**Nationaal Lucht- en Ruimtevaartlaboratorium**

National Aerospace Laboratory NLR

## Executive summary

# Adaptive training methodology: skills analysis for the design of a Targeting Pod training programme

Finding and tracking a target, and delivery of a weapon onto the target, using a targeting pod (TGP) requires a highly complex set of skills of a fighter pilot. Considerable amounts of training time and effort are required to master these complex skills. However, available training time is limited. Training effectiveness can be improved by using adaptive training, meaning that the difficulty of the task being trained is varied as a function of actual trainee performance. This paper describes a skills analysis method that facilitates the design of an adaptive training programme for mastering TGP skills based on the 4C/ID method, which assumes that complex skills should be mastered by practicing whole tasks like e.g. typical TGP missions. A start has been made with a systematic analysis of the complex skills that are required for operating the TGP is carried out in consultation with experts. Based on an operational conditions analysis, the difficulty of the task (and hence the level of required skills) is determined. Final results of this analysis can be used to adjust the actual training level related to trainee performance. This focus of the report is on presenting a method to enable adaptive training. TGP training serves as a very suitable application area and a start has been made towards an exemplary training analysis for this application area.

**Report no.**
NLR-TP-2007-820

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**Report classification**
UNCLASSIFIED

**Date**
November 2007

**Knowledge area(s)**
Aeronautical Human Factors,
Training & Flight Simulation

**Descriptor(s)**
adaptive training
complex skills
fighter pilots
whole-task training

This report is based on a presentation held at the HFES Europe Chapter Annual Meeting Sheffield, UK, 8-10 November 2006.

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| | |
|---|---|
| Customer | NLR |
| Contract number | ---- |
| Owner | NLR |
| Division | Air Transport |
| Distribution | Unlimited |
| Classification of title | Unclassified |
| | November 2007 |

**Approved by:**

| **Author** | **Reviewer** | **Managing department** |
|---|---|---|
| | | |

# Contents

## Abbreviations

| | |
|---|---|
| 4C/ID | Four Component Instructional Design |
| ADAPT$^{IT}$ | Advanced Design Approach to Adaptive Training – Interactive Tools (EU project) |
| CCTV | Closed Circuit Television |
| IR | Infrared |
| EU | European Union |
| TGP | Targeting pod |

# 1 Introduction

A typical task for a fighter pilot is to eliminate an indicated enemy target. To facilitate this task modern fighter aircrafts are equipped with a targeting pod (TGP). The camera of the TGPs allows the fighter pilots to see the environment farther, sharper and more detailed, and therefore improve their ability to precisely pin-point an enemy target. The TGP is controlled via multifunctional user interfaces (Multi-Function Displays or MFDs). Given the high velocity of the aircraft to minimise amongst others exposure time to threats, it follows that the operation of the TGP requires complex skills. Training of those complex skills takes considerable time. However, available training time is limited. Therefore the training has to be efficient, i.e. it has to produce the desired effect in a minimum amount of time. A training programme is considered to be effective when the necessary skills mastered in training situations are transferred successfully to real-life situations. A training programme is efficient when it realises the same effect for less (e.g. time, effort, or money). Efficient training takes place when training is at an appropriate level of difficulty. The essence of adaptive training is that the difficulty of the training programme is adjusted based on how well the trainee is performing during the training such that it realises the same effect in less time than a fixed training programme.

This report focuses on presenting a method to enable adaptive training. TGP training serves as a very suitable application area and a start has been made towards an exemplary training analysis for this application area. Note that completion of the analysis does not fit into the scope and timeframe of the NLR project “Adaptive Training”.

The next section will briefly outline training design principles that ensure effective training and provide a basis for adaptive training.

## 2 No efficiency without efficacy: the 4C/ID method

If a training programme has poor transfer to real-life situations, making this programme adaptive will not likely result in a high transfer. Van Merriënboer's (1997) 4C/ID (Four Component Instructional Design) model meets the requirements for designing an effective training programme for the following reasons. First, 4C/ID intents to design the training programme so as to maximize the transfer of skills from the training environment to real situations. The focus on the integration and coordinated performance of task-specific skills is a central design aspect of 4C/ID. Second, the 4C/ID model recommends a mixture where part-task practice supports the complex whole task learning. Finally, the 4C/ID method uses standard performance requirements as the criterion when assessing the trainee's actual performance.

4C/ID based training contains a sequence of whole tasks, a set of part tasks, and two types of knowledge presentation. The sequence of whole tasks is formed by main learning tasks which aim to integrate sub-skills by emphasising authentic, whole-task situations from the very beginning. "Authentic" means that the exercises are derived from real practice. "Whole task" implies that sub-skills should be practised in an integrated way. Learning should be practice-based, and training should focus on integration of the complex skill as a whole, instead of isolated sub-skills. To prevent that trainees get overloaded, training should start with simple situations, which gradually become more complex. Furthermore, learning tasks of similar difficulty, but varying in operational conditions and particular problems, should be grouped together. Learner support is provided to a high extent in the first learning tasks, which is decreased gradually such that finally the trainee is able to perform the task without support. The set of varying learning tasks with similar difficulty and gradually decreasing amount of learner support is called a task class. The sequence of task classes makes the backbone of training and will be designed first. The part tasks are designed for those actions that require a high automatism and need to be trained extra to gain these automatisms. Only after having sequenced whole and part tasks, knowledge items are being added to the design in order to support either insight (supportive information presentation) or task execution (just in time information presentation).

The 4C/ID model forms the basis for the adaptive training principles that are currently being developed at the National Aerospace Laboratory for the purpose of TGP Training. A previous attempt to use 4C/ID principles for adaptive training was a project using fuzzy logic principles (Van Merriënboer, Luursema, Kingma, Houweling, & de Vries, 1995). A 6$^{th}$ Framework EU project (ADAPT$^{IT}$, Van der Pal, 2003) was dedicated to develop a pragmatic version of 4C/ID and to ease the construction of adaptive algorithms. The resulting ADAPT Method (De Croock, Van Merriënboer, Van der Pal, Abma, Paas & Eseryel, 2002) has identified more specific ingredients for adaptive training and made it easier for training designers to use them. A recent project focused on a particular algorithm in which trainee performance and mental workload were used to select the next exercise in a part task sequence (Salden, 2005). While these efforts were successful or promising, they were providing adaptive training only in a limited way and did not provide a systematic adaptive principle for the full training design method.

The next sections attempt to relieve the design gap for adaptive training programmes. The starting point for a well-developed adaptive training programme is a systematic and sufficient differentiation of difficulty levels, combined with an easy application of these difficulty levels. Only then, the task difficulty can be optimized to the individual trainee's needs. This paper discusses a method that systematically differentiates between difficulty levels of the task. The method will be illustrated with the target targeting task.

# 3 Efficient adaptive training programme: the adaptive variable

Efficient training takes place when training is at an appropriate level of difficulty. Each adaptive training programme consists of three elements: an element that can be adjusted (the adaptive variable), an element that measures how well the trainee is doing (the performance measurement), and an element that changes the adaptive variable based on the performance measurement (Kelley 1969). In Figure 1 these elements and their relationship are illustrated. The appropriate level of difficulty is realised through the adaptive variable. Therefore, the critical element of an adaptive programme is the design of the adaptive variable.

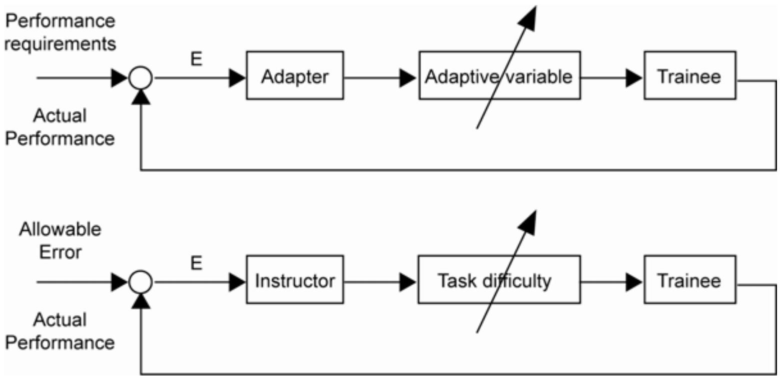


*Figure 1: Elements of adaptive training environment. The adapter is played by the instructor, the adaptive variable can be any adaptable component of the training environment; the variable that is chosen is the task difficulty because it comes close to the variations that occur in real life situations.*

## 3.1 Defining the adaptive variable: task difficulty

The adaptive variable can be any component of the training environment that can be adjusted, for example the performance requirements, the amount of learner support or the difficulty of the task. It is impractical to vary all the possible components together. Therefore some decisions have to be made with regard to the choice of the adaptive variable.

In contrast to most training principles, the 4C/ID ideal is to keep the performance requirements at the required (real life) level already from the start of training. In practice, standard performance requirements define a maximum allowable deviation from pre-set targets. For instance, a beginning pilot must land the aircraft safely on the runway as well as the expert pilot. However, the expert pilot may be allowed to land under more severe conditions like having more side-wind or using a short runway. Due to its resemblance with real life it is not illogical to use the allowable performance error as the standard at which the performance of the trainee is measured. Naturally, such standards are difficult to reach for trainees without introducing certain instructional arrangements and/or environmental conditions.

The primary instructional instrument to accommodate to trainees is the task difficulty. This is a variable that can be considered as the global tuning knob on old radios. The radio channel searched for may be reached, but it is not easy to set it sharp. For fine tuning, another control is required. A similar principle is suggested by 4C/ID. Once a rough indication of task difficulty has been set (for a range of training tasks), further fine tuning can be achieved by varying the learner support to ensure the trainee can deal with the given task.

In this paper we focus on the primary variable: task difficulty. How the standard for the allowable performance error and the function between the actual error and the task difficulty should be designed is not discussed in this paper.

### 3.2 Analysing the task difficulty

A task requires a set of actions, and is person independent. The way an individual person carries out the required set of actions are the skills. Skills are person dependent. Some skills take more time to master than other skills. The task difficulty depends on the number and type of actions that have to be combined concurrently and on the precision this combination has to be carried out. A task becomes more difficult when more actions have to be executed simultaneously. The type of action also determines task difficulty (compare ‘making decisions with incomplete information’ with ‘executing a standard procedure’).

To determine the task difficulty, the task has to be analysed based on the required actions that have to be carried out concurrently including the precision of their (concurrent) execution. Actions that are interrelated such that they cannot be trained separately are combined into action sets. An example of a set of actions that cannot be separated is, for instance, engaging the clutch and pressing down the gas pedal when driving off in a vehicle. The analysis is illustrated in Figure 2.

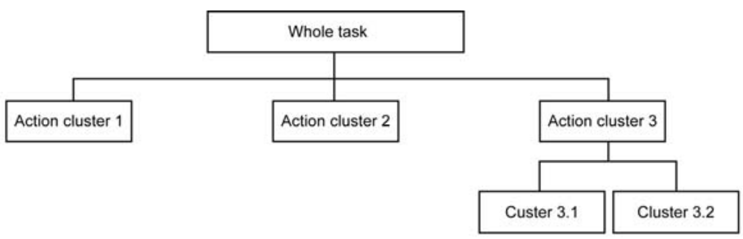


*Figure 2: Action (skills) analysis and combined actions based on a whole task*

The number of actions that has to be carried out concurrently and the required precision (i.e. the task difficulty) can be manipulated by system and by operational conditions. An example of system conditions that influence the difficulty of the task driving-off is the kind of car that is used. Driving-off is classified as more difficult for a petrol car than for a diesel car, because for a (low-power) petrol car it requires a concurrent combination of engaging the clutch and pressing down the gas pedal whereas for a diesel car it may require only engaging the clutch. Operational conditions can be the weather, day time, traffic, the target, or the slope of the road.

During normal basic training, system conditions do not change during the task, e.g., .there is no unexpected malfunctioning of the system. Therefore, the operational conditions remain for manipulating the task difficulty.

### 3.3 Structuring the differentiation of task difficulty

The differentiation of the task difficulty from easy to difficult should be logical and should lead the trainee through a sequence of task difficulties that are highly relevant to the skills he is expected to master (Kelley, 1969). For structuring, two basic methods of differentiation can be distinguished, the part-task and the whole-task methods. Part-task methods differentiate between task difficulties by isolating part tasks from the whole task. The trainees are lead through the part tasks one by one. Once they have reached the required performance level for a part task they are offered another part-task until they are able to carry out the whole task at the required performance level. The progression method from the part tasks to whole task can be pure part-task training, progressive part-task training, or repetitive part-task training. Whole-task methods offer a whole task directly at the outset of the training. The whole task ideally incorporates all the interrelated skills the trainee has to master. The training starts with the easiest whole task that can be encountered in real life and progresses to the most difficult whole task. The difference between part-task and whole-task progression methods is illustrated in Figure 3.

| Whole task | | | |
|---|---|---|---|
| Cluster 1 | Cluster 2 | Cluster 3 | |
| | | Cluster 3.1 | Cluster 3.2 |
| Level 1 | Level 0 | Level 0 | Level 0 |
| Level 2 | Level 0 | Level 0 | Level 0 |
| Level 3 | Level 0 | Level 0 | Level 0 |
| Level 3 | Level 1 | Level 0 | Level 0 |
| Level 3 | Level 2 | Level 0 | Level 0 |
| Level 3 | Level 3 | Level 0 | Level 0 |
| Level 3 | Level 3 | Level 1 | Level 0 |
| | | | |
| Level 3 | Level 3 | Level 3 | Level 3 |

*Figure 3: Illustration of the progressive part-task method. Four levels of difficulty are distinguished in this example. The (part)-task difficulty is classified from 0 to 3, level 0 means no actions required, level 1 minimum action is required and level 3 maximum action is required. The most difficult whole-task level implies that the trainee must have mastered all the required actions at level 3.*

The part-task method guarantees that all tasks and related skills are covered in the training programme. A drawback with regard to effectiveness is that it may neglect the interrelation between skills across the part tasks, which may result in a hampered transfer of the skills to real-life tasks (Farmer, 1999; Van Merriënboer, 1997). A drawback with regard to efficiency is that the part-task methods can result in a roundabout progression taking more time than strictly necessary. Another drawback with regard to efficiency of adaptation is that part-task methods offer a less flexible differentiation of task difficulty. Nevertheless, part-task methods remain necessary for those part tasks that require precise execution of tightly interrelated actions that have to be practiced often before it is mastered at the required level.

Whole-task methods partly solve the drawbacks of the part-task methods. For whole-task methods there are theoretically a vast number of possibilities for structuring the difficulty progression, as is illustrated in Figure 3. The training designer needs to define in consultation with subject matter experts, a criterion which reduces the vast number of possibilities to a manageable set of possibilities. Criteria that can be used are, for example, the frequency of certain task situations, importance of certain task situations, or the time available for training. Whole-task training is unavoidable for those tasks which require closely interrelated skills (Salden, 2005). The drawback of the whole-task method is that the easiest task can still be too demanding for the trainee. In this case the trainee must be given extra support.

Trainee support takes the care of those actions (skills) which the trainee cannot handle concurrently: at first the trainee gets much support, which will be decreased gradually as the trainee gains more proficiency. The trainee support may be provided by an instructor, by simulation or by an intelligent tutor system. Using trainee support, a simple part-task event (cf., the first row in figure 3: a level 1 practise of cluster 1 action) may change into a simple whole task event. And yet, no action is required from the trainee on the other action clusters, but the trainee does achieve some understanding, awareness of the actions in the whole task context, even though it is merely performed by the instructor or the system. This differs from a purely part-task training sequence, in which the whole task context is not given at all. Note, that for the TGP example presented below, no trainee support is considered and therefore, the first whole task is defined such that all actions are performed at least on the easiest level.

# 4 Designing the adaptive variable for training the TGP

Each real life task poses different questions for which decisions have to be made, requiring each adaptive programme to be developed specifically. A typical task for a fighter mission is to eliminate a specific target at a given location in a short time period.

The TGP is a system that is designed for precision pin-pointing of targets. The high quality cameras (visible and infra-red spectrum) with extreme zoom capabilities allow pilots to attack the enemy targets with precision-guided weapons. The latter may use a laser designator for precise delivery of laser guided weapons. The TGP is mounted externally to the fighter aircraft, and is operated through the man-machine interfaces in the cockpit: the multifunctional display (MFD), the side stick controller (SSC) and the throttle. These interfaces are also used to control the aircraft itself and other systems such as the radar and navigation system.

## 4.1 Skills analysis for the task difficulty: the targeting task

According to a pure whole-task method, a fighter pilot should be trained how to concurrently fly, navigate, communicate and target the enemy from the outset of the training. In practice this is not the case because carrying out the whole task is much too difficult. Therefore, for the whole "eliminate enemy" task, the required actions are identified and combined in part-tasks based on the required actions and their extent of interrelationship. A criterion for prioritizing the part-tasks that is used in practice is the interrelationship of the required actions across the part-tasks. First, the part task is trained for which skills have to be mastered that are a prerequisite for carrying out the other part tasks. For training for fighter tasks, this implies that the pilot first is trained to fly, navigate and communicate because these skills are general and conditionally for carrying out more specific tasks such as targeting. Nevertheless, these actions can be trained such that they prepare the pilot for specific tasks in the future. For example skilful manoeuvring of the fighter aircraft may make striking the enemy target easier. Flying and targeting are not entirely independent from each other. When the trainee has mastered the required general skills, the skills specific for carrying out the targeting task are trained.

For the present, the design of the adaptive variable is limited to the part-task "targeting". This has two main practical reasons. First, the preferred means for training are desktop trainers since they can be taken to mission locations to practice on site specific situations. Second, usually the use of the TGP is trained only after the pilots obtained their flight license. TGP training is an additional qualification-training. To preserve the idea of whole-task training, the flying, navigation and communication tasks are offered but kept at a difficulty level that the pilot is able to handle himself. In Figure 4 this analysis is illustrated. The tree shows which actions may have to be carried out concurrently and repeatedly.

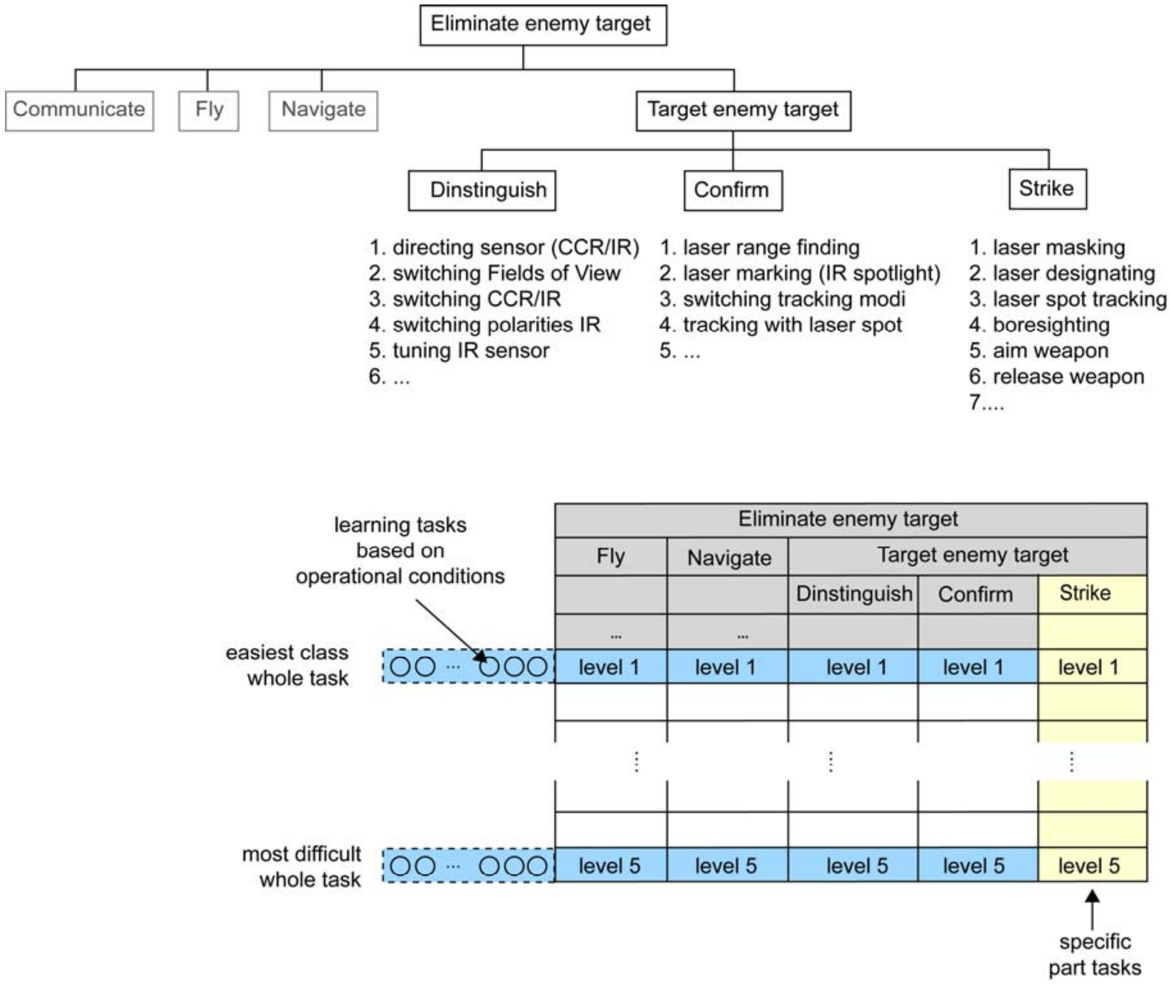


*Figure 4: Skills analysis and proposed combined actions of the "eliminate enemy"-task*

## 4.2 Operational conditions analysis for defining task difficulties

The actions/skills analysis is used to determine which actions have to be carried out for the assigned task and which of them have to be carried out concurrently. Given the systems (aircraft, TGP etc), the operational conditions determine the number of concurrent actions and their preciseness. Those operational conditions that require more concurrent actions and more preciseness make the task more difficult.

The operational conditions that influence task difficulty are divided into three main groups: conditions that relate to the target, to the surface and to the atmosphere. Target conditions influencing the task difficulty are for example its mobility (none/extreme), geometry (size, form, outline), its colour and temperature difference relative to its environment, and location (known/approximately know/unknown). Surface conditions are for example the hilliness of the area or the occurrence of other or false targets. Atmospheric conditions are for example light conditions and the presence of moisture (fog, rain).

The operational conditions which provide the most difficult targeting task are first determined, followed by the determination of the operational conditions which provide the easiest targeting task. Finally the difficulty levels in-between are defined. Each difficulty level represents a task class. For each task class a set of operational conditions has to be designated, which results in learning tasks that approximately have the same difficulty level. The operational conditions should be designated such that they produce a sufficient variability between the learning tasks in the same class. The learning tasks should vary just like the tasks in the real operational situations so as to enhance a successful transfer of the mastered skills to real situations.

An example of a set of operational conditions that generate a task at the most difficult level is a well camouflaged small extremely movable vaguely outlined target in a highly cluttered hilly environment of which the location is not known at dusk in foggy weather.  This set of conditions requires a maximum number of concurrent actions of which some have to be carried out with a delicate touch because the target is small and extremely movable. Because the electro-optical range between target and environment is not globally discriminating the pilot has to switch repeatedly between the CCTV camera and the IR, possibly switching hot-black and hot-white sensor polarities. Meanwhile, the pilot has to switch between the different fields of view because the location is unknown and a large area has to be scanned. In addition, the pilot has to fly and navigate within the boundaries of justified operation while avoiding exposure to potential threats.

An example of a set of operational conditions that generates a task at the easiest level is a large purple immobile cube in a plain yellow environment at a given location at daytime in clear weather. Actions required by the pilot to locate the target are limited as much as possible, allowing focussing on the targeting task.

The number of intermediate difficulty levels can be vast due to the infinite possible combinations of operational conditions. To limit the infinite number of possible difficulty levels, the task situations that can be encountered in real life have to be limited at importance and frequency of occurrence. The choice for a sophisticated set of task classes that represent the majority of the important task classes draws heavily on the expertise of the instructor.

### 4.3 Structuring difficulty progression

The flexibility of the 4C/ID method can now be illustrated. Depending on the entry level of the trainee, the level of difficulty of the part-tasks flying and navigating can be adjusted. For example, if the trainee is very experienced in flying the aircraft, the level of difficulty of these part tasks can be set to a maximum level whilst keeping the difficulty of the targeting task at the easiest level. When the trainee is less experienced, the level of the flying task is made easier to allow sufficient focus on the targeting task.

Depending on the performance progression of the pilot, the levels of the targeting task can be adjusted and varied by the instructor to optimise the learning progress.

# 5 Discussion & Conclusion

The analysis of TGP training tasks is not yet completed. How and to which extent the whole-task is decomposed in part-tasks should be weighed by the designer in consultation with other experts and instructors. Factors that may be taken into account are the means that are available for training, the skilfulness of the trainee, and the time that is available for training. In order to allow the instructor for such flexibility, the database of training tasks has to be sufficiently large and tasks should be easily selectable. This will set specific requirements to the structure and interface of the task database. Adaptive training development will follow. This will start with guidelines for instructors and a database of training tasks. Based on the results of adaptive TGP training, task selector algorithms for automated adaptive training may be developed.

Adaptive training programmes are a means to realise a desired effect at an optimal expense. The 4C/ID method ensures an effective training programme but is not adaptive yet. To make this method adaptive requires a systematic and sufficient differentiation of difficulty levels in combination with sufficient variability within a given difficulty level. This way the level of difficulty can be optimized to the trainee's performance progression so as to ensure optimal training effectiveness and efficiency. Task difficulty is related to the number of actions that have to be carried out concurrently with a given precision. Each real life task requires a separate action/skills analysis to specify the required actions and their concurrence. Task difficulty can be manipulated by the operational conditions. Those conditions that require more concurrent actions and more precision are designated to a higher level of difficulty. Using 4C/ID as a basis, this paper discussed how to analyse systematically the fighter pilot task of targeting of an enemy target.

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