, classrooms, briefing rooms, and so on. Aircrew may also require additional ancillary equipment in a training aircraft. Furthermore, other resources such as aircraft maintenance staff, airspace restrictions, air traffic control staff and aviation fuel also need to be modelled. In order to make an individual trainee’s progress dependent on the availability of resources, the particular resources that are needed to complete an event must be specified for each and every event in a curriculum. This attachment of resources at the event level is an important requirement. This is to enable a model to know which resources - and how many of each - need to be available for a trainee to complete an event. This requirement implies that when one or more resources that are needed to do an event are unavailable, the trainee must wait until such time that all resources are available again. That is, the model must be able to postpone or reschedule training events based on resource unavailability.

The explicit inclusion of resource considerations within a model, therefore, gives rise to the need to include the operational availability of resources as well. This can be considered in two ways: (a) a stochastic approach to determine whether a particular resource is available or not at a particular time based on its mean operational availability (operational availability is an input here) or (b) a discrete event simulation approach to derive a particular resource’s availability based on its supporting functions (operational availability is an output here).

The latter approach is a separate Herculean task in its own right. For example, if the resource in question were the fleet of training aircraft, then the operational availability of individual aircraft in the fleet will depend on a number of factors including its airframe hours, scheduled and unscheduled maintenance regimes, repairs and overhauls, inventory of equipment and parts and so on. In fact, its whole supply chain, including the maintenance staff, need to be modelled to predict its availability with reasonable accuracy.

### 2.4 Working Hours

This refers to the hours during the day when a resource is available for training. For example, a flight instructor may not be available for training outside of normal business hours or a simulator technician may only be available during the morning shift. Working hours (or operating hours) is similar to operational availability: that is, outside of a resource’s working hours, it is deemed unavailable. Thus, for a resource to be available for training, it must be deemed operationally available as well as fall within its working hours.

Extending or shortening the working hours of various resources has a significant impact on the progress of trainees. How this pace of progress is balanced against the daily work load of individual resources is a question that training models must help answer.

### 2.5 Cancellation Rates

This requirement refers to the likelihood of a scheduled training event being cancelled or postponed. The reasons that trigger a cancellation or postponement are manifold. Bad weather, aircraft not being available, training equipment or supplies such as Night Vision Goggles, maps or fuel not being available, training area not being available, training circuit being saturated, and the Air Traffic Control not being available are some of the main triggers for flying event cancellations.

Event cancellation rates are highly variable. If the model is simulating a future training solution, then it must first be validated against present (or past) programmes by using real-world cancellation data from training event logs. If a training programme is offered across multiple locations, then the cancellation rate due to bad weather must be adjusted for the likely weather conditions in each location.

Event cancellation triggers for simulator events can be different to those for flying events. In general, flying events are more likely to be cancelled than simulator events. The likelihood of classroom-based events being cancelled is even less so. The model must provide for cancelled events to be re-scheduled for a later time. The model must also provide for some cancellation triggers to affect multiple events. For example, bad weather may force all flying events scheduled for the day to be cancelled. Strong winds may only impact on helicopter pilots scheduled to practice their hovering and not impact on other flying events. Such cause and effect relationships need to be included in a model, too.

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**Figure 4:** A Marshalling Simulator will have greater availability than its real-world counterparts (training aircraft + training vessel).
2.6 Trainee Pass Rates
This is the likelihood that an individual trainee will pass a particular assessed event in his or her curriculum. As such, pass rates will vary depending on the trainee and the event. Abstracting above these dependencies, typically, pass rates are lower at the start of a module (as trainees come to grips with the learning outcomes required of them) than in the middle (when trainees have become more competent). Pass rates reduce again at the end of a module as assessments get more difficult.

Good training models must incorporate such user-defined bathtub-shaped curves. Usually, ground school events have the highest pass rates, followed by simulator events and then more complex flying events.

2.7 Remedial and Re-test Process
When trainees fail an assessed event, a remedial plan must be assigned to them. For example, if trainees fail a routine flying or simulator event, they may have to complete tutorial sessions with their instructor before re-flying the failed event. If trainees fail a critical simulator event, they may have to complete tutorial sessions, spend time with a psychologist and some more time in the simulator before re-flying the failed simulator event. If trainees fail a critical flying event, they may have to do all of the above and some more time in the aircraft before re-flying the failed flying event. A detailed remedial plan is a must-have requirement for training models.

2.8 Non-Training Days
This refers to the weekdays when no training occurs - such as public holidays, base safety days, and the stand-down period during the Christmas/New Year break. Other unscheduled non-training days - such as base closure due to natural disasters – may also warrant inclusion.

3. APPROACH
Once the requirements detailed in the previous section are captured in a model, how the actual conduct of day-to-day training is realized needs to be modelled, too. The distinction between requirements and the modus operandi of training is a subtle one. Hypothetically, two flight training schools in different countries may train commercial pilots using an identical mix of resources and curricula. But one school can consistently churn pilots out faster than the other. One reason may be the different health and safety regulations that the two schools subscribe to. In this section, we focus on modelling the concept of operations for aviation training.

3.1 The Conceptual Model
Our modelling approach aims to preserve the subtle difference between the inputs to the model and how they are processed during a simulation. The manner in which this has been done is to first develop a conceptual model of training that is independent of any modelling implications to follow later.

Figure 5: A Conceptual Model for Aviation Training.
Figure 5 shows a conceptual model of aviation training that has been stripped to its bare essentials for ease of explanation. It can be thought of as a flowchart of events from the trainees’ perspective as to what they can expect from enrolment until graduation. Upon arrival, trainees are assigned their respective curricula. This is followed by two nested loops that trainees go through repeatedly until they emerge from the training system in one of two ways: course completion or course suspension.

The outer loop governs trainee progress at the module level and the inner one at the event level. Every time a trainee traverses the outer loop, he or she would go through the inner loop several times. Progress in the inner and outer loops depends on the trainee passing the assessed events and modules, respectively. Where trainees fail assessed events, they are assigned remedial events that they have to successfully complete before joining their course mates. This is denoted by the right-hand branch to the inner loop.

Trainees spend their time in two ways in the conceptual model. Firstly, time is taken to complete their training events, the duration of which is specified in the curriculum. The total amount of time spent on this is the absolute minimum duration for a trainee to graduate. This minimum is a constant for all trainees who do the same course. Furthermore, this minimum is independent of resource levels (i.e. the minimum is achievable only with infinite resources).

Secondly, trainees must wait for resources to become available. This time is wasted and is dependent on resource levels. It can also vary among trainees who do the same course. Nor is waiting restricted to resource unavailability only. Naturally, trainees need to wait out week-ends, public holidays, etc. Trainees may also have mandatory rest periods to contend with between back-to-back simulator events or flying events. A trainee’s course completion time can be defined as the sum of the absolute minimum (driven by curriculum) and the total waiting time (driven by resource levels and regulatory constraints). Much of the focus in training systems analysis is on seeking a balance between resource levels and course completion times.

The advantage of developing a conceptual model is that it can be verified and validated by aviation training subject matter experts who may care very little for modelling.

3.2 The Functional Model

Once a conceptual model for a training solution is given the thumbs-up by the training experts, its constituent parts need to be mapped to functional blocks in a chosen simulation tool. Figure 6 below shows the functional model for an ExtendSim™ realization. Each functional block (blue rectangle) can be uniquely mapped to activities (green and brown rectangles) in the conceptual model in Figure 5. For example, any training model, regardless of the simulation tool chosen to realize it, will require a trainee arrival process. In ExtendSim this will be achieved by using an Create Item block.

![Figure 6: An ExtendSim Functional Model for Aviation Training](image-url)
4. THE GAT MODEL

We developed a process model, called the Generic Aircrew Training (GAT) model, in ExtendSim that takes into account the requirements detailed in Section 2 and using the approach outlined in Section 3. ExtendSim is a versatile commercial-off-the-shelf discrete event simulation tool that is perfect for modelling any process that requires the scheduling of events based on complex criteria – such as aircrew training programmes. We are presently able to simulate 10 years’ worth of training in 2 minutes.

What the GAT Model does is to simulate the training activities of aircrew trainees from enrolment to graduation. It takes into account the likely factors that most impact on a trainee’s rate of progress and produces performance measures to indicate how efficient or otherwise the training programme is. The factors that affect trainee progress are many and varied: the key ones are the depth of the training curriculum, aircraft, simulator, instructor and other resource numbers, operating hours for the resources, the number of intakes (classes) per year for a course and the number of trainees in a class, maintenance activities, weather and other considerations that induce delays, and non-training factors that place demand on the resources (e.g. secondary missions, maintenance flights for aircraft and currency training for instructors). The GAT Model has been successfully validated using the data from the Helicopter Qualification Course (HQC) at the Army Aviation Training Centre in Oakey.

ExtendSim’s rich capabilities in modelling any kind of process is not matched however, by its capabilities to display results as graphs or charts. In the GAT model where the volume of output data being captured is very large, ExtendSim’s inherent ability to enable an analyst to ‘slice and dice’ the output results in meaningful ways is limited, too. For example, if you wish to look at only the flying events from the list of all the recorded events in an output table, then a ModL script in a Value Equation Block is needed to read the relevant records from that output table and write to another output table. If you wish to now narrow your interest to flying events undertaken by Navy Aircrewmen who have been assigned C-CAT instructors, another ModL filtering script is required.

Depending on the follow-up questions that spring up from the results furnished by the GAT model, dozens of such scripts need to be written and tested. If this process can be automated – and also improve the quality of the visual displays in the meantime – then that would significantly cut down the time spent on model development, validation and verification, customer engagement and presentation.

5. SAMPLE OUTPUTS

The above objective is precisely what we have accomplished by integrating the GAT Model with the Boeing Analysis for Simulation Environment (BASE) software tool, a product developed and supported by the SAL. The output tables from the GAT Model are exported in a manner that can then be directly imported by BASE. Three sample outputs from BASE are explained below.

Figure 7 shows course completion times for pilots in a military helicopter training school that caters for different types of aircrew. In BASE, metrics such as time to train in a particular course, broken down by time to complete individual modules in it, can be readily built from the training events log.

Figure 8 shows the number of simulator events done in a day at the same school. It is broken down into events done on different simulator types. Such displays allow course designers to draw insights about where the bottlenecks related to different simulators are and how to remedy them.

Finally, Figure 9 below is a bar chart that shows the number of sorties flown in a day – coloured by daytime (red) and night-time (blue) flights. Knowing when most of the night flights need to occur allows course designers to apportion the right amount of resources for such peak periods.