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Low-cost simulators 1c: Training analysis of 9 military training areas

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Het EUCLID programma stimuleert de ontwikkeling en kosten-effectieve produktie van systemen die voorzien in de toekomstige Europese militaire behoeften. Eén van de Research Technologie Projecten (RTP) binnen EUCLID is RTP 11.8, getiteld: "Low-cost Simulators". Low-cost simulatoren worden gedefinieerd als een nieuwe klasse van trainers die, door gebruik van commercieel beschikbare en opkomende technologieën, hogere baten-kosten ratio's opleveren dan full fidelity simulatoren.
Het onderzoeksproject wordt uitgevoerd in opdracht van de ministeries van defensie van de vijf participerende landen van RTP 11.8: België, Frankrijk, Duitsland, Griekenland en Nederland. Het project loopt onder de naam: **ELSTAR**, een acroniem voor: **E**uropean **L**ow-cost **S**imulation **T**echnology for the **AR**med forces. Dit rapport bevat het verslag van de trainingsanalyses die onderdeel vormen van het eerste werkpakket.
Omdat trainingssimulatoren als doel hebben mensen praktische vaardigheden te trainen is leeroverdracht de kritische en beslissende factor in de specificatie, ontwikkeling en toepassing van simulatoren. De ELSTAR benadering voor onderzoek naar de ontwikkeling van low-cost training simulatoren is het identificeren en selecteren van kritische taakelementen die zonder hoge kosten met een hoge mate van fidelity kunnen worden gesimuleerd.
In het eerste deel van dit werkpakket is voor het gehele spectrum van militaire taken nagegaan welke taakdomeinen potentieel geschikt zijn voor low-cost simulatortraining. Vervolgens zijn 9 trainingsgebieden omschreven die deze taakdomeinen bevatten. Teneinde de initiële selectie te toetsen is daarna veldonderzoek verricht naar werkelijk gegeven trainingsprogramma's. De gegevens van het veldonderzoek zijn vervolgens gebruikt voor het analyseren van de trainingsprogramma's. Dit rapport bevat de methode en de resultaten van die analyses.
Het doel van de analyses is het identificeren van de kritische taakvariabelen en 'cues'. Eerst zijn de hoofdtaken vastgesteld en is nagegaan op welk type vaardigheden deze een beroep doen (bv. cognitieve vaardigheden, perceptief-motorische vaardigheden). Vervolgens is aangegeven wat de functionele eisen zijn aan een gesimuleerde omgeving waarbinnen deze vaardigheden effectief geleerd kunnen worden. Tenslotte is voor elk trainingsprogramma aangegeven wat de mogelijkheden en beperkingen zijn voor low-cost trainingssimulatoren. Geconcludeerd wordt dat de resultaten voldoende aanknopingspunten vormen om in het laatste onderdeel van dit werkpakket de selectie van 9 op een verstandige manier verder in te perken tot 3-5 trainingsgebieden.

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Low-cost simulators 1c: Training analysis of 9 military training areas

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SUMMARY

The objective of the EUCLID RTP11.8 ELSTAR project "Low-cost simulators" is to develop guidelines for the specification, development and application of low-cost training simulators. Low-cost simulators are trainers that, through the use of commercially available and emerging technologies, provide superior benefit-to-cost ratios when compared to full fidelity simulators.

First, the full spectrum of military tasks is screened on their potential for cost-effective simulator training. Next, 9 training areas were defined covering those task domains for which further investigation of low-cost simulator training solutions seemed promising. Then, field research was conducted on actual training programmes in order to verify the initial selection. The data of the field investigations were used for analysing the training programmes to determine global functional requirements of training simulators. The present report presents the methods and results of those analyses.

The goal of the analyses is to identify the *critical* task variables and cues for the training programmes of the defined 9 training areas. First, the principal subtasks of the training programme are identified and the nature of the task-specific skills are characterized (e.g. cognitive, perceptual-motor). Then, the functional requirements of learning environments in which the necessary skills can be learned, are addressed. Finally, for each training programme, the opportunities and restrictions for developing low-cost training simulator solutions are discussed. It is concluded that the results provide the information necessary to intelligently narrow down the current selection in the final phase of this work package.

Low-cost simulatoren 1c: Trainingsanalyse van 9 militaire trainingsgebieden

K. van den Bosch, J.E. Korteling en W. van Winsum

SAMENVATTING

Het doel van het EUCLID RTP11.8 ELSTAR project "Low-cost simulators" is het ontwikkelen van richtlijnen voor de specificatie, ontwikkeling en toepassing van "low-cost" training simulatoren. Met low-cost simulatoren kunnen, door effectieve en efficiënte toepassing van beschikbare en aankomende technologieën, trainingen worden verzorgd met een gunstiger prijs/prestatie verhouding dan met "full-mission" simulatoren.

Eerst is voor het gehele spectrum van militaire taken nagegaan welke potentieel geschikt zijn voor low-cost simulatortraining. Vervolgens zijn 9 trainingsgebieden omschreven die deze taakdomeinen bevatten. Teneinde de initiële selectie te toetsen is daarna veldonderzoek verricht naar werkelijk gegeven trainingsprogramma's. De gegevens van het veldonderzoek zijn vervolgens gebruikt voor het analyseren van de trainingsprogramma's. Dit rapport bevat de methode en de resultaten van die analyses.

Het doel van de analyses is het identificeren van de kritische taakvariabelen en 'cues'. Eerst zijn de hoofdtaken vastgesteld en is nagegaan op welk type vaardigheden deze een beroep doen (bv. cognitieve vaardigheden, perceptief-motorische vaardigheden). Vervolgens is aangegeven wat de functionele eisen zijn aan een gesimuleerde omgeving waarbinnen deze vaardigheden effectief geleerd kunnen worden. Tenslotte is voor elk trainingsprogramma aangegeven wat de mogelijkheden en beperkingen zijn voor low-cost trainingssimulatoren. Geconcludeerd wordt dat de resultaten voldoende aanknopingspunten vormen om in het laatste onderdeel van dit werkpakket de selectie van 9 op een verstandige manier verder in te perken tot 3-5 trainingsgebieden.

1 INTRODUCTION

1.1 The ELSTAR project

The project "Low-cost Simulators" is one of the research projects of the European Cooperation for the Long Term in Defence (EUCLID). EUCLID is a defence technology development programme, with the aim to enable European defence industries to maintain and to improve their position in the international military technology market. Projects are initiated and carried out within a number of Common European Priority Areas (CEPAs). CEPA 11 is concerned with the question how simulation can be utilized for military purposes. It consists of several Research Technology Projects (RTPs), each studying different aspects of simulation.

The present project "Low-cost simulators" is the 8th in a series of CEPA 11 Research Technology Projects, hence its code: RTP11.8. The aim of the project is to identify, within the full spectrum of military tasks, opportunities for applying low-cost simulation technologies. Low-cost simulators are trainers that, through the use of commercially available and emerging technologies, provide superior benefit-to-cost ratios when compared to full fidelity simulators.

The project is carried out under contract of the Ministries of Defence of the five participating countries (Belgium, France, Germany, Greece, the Netherlands). The adopted project name is **ELSTAR**, standing for: **E**uropean **L**ow-cost **S**imulation **T**echnology for the **AR**med forces.

This report presents the methods and results of the training analyses of 9 training programmes that were identified as potentially promising for developing low-cost training simulators. The context for this study will be clarified below.

1.2 WP1: Analysis of military training

The first ELSTAR work package involves "Analysis of military training", and provides the basic framework of the project. In this work package, the full spectrum of military tasks is inventoried in order to select 3-5 military training areas that are considered especially suitable for cost-effective simulator training.

In WP1a four main criteria were used to evaluate whether a particular military task domain is potentially suitable for research into low-cost simulator training: training need, simulator need, generation of knowledge, and simulation simplicity (see Korteling, Van den Bosch & Van Emmerik, 1997). A total of 29 task domains were selected for further study. These task domains were covered by 9 training areas.

In WP1b, actual training programmes, representing the identified training areas, are investigated in order to verify whether the initial selection of task domains is warranted (see Helsdingen, Korteling, & Van den Bosch, 1997).

In WP1c, the investigations were continued by analysing the training programmes in order to determine global functional requirements of training simulators. This activity was carried out by the TNO Human Factors Research Institute. In addition, cost-utility analyses were carried out in order to compare the selected training programmes with respect to costs required to develop training simulators, and the benefits (utility) that may be expected from them. This activity was carried out by IABG, Germany. The present report contains the TNO contribution: the methods and results of the training analyses.

Finally, in WP1d, the selection will be narrowed down to 3-5 training areas that are most promising with respect to their prospects of developing low-cost simulator training solutions.

2 TRAINING ANALYSIS

2.1 Introduction

When a (military) organisation decides to acquire a simulator for purposes of training, commonly the first step is to directly translate operational requirements into simulator requirements. Given the fact that project teams usually consist of operational users and technical specialists, this is not surprising. The often taken approach is to try to achieve the best possible fit between the training and the task environment (pursuing high physical fidelity). This, however, is likely to inflate costs, and an expensive simulator does not necessarily guarantee good performance (e.g. in terms of high transfer-of-training). In this section we will argue why training analysis is needed as an intermediate step to arrive at cost-effective simulator specifications.

The validity of an existing training simulator can only be determined in the context of a specific training programme. Without information about the goals of the training programme, it is impossible to conclude whether or not a simulator's functionality meets the training requirements. In the same fashion, it is impossible to state that a (low-cost) training simulator is feasible to fulfill a certain training need, unless there is sufficient information about the training objectives. Thus, in order to determine whether a military task domain is suitable for low-cost simulator training, a global idea of the training requirements is needed. Such information is obtained through training analysis.

The purpose of training analysis is the definition of training need in terms of (a set of) related training objectives. This is an important stage in the specification of training simulator requirements because if the simulator is unable to address them, or if the training objectives do not match the task requirements, then the training programme will be useless. Under such conditions, no transfer-of-training can be expected.

Thus, in the specification and implementation of a low-cost training simulator, a complete training analysis is needed. To define a complete set of training objectives for a specific training programme is an arduous undertaking. At this stage in the ELSTAR project, however, it is not necessary to perform such complete analyses for the training programmes representing the earlier selected 9 training areas. The goal now is to identify, for each training programme, the potential and problems for achieving low-cost training simulator solutions. This can be achieved with a more global form of training analysis. At a later stage in the project, when a demonstrator of a low-cost training simulator is going to be produced (WP3b), then a complete training analysis will be required.

In this work package (1c), the goal of training analyses is to identify the *critical* task variables and cues for the training programmes of the earlier selected 9 training areas. The results will be used to assess opportunities for low-cost training simulator solutions and to complement any inconclusive results of cost-utility analyses.

2.2 Methods

Performing a task requires task-specific skills. Such task-specific skills can only be acquired in learning environments including all critical task elements in a functionally valid manner (thus, eliciting the same stimulus-response sequences as in the actual task environment). For instance, for the (sub)task "driving a car smoothly through a curve", the driver primarily uses the inside-curve line on the road to control his steering behaviour. Thus, the inside-curve line is a critical task element for this subtask. An adequate learning environment represents this cue with such degree of fidelity that it enables the trainee to perform and practice this particular subtask. Note that this not implies that high physical fidelity is needed.

In line with the example above, the tasks of the training programmes of the selected 9 training areas will be analysed in order to formulate functional requirements of a training simulator. As argued above, performing full training analyses is beyond the scope of the present work package. Therefore training analyses will focus upon 2-3 selected *principal* and *critical* subtasks. Selected subtasks are principal because they are basic to the main task rather than marginal; selected subtasks are critical because developing a simulated environment requires challenging rather than trivial problems to overcome.

The results of the field inventories (WP1b) are used as input for the analyses. Each training area is introduced with a basic overview of the common base training programme. Next, the principal subtasks are identified and the nature of the task-specific skills are characterized (e.g. cognitive, perceptual-motor). If appropriate, a selection of principal and critical subtasks is made. Then, the functional requirements of learning environments in which the necessary skills can be learned, are addressed. Finally, for each training programme, the opportunities and restrictions for developing low-cost training simulator solutions are discussed.

2.3 Results

2.3.1 Training area 1: Wheeled-vehicle control

2.3.1.1 Introduction

The training of drivers for the Mercedes Benz 290 GD was selected as the common basis for representing the training area wheeled-vehicle control.

This training area is characterized by having its own laws and regulations. However, the learner driver not only has to learn about traffic laws and regulations. Driving a wheeled vehicle requires substantial cognitive, procedural and perceptual-motor skills, and the interaction with the environment plays a dominant role. The driver interacts with many objects such as vehicles, pedestrians and traffic signs. In comparison with other platforms, such as ships or aircraft, the task environment is very complex: behaviour of other traffic participants affects behaviour of the driver and vice versa. The sheer amount of situations and other traffic participants that are encountered during task execution and the complexity of these require substantial traffic insight. This is what makes this training area so demanding. In addition, the static environment, for example the type of road, and road signs, strongly affects required behaviour.

An important characteristic of driving a wheeled-vehicle is that most of the sensory input that is needed for task performance is visual. Another important characteristic is that most important visual input is derived from the immediate surroundings of the vehicle. This ranges from a few hundreds of metres in front and a more limited distance to the rear, left and right. In this cocoon around the vehicle all information can be found that is needed for optimal task performance.

2.3.1.2 Selection of critical subtasks

According to the analysis of WP1b the task of the driver of a wheeled-vehicle can be divided into three main subtasks: 'vehicle control', 'traffic participation' and 'terrain driving'.

Vehicle control concerns the basis aspects of steering and controlling the platform in relation to the immediate environment ('to move'). It requires mainly information from the instruments on the dashboard panel and the static road environment.

Traffic participation concerns several aspects of manoeuvring in traffic, such as overtaking other vehicles and negotiating intersections. In the analysis of WP1b this subtask is divided into smaller subtasks according to road type. Task performance depends on cognitive skills concerning rules and regulations and on visual roadside information such as traffic signs and road type. Even more important is the visual information concerning other traffic in the surroundings of the vehicle.

Terrain driving concerns driving in areas with unpaved roads, in rough uneven terrain, in tracks, through woods, shrubberies and over hills. Performance on this subtask strongly depends on depth perception, motion cues and knowledge of the vehicle limits and of vehicle behaviour under extreme circumstances.

2.3.1.3 Functional requirements

Because the three subtasks are characterized by different training goals and required input in order to reach those goals, the functional requirements vary among subtasks. Yet, there are some common functional requirements.

The driver forms an integrated system with the vehicle and the immediate surroundings. Especially for training the driver-vehicle interaction, a realistic vehicle model is required that transfers driver control actions into movements in space.

Also, the images of the outside world have to be presented from the viewpoint of the driver as 3D images with realistic perspective and distance cues. The horizontal field of view (FOV) needs to be 150-180 degrees at minimum while the information of the rearview mirrors must be available in some form as well. The required FOV depends partly the subtask: terrain driving, especially on steep slopes, requires a larger vertical FOV than the other two subtasks. But normally a vertical FOV of around 40 degrees should be sufficient.

The critical objects required for driving, such as traffic lights, must be visible and recognizable from a distance of a couple of hundred metres (say 300-400 metre) in front. The resolution of rearview images may be smaller.

The estimation of distance and speed of objects, and especially time to objects, is an important cue for driver control actions. It is therefore important that the optic expansion of relevant objects is fluent and accurate. This means that the frame rate must be sufficient (more than 20 frames per second), that the resolution must be high enough and that the graphical simulation of the size of objects as a function of distance and angle must be accurate.

Other functional requirements depend on the subtasks and are discussed separately.

Vehicle control

In the task analysis of WP1b vehicle control was divided into several smaller subtasks: 1) to start, drive off and halt; 2) accelerating and braking; 3) gearing; 4) to drive straight ahead and faint curves; 5) sharp curves and intersections; and 6) special manoeuvres. The most important training goals of these subtasks involve learning how the vehicle operates, the movement-force control characteristics of the controls, and how it responds to these control actions.

For training of these subtasks it is required to have a mockup in which procedures such as starting, driving off and gearing can be trained. Vehicle controls, for example a steering wheel, a brake, an accelerator, a clutch and a gearstick, have to be represented realistically in a mockup, together with instruments in a dashboard panel that give feedback of speed that may be required for gear switching. The response characteristics of the controls and displays should mimic those of reality.

For this kind of procedural training auditive cues play an important role as well. Auditive feedback of engine noise that is presented to the driver realistically while it responds to gear switching and the rotations per minute is an important cue for the training of vehicle control.

A static road layout with several kinds of curvatures is needed for training steering and speed control during curve negotiation. In this, an accurate vehicle model that responds realistically to driver control actions and road friction is indispensable. The driver has to be trained to adjust speed for several different kinds of road curves and to detect the relevant characteristics of the road segments well in advance.

Traffic participation

The main task of traffic participation was divided into seven different subtasks, based on a categorization of road types: 1) residential area or shopping centre; 2) minor road in urban area; 3) major urban roads; 4) country- and secondary roads; 5) 80 km/h road; 6) motorway and 7) highway. In addition to the required functionality referred to under the heading of vehicle control, a number of other requirements must be met. The most important training goals of this subtask concern the training of cognitive skills and of perceptual-motor skills.

The cognitive skills concern the application of knowledge of traffic rules and regulations and the accurate and fast recognition of traffic situations that demand a safe response of the driver. For example, the driver has to recognize the present type of road, the restrictions it puts on the maximum velocity and the types of other traffic that can be expected on roads of the present type. Also, the driver has to be able to decide under time pressure whether it is safe to merge into another traffic lane, etc. For the training of the cognitive skills the environment to be presented to the driver has to be rich enough to train a sufficient amount of different relevant traffic scenarios. Different types of roads must be available in the training databases. Also, a large number of traffic signs and other traffic participants such as vehicles must be represented in the training scenarios.

The perceptual-motor skills refer to how and when the response of the driver to other objects is executed. The driver has to be trained to decelerate gently for a traffic light, a decelerating lead vehicle, to estimate gaps in the traffic stream while negotiating intersections, to evaluate whether overtaking is safe and so on. All this requires the training of recognizing the spatial and temporal characteristics of the vehicle in relation to other objects. This not only requires an accurate representation of vehicle dynamics in terms of the vehicle model. It also means that other traffic must be modelled accurately since an important training goal of this subtask is to learn to interact appropriately with other traffic. Finally, distances between the vehicle and other objects, speeds, and time-to-collision must be perceived the same way as in reality.

Terrain driving

Terrain driving was not divided into subtasks. It involves driving in areas with unpaved roads, rough terrain and steep slopes. The vehicle model must be very complex since the vehicle dynamics must be modelled under extreme and instable circumstances. Also the correlation between the terrain and the vehicle movements must be high. This requires a complex terrain model with variables representing the mechanical characteristics of the subsoil. In order to learn to drive in rough terrain mechanical motion cues are essential. This means that for this subtask a complex motion base is certainly needed. Thus, this subtask differs from the other two subtasks in the essential input information: it is less visual and more proprioceptive. But even so, also the type of visual input differs. In terrain driving depth cues at close range are more important compared to the tasks of vehicle control and traffic participation. For example, the quality of the subsoil, the depth of potholes, ditches and the hight and solidity of obstacles must be evaluated accurately in order to choose the right speed and gear. Thus, terrain driving requires stereoscopic presentation of visual information with a very high level of detail.

2.3.1.4 Conclusion

There is a high need for developing training simulators for wheeled-vehicle control: the number of trainees is high and a simulator may reduce environmental burden, provide better support for instructors and reduce training costs. The three subtasks of vehicle control, traffic participation and terrain driving differ greatly in training goals, type of skills to be trained and functional requirements.

Training of vehicle control entails predominantly procedural training and learning how the vehicle responds to driver actions under different environmental circumstances. This results in an internal model of vehicle behaviour and it requires an accurate simulated vehicle model.

Training of traffic participation mainly concerns the transfer of cognitive skills and perceptual-motor skills. The training scenarios need to be diverse en the visual environment has to be rich in types of objects like road types, traffic signs and other vehicles. Traffic has to behave realistically in order to train appropriate interaction with traffic. This suggests that a realistic model of traffic behaviour has to be included in the simulation in order to reach the training goals for this subtask.

Training of terrain driving requires a complex vehicle model, a complex motion generation system and a high correlation between information in the terrain database and vehicle movements. Also, depth information at close range is important for training of this task.

2.3.2 Training area 2: Air platform navigation

2.3.2.1 Introduction

For this training area two training courses were selected as the common basis. The training course *'Army Aviation Helicopter pilot training'* provided at the German Army Aviation was selected as one common basis for representing this training area.

In WP1b, the task was described in general terms as navigation by use of instruments or on direct vision. The platform selected was a helicopter of unspecified type. The global mission was defined as to fly and navigate a helicopter in low and high threat environments. This means that, in contrast to a number of other known helicopter training analyses, the pilot and the navigator are the same person. According to the analysis of WP1b, the task of navigation while flying a helicopter is embedded in a number of other tasks such as flying the machine. Also other non-navigation subtasks such as judging the weather situation and looking out for airborne and ground threats are performed in parallel to navigation but specified as subtasks of navigation in the task analysis of WP1b. In the present analysis, the requirements for non-navigation subtasks are only referred to in so far as they are indispensable for navigation. This means that not all requirements for optimal performance of subtasks are analysed here. Only the requirements for *navigation* training are referred to. On the other hand, some important elementary subtasks that are involved in the preparation of navigation, such as flight planning, are not included in the task analysis described in WP1b. Instead they are referred to as input for the various subtasks.

The second common basis selected for the training area air platform navigation is *'low level flight of a fighter bomber'* (MRCA Tornado). The mission is described as to navigate a low level flight on an air platform with and without instruments in a high threat environment. The navigation training components are interwoven with other aspects of flying a fighter bomber in the training course *'low level flight training'*.

Both the rotary- and fixed-wing training course have a number of similarities. In both cases the navigator and the pilot are the same person, and both task analyses involve a number of non-navigation tasks in addition to navigation tasks. But the differences are also large: low level flight of a fighter bomber is carried out at high speed at a low altitude under high time pressure over land and over sea. The training course for flying and navigating a helicopter is carried out at a lower speed at low and high altitudes over land.

2.3.2.2 Selection of critical subtasks

Army Aviation helicopter pilot training

According to the analysis of WP1b the task of the navigator in a helicopter can be divided into seven main subtasks:

1 navigation by direct vision at an altitude of 500 ft GND and above
2 at 100 ft above ground, i.e. contour flight
3 at 10-30 ft above ground i.e. nap of the earth flight. These three subtasks are divided into:
  - 1.1; 2.1; 3.1 general tasks
  - 1.2; 2.2; 3.2 comparison of terrain features with map symbology
  - 1.3; 2.3; 3.3 course and time planning
  - 1.4; 2.4; 3.4 a combination of the last two subtasks
  - 1.5; 2.5; 3.5 weather judgement
  - 1.6; 2.6; 3.6 airspace scanning for airborne threats
  - 1.7; 2.7; 3.7 ground scanning for ground threats
  - 1.8; 2.8; 3.8 tactical evaluation

4 navigation by usage of electronic navigational equipment (all heights above ground)
5 visual night flight according to ICAO-regulations (International Commercial Air Traffic Organisation) in 500 ft above ground or more
  - 5.1 general task
  - 5.2 Instrument Flight Regulations routing system

6 visual night flight according to military regulations in 250 ft above ground and higher
7 visual night flight with sensors according to military regulation.

The first three subtasks share the same eight more specialized subtasks. This is because these subtasks only differ in flying altitude from 500 ft GND and above to nap of the earth flight. This results in a variation of workload: flying lower implies a higher workload because the pilot/navigator has less time to move the eyes off the path the helicopter is flying. This means that as altitude is lower, the time that can be allocated to the navigation part is less and time pressure is higher. This will typically result in a higher glance frequency at navigation aids or navigation cues outside the helicopter with a smaller glance duration per single glance as flying altitude is lower. However, workload is not the only factor that varies as a function of altitude. Also, the nature of the outside view changes because relevant objects are more often obscured and chances of colliding into objects are higher as flying altitude is lower, and the angular motion speed of objects is higher.

The second dimension hidden in the categorization of subtasks is flying on direct vision versus flying using instruments. For the domain of navigation this extents to navigation on direct vision, using landmarks and terrain characteristics that are compared with the maps and flight plan versus using the instruments for navigation. The subtasks 1, 2 and 3 involve flying on direct vision, subtasks 4 and 7 involve navigation based on instruments and sensors while subtasks 5 and 6 constitute a mixture of the two.

The third dimension in the categorization of subtasks is navigation versus non-navigation subtasks. Examples of non-navigation subtasks are weather judgement, airspace scanning for airborne threats, ground scanning for ground threats and tactical evaluation. Yet, these subtasks have an important function for the general task of navigation because the output affects navigation decisions. For example, while performing the subtask weather judgment, the weather is observed. Depending on the weather forecast or observed weather it is decided whether the flight can be continued and if so, whether the flight path has to be changed. This implies that, just as in the case of flight planning, subtasks (such as weather judgment) serve as input for the navigation task.

Low level flight of a fighter-bomber Tornado

According to the analysis in WP1b, the task of the navigator of a Tornado can be divided into:

1 start up, taxi, take off and landing, missed approach, visual approach, overhead pattern
2 descend to low level flight
3 low level navigation (cruise) under all mission and weather conditions, including terrain following and terrain masking flights with full system (autopilot functions) and with reversatory system (system failures)
4 low level navigation (cruise) under all mission and weather conditions over sea
5 defence against air threat, air combat.

Of these, subtasks 1 and 2 involve mainly the control of (flying) the platform. They contain further decomposed subtasks such as control of air speed, pitch and altitude, etc. The subtasks 3 and 4 involve navigation at low altitude above land and sea. These subtasks involve activities such as map comparison, identify way points, locate own position on the map, search for typical land marks such as railroad tracks, recognition of way points by visual reference or radar, estimation of distances, etc. Subtask 5, defence against air threat, has only one element that is related to navigation: keep situation awareness. Most further decomposed subtasks of defence against air threat and most activities specified hereunder are not related to navigation.

There are also a number of subtasks, such as assessment of weather conditions that serve the purpose of selecting another flight path if necessary or aborting the mission.

In conclusion, the subtasks contain a dimension navigation versus non-navigation subtasks that is comparable to the helicopter pilot training domain. In all cases workload is high since a number of different tasks, i.e. controlling the plane, navigating and searching for air threat have to be performed simultaneously at low altitude and high speed. There is no specific distinction between instrument flying and flying on direct vision since visual input of the outside view is specified to be present continuously. There is no provision for night flying or flying and navigating on instruments only.

2.3.2.3 Functional requirements

If the conjunction of both common bases is used as the starting point for the functional requirements, the following issues arise:

1 Navigation needs to be trained under different levels of workload and/or speed. Although navigation (determining the direction and magnitude of the flight vector) and flying (controlling the platform) is often carried out simultaneously, this does not necessarily imply that a low cost simulator is used to train both tasks at the same time. Thus, navigation can probably be trained more cost effectively as a part-task. For the task of navigation the task of controlling the platform has a dual function: it induces workload which can be simulated by other means as well and it results in global and local movement of the platform which is necessary for navigation. Without global movement there is no navigation and no checking whether the actual flight path deviates from the planned flight path. However, how the movement on a local level is executed and is experienced by the trainee may be less relevant for the purpose of navigation training. This suggests the following points:
   - It is questionable whether an accurate vehicle model that transforms pilot control actions into roll, pitch, yaw and movements is required.
   - It is questionable whether a mockup of a cockpit with realistic controls is required.
   - It is questionable whether a moving base for motion sensation is required.
   - It is questionable whether the generation of engine sounds and smell as sensory inputs is required.

2 Navigation needs to be trained while scenes are visualized from low and high altitudes. Techniques such as matching the outside view with a map, dead reckoning with ground speed and time, detection of way points, recognition of flight paths and detection of deviations from planned flight paths, etc. can be trained this way. The demands on the graphical resolution of the images are substantial, especially if the scene is visualized from a high altitude.

3 Navigation needs to be trained under night and instrument navigation conditions. In this case the demands on graphics resolution and databases are reduced significantly. However, the demands on specific sensor output such as radar images are higher while the instruments needed for navigation have to be represented realistically in the simulator and with identical functionality as in the real platform.

4 Provisions must be made in the simulation that require an alteration of route and flight path. This simulates intrusions on the navigation plans by weather circumstances or threats.

2.3.2.4 Conclusion

There is a high need for simulation of air platform navigation given the high training costs. A part-task training simulator may be cost effective if the required databases can be developed to produce graphics at a sufficiently high resolution to allow landmarks and terrain features to be recognized from several kilometres.

There are already several training simulators for navigation, based on instruments only. This suggests that the challenges for this training area in this project lie in the low-cost simulation of air platform navigation based on outside-view visual information.

2.3.3 Training area 3: Using (head mounted) infra-red, and image intensifier equipment

2.3.3.1 Introduction

The training of main battle tank commanders, provided at the Tracked Vehicle Training Centre "Avlona" (Greece), is selected as the common basis for representing this training area. The tasks of interest refer to the use of infra-red or image intensifier equipment for land platform operation.

Image intensifiers provide a fairly clear picture of the environment, with a range of a few hundred metres. Such devices are therefore often used to achieve platform mobility (movement and navigation functions) during the night.

Thermal sight equipment, utilizing infra-red technology, detects temperature differences in the environment and displays the shape of heat-emitting objects. Such devices are used for detection, identification, and engagement of targets during night- and daytime.

2.3.3.2 Selection of critical subtasks

According to the analysis of WP1b, the task of a tank commander can be divided into four main subtasks: "observing and navigating", "target acquisition", "weapon delivery", and "communicating". Of these, the first two are relevant in the context of the use of optical equipment.

In "observing and navigating", the commander determines the tank's whereabouts and inspect its surrounding environment. This function is of particular importance when moving in traffic, in tactical formations, moving in traffic, in hostile or unknown areas, and for scanning the horizon for possible targets.

In "target acquisition", the tank commander must constantly scan the environment for possible targets, using the assistance of thermal sight or other optical equipment.

2.3.3.3 Functional requirements

Although image intensifiers and thermal sight equipment both have the function to enable a view on the outside world in poor light conditions, they are very different devices, and are used for different functions. The image intensifier is a short(er) range device, and the tank commander uses it primarily for navigating functions. Thermal sight equipment is especially suitable for target acquisition. Training tank commanders to perform these functions in a simulated task environment demands the generation of different cues. The required functional specifications for training simulators will therefore be addressed separately.

Observing and navigating

The training objective directly related to this training area is that the commander must be trained to use the image intensifier equipment to inspect the (immediate) environment of the tank, to determine the appropriate path to achieve a given or desired position, and to give directions to the driver accordingly. He must be trained to perform this task in different environments, including rugged terrain, (flat) country roads, and urban areas. In addition, the task must be trained under different tactical conditions (friendly, tactical engagement).

Representation of environment
In order to provide a valid learning environment for training of navigational skills, a simulator must be able to generate the visual cues that are relevant to this type of task in sufficient quantity and with a sufficient level of detail. The cues that are relevant differ for each type of environment. A few main categories are discussed below:

<u>For navigating in rugged terrain:</u>
The cues to be generated should allow a tank commander to be able to:

- determine the nature of the surface (terrain, rocks, paved road, dirt road), either directly or through inferencing because of the presence of related objects (e.g. rocks, grass, small plants, lamp posts, etc.)
- identify static objects (e.g. trees, rocks, bushes, shacks, etc.)
- detect and identify dynamic objects ((e.g. friendly or hostile) vehicles, etc.)
- detect and identify possible obstacles (e.g. fissure, fences, etc.).

<u>For navigating on non-residential country roads:</u>
During peace time, tank commanders always navigate on direct sight. Navigating by means of optical equipment only would be too dangerous. During times of conflict or war, the commander must be able to navigate solely by using optical devices (e.g. under NBC threat). Fortunately, the road dynamic scenes are much less complex during tactical engagement operations than during peace time (no pedestrians, cyclists, cars; only friendly and enemy (military) vehicles). In terms of training, this is fortunate because the training scenarios do not need the complex representation of other civilian traffic.

The cues to be generated should allow a tank commander to be able to:

- identify static objects (e.g. buildings along the road, bridges, cross-roads, intersections, parked vehicles, etc.)
- relate features and objects, perceived through his optical device, to symbols on a map, so that he can localise his position
- detect and identify dynamic objects (oncoming and passing vehicles).

For navigating in urban areas:
Again, skill in performing this task has to be acquired under conditions of tactical engagement only.
The cues to be generated should allow a tank commander to be able to:

- identify static objects (e.g. buildings, squares, roundabouts, bridges, cross-roads, intersections, road name signs, parked vehicles, etc.)
- relate features and objects, perceived through his optical device, to symbols on a map, so that he can localise his position
- detect and identify dynamic objects (oncoming and passing vehicles).

Representation of operating environment
The visual quality of the display (image size, resolution, brightness, field-of-view, etc.) should be identical to the original equipment. This can be achieved by using an original display in a trainer, or by a high-fidelity simulation of its visual characteristics. The device controls (metres, levers, buttons) do not necessarily have to be high-fidelity, because they are not essential to the critical aspects of the task: visual information processing.

Target acquisition

The training objective directly related to this training area is that the commander must be trained how to constantly scan the environment for possible targets, with the use of thermal sight equipment. Image intensifiers are used simultaneously to scan the environment for objects that can not (easily) be detected with thermal image. Once an object (vehicle, helicopter, warrior, squad) is detected the commander must determine its type, direction, and whether it is a friend or foe. The range of view is typically larger than in navigation tasks. Target acquisition is typically performed under high-threat conditions, in all kinds of environments, including rugged terrain, (flat) country roads, and urban areas. For target acquisition purposes, thermal image devices are not only used during night time, but also during day time.

Representation of operating environment
The visual qualities of the thermal image display (image size, resolution, brightness, field-of-view, etc.) should be identical to the original equipment. This can be achieved by using an original display in a trainer, or by a high-fidelity simulation of its visual characteristics. The device controls (metres, levers, buttons) do not necessarily have to be high-fidelity, because they are not essential to the critical aspects of the task: visual information processing. An

image intensifier is often used as supporting instrument for scanning the environment. For complete training in target acquisition, the operating environment should also contain a simulated image intensifier.

Representation of environment

In order to provide a valid learning environment for training in thermal image target acquisition, a simulator must be able to generate the relevant visual characteristics of thermal images of all kinds of terrain and objects. The visual information generated by the real device is determined by a number of factors, including: the quality of the thermic sensor, the heat-absorbing and heat-emitting qualities of terrain and objects, and thermal conditions (time of day, humidity, wind direction and speed, atmospheric pressure, etc.). In a training simulator, the effects of these factors on image quality should be simulated. At this stage of analysis, full-fidelity simulation does not seem to so be necessary for purposes of (initial) training. However, to specify the minimum level of fidelity sufficient for training requires further research.

The cues that are relevant for training thermal image interpretation differ for each type of environment. A few main categories are discussed below:

<u>For target acquisition in rugged terrain:</u>

A simulator should be able to generate the cues that allow a tank commander to be able to:

- identify static objects (e.g. trees, rocks, bushes, shacks, concealed parked tracked vehicles, friendly and enemy artillery installations, etc.)
- detect and identify dynamic objects ((e.g. friendly or hostile) vehicles, animals, infanterists, etc.).

<u>For target acquisition on non-residential country roads:</u>

In times of conflict, a tank commander must be able to detect and identify objects and vehicles on their thermal pattern, as registered by a thermal image device.

The cues to be generated should allow a tank commander to be able to:

- identify static objects (e.g. buildings along the road, parked vehicles, etc.)
- detect and identify dynamic objects (oncoming and passing vehicles, infanterists, etc.).

<u>For target acquisition in urban areas:</u>

Target acquisition is a task that is typically performed under high threat conditions. Field training is therefore difficult to realize because during peace time the thermal scene of urban areas is much too complex (too many cars, pedestrians, and other heat sources). In the future, simulation may be used to create scenes of urban areas under conditions of tactical engagement, thus opening training possibilities that are hitherto not feasible.

The cues to be generated should allow a tank commander to be able to:

- identify static objects (e.g. buildings, parked vehicles, etc.)
- detect and identify dynamic objects (oncoming, crossing, and passing vehicles, snipers, etc.).

2.3.3.4 Conclusion

There is a high need for developing effective and affordable simulators for training officers in using optical devices because modern warfare more and more requires forces to be able to operate at night and under poor sight conditions.
Typical issues of training include getting used to the green coloured image that optical devices provide; to correctly interpret the distance, dimensions, and direction of objects. But the principal challenge for realizing low-cost training solutions seems to be the generation of databases. This is especially true for thermal image interpretation training, because it has a larger operational range and requires many data on terrain, weather, and object characteristics. Furthermore, generating simulated thermal images requires difficult calculations including many parameters. This may not be a problem if the image is from a stationary point of view. If, however, images need to be presented from a moving point of view (e.g. a riding tank), then the constantly changing images need to be generated in real time. This is, at present, still a problem.

2.3.4 Training area 4: Manoeuvring unmanned platforms

2.3.4.1 Introduction

For the control of unmanned platforms the tasks of the external pilot of Unmanned Aerial Vehicles (UAVs) was chosen as the area to be trained: the common basis selected was training of the external pilot of the AAI Shadow (600 or 200) UAV.

An UAV is controlled by an external and an internal pilot. The global mission was defined as follows: The external pilots primary responsibility is to safely take-off the UAV, perform after takeoff control checks, then relinquish control to the internal pilot pending a "go" on all systems. The internal pilot then assumes control and flies the UAV on instruments to its target(s) for reconnaissance/surveillance. Upon returning home after the mission is completed, and within visual range of the external pilot, control is then transferred to the external pilot (positioned at the runway) for landing and recovery. The external pilot is trained for day and night operations.

2.3.4.2 Selection of critical subtasks

According to the analysis of WP1b, the task of the external pilot of an UAV can be divided into three subtasks:

1 Check
2 Take-off
3 Landing.

For these subtasks direct visual and auditive information of the UAV and the environment are used by the external pilot. The critical conditions are rough terrain, short runways, powerful wind, heavy rain or snowfall, noisy environments, bad visibility due to fog or low clouds or with night-time landings, variable wind speeds at different altitudes and tight schedule.

The subtasks 'check' is described as "to check all controls of the external pilot and also of the internal pilot, to check payload behaviour, flaps and rudder while motor running, the external pilot uses motor sounds to check acceleration, etc.". Visual inspection of the real apparatus and auditive cues play an important role during this subtask. Motor sounds have an important diagnostics value.

The subtask 'take-off' is described as "to take the UAV and bring it to an altitude of approximately 300 metres, then relinquish control to internal pilot". In this, direct visual information about position and behaviour of the UAV is important input for this subtask.

The subtask 'landing' is described as "after flight the UAV is flown back into visual sight of the external pilot and he takes over control over the UAV, and then recovers the UAV". Here again, direct visual information of UAV position and behaviour is important input for this subtask.

2.3.4.3 Functional requirements

The functional requirements of the take-off and landing subtasks are similar. However, the functional requirements of the first subtask 'check' are different. Simulation of this subtask would require almost identical engine sound and visual information as the real check in order to perform the task on a satisfactory level. The platform has to be inspected visually from all direction, the operation of the rudders has to be tested and the integrity of the payload must be tested as well. Also, subtle auditive cues in the engine sound of the real machine are important for learning to interpret this sound and evaluate whether the machine operates as it should. These requirements are so demanding that it is questionable whether a simulation of this subtask would be cost effective. A physical model of the platform together with a real engine may be sufficient as a training model for this subtask.

The take-off and landing subtasks require high quality input on the position of the platform in three-dimensional space. In the task analysis described in WP1b it was stated that UAV altitude fidelity is of key importance for simulator training value. This requires high resolution graphics with a large horizontal and vertical field of view, since the altitude and approach speed must be accurately assessed from a distance of several hundreds of metres. This is especially important for landing. This task needs to be trained to a high level of skill since the cost of damage caused by crashes is very high. In addition, the relation between operator control behaviour (the input from the control panel) and the movements of the platform requires substantial training because the UAV is perceived from varying distances and stimulus-response compatibility is low: the movement of the UAV has no direct perceptual coupling to pilot control actions. For example, if the UAV approaches the landing area, a steering correction to left results in a perceived movement to right. This indirect perceptual-response coupling in which the platform has widely varying positions with respect to the position of the operator (external pilot) requires substantial training, especially as poor visibility and wind may complicate task performance considerably.

Simulation of this would require a complicated model of the movement dynamics of the UAV under varying conditions of wind speed. Also, as indicated, the horizontal and vertical field of view must be large and the image quality needs to be of high resolution and very realistic. Since training of perceptual-motor skills is of key importance for the subtasks take-off and landing, the coupling between the control panel actions and perceived movements of the platform must appear highly realistic from a large distance.

Because the external pilot is not in the vehicle, he perceives a constant visual scene. This relaxes the complexity of simulating an adequate visual environment considerably. A possibility is to create a (constant) visual environment by using a slide, and to superimpose one or more targets.

2.3.4.4 Conclusion

The subtasks take-off and landing require training of perceptual-motor skills to a high skill level, since erroneous performance on these tasks may result in crashes and high costs. The perception-response coupling between the control panel actions and the calculated movements of the platform, and the resulting visual presentation of the platform's dynamic behaviour to the perspective of the external pilot, must be highly realistic. One solution, that is already often used at UAV training centres, is to train external pilots with using a scale-model (1:2 or 1:4) of the real UAV. Evidently, the scale model is not equipped with a pay-load. For reasons of transfer it is extremely important that the dynamic characteristics of the scale-model mimic that of the real system. This type of field-training may, at present, be more suitable than low-cost simulator training.

The selected common basis for this training area was the training of the external pilot. This training course was selected because it was not possible to get access to detailed information about the training of internal pilots and image interpreters. However, it is likely that low-cost simulator training for these operators is much more feasible. The fact that these operators perform their task in a degraded operational environment (e.g. no sense of vehicle movement, limited visual information) indicates that the technological demands required to simulate task-relevant cues are indeed feasible.

2.3.5 Training area 5: Operating within-visual-range, fire-and-forget, single-unit operated weapon systems

2.3.5.1 **Introduction**

The training of Stinger teams, provided at the "Technical Air Force School 3" in Fassberg (Germany), is selected as the common basis for representing this training area.

A Stinger is a portable ground-to-air weapon system. It consists of a launching tube, a back sight system, and a heat-seeking missile. The tube is approximately one metre long. The system is operated from the shoulder of a Stinger gunner.

A Stinger team consist of two soldiers: a gunner and a commander. Air-to-ground defence missions always involve several Stinger teams, each covering a certain air section. The operation of the Stinger teams is coordinated by an Anti Aircraft Officer.

The mission of a Stinger team is to defend an object against attacks from enemy aircraft or helicopters. The position of a team is 3-5 km away from the object to be defended. The Stinger team fights enemy air threats from a distance between 0.5 and 6 km. Attacking enemy air targets from 6 km is only possible with pre-warning, because target identification at this distance is impossible.

At the mission preparation, the team commander receives information about the nature and direction of expected threats. The team commander visually inspects the assigned air sector (using binoculars and with bare eyes). If a target is detected, the commander gives an order to the gunner to activate the weapon, and starts the identification process. Depending on the identification result, he either gives order to engage the target, or to cancel weapon activation.

If an aircraft approaching with a speed of 250 m/s (900 km/u) is detected at a distance of 4 km, then the Stinger team has 14 seconds left to attack. Assigning a target to a gunner takes the commander approximately 1-2 s. Activation of the Stinger system requires 3-5 s, and target identification approximately 2-8 s. Taken together, this implies that engagement is demanded within 11 s from target detection. Given the fact that decision errors are intolerable, this demonstrates that time pressure is a critical variable in the operation of Stinger teams.

2.3.5.2 **Selection of critical subtasks**

According to the analysis of WP1b, the task of a Stinger team commander can be divided into three main subtasks: "to detect target(s)", "to identify target(s)", and "to confirm or cancel target engagement".

The task of a Stinger gunner can be divided into four main subtasks: "to activate the weapon", "to acquire target(s)", "to deblock the weapon", and "to conduct weapon delivery".

2.3.5.3 Functional requirements

Given the input of WP1b, the following principal knowledge and skills make a competent Stinger gunner and Stinger commander.

- procedures (weapon operation, communication)
- target detection and identification
- aiming and firing at air targets.

Skill in operating the weapon system is very important. This can be trained very well with the real system. Likewise, the use of communication equipment and communication procedures can also be trained off-line. However, weapon operation and communication procedures are not the critical training factors. The crucial aspect is to respond as a team adequately and rapidly to events in air space. It is this part of the task that can not easily be trained without simulation. The challenge is to specify visual requirements that can be accomplished with low cost simulation technology, but will nevertheless be sufficient to achieve high transfer-of-training. Therefore, in the context of research into low-cost simulation opportunities, the accent will be on simulating the visual aspects of the Stinger task environment.

Representation of environment

Detection

Detection takes place in the visual periphery, where the resolution of eye is relatively low and where colour perception is not important. Simulation of the precise shape of air targets is probably not required, but it is important that the relative flux (contrast times area) matches that of the real aircraft in a real environment.

Field of view

Allocated air sectors are usually 60 degrees horizontally.

Identification

Identification usually takes place by means of binocular (foveal sight). It requires perception of the precise shape of the air target in all its details, thus demanding a very high resolution.

Distance and size estimation

Estimating the distance of an aircraft is dependent upon the flux and its orientation. The relative speed of change in flux over time determines its approach speed. The size of an aircraft is estimated by comparing the span width to the foresight ring (no optics).

Aiming

Aiming and tracking are continuous loop, perceptual motor tasks. This requires a high update frequency of the simulated target (the visual background scene can be constant, see also the analysis on area 4), because time delays make it difficult to keep the target in track.

Representation of operating environment

High fidelity replica of weapon and communication equipment should be present in the simulated task environment.

2.3.5.4 Conclusion

The training need of Stinger teams primarily involves skills of the gunner (aiming, tracking, and shooting), and of the commander (detection, identification, and decision). For obvious reasons, full-task field training of Stinger teams is impossible. Part-task field training is being done for detection and identification aspects, but this is also very limited because the air forces generally have few or no foreign aircraft available (for training).

Adequate practical training of the Stinger team can therefore only be realized with simulators. The fact that the (psychomotor) tasks of the gunner need to be executed accurately and rapidly requires realistic and valid training equipment (i.e. a replica of the weapon system). Even little deviations from the actual system may seriously impede transfer of training. The challenge for providing a good training environment for the commander primarily concerns issues of perception. Meeting the task demands requires high quality image generation systems.

Trainers that are currently in use in the forces generally make use of a dome. This technology meets the training requirements fairly close. Disadvantages are, however, that training is fairly expensive, and the immobility of the training system. Research into new and alternative technologies, like Head Mounted Displays (HMDs) and Virtual Environment (VE), is already going on. One of the significant problems of the application of these technologies seems to be the visual and physical interaction with the Stinger weapon (i.e. if the operator looks through his HMD to his hands, he should see the weapon, so therefore the simulation system should have exact information about the position and location of the weapon at all times).

2.3.6 Training area 6: Operating within-visual-range, guided, fire-and-forget, coordinated weapon systems

2.3.6.1 Introduction

The training of Forward Air Controller officers (FAC-officer), provided at the "Centre de Formation des contrôleurs Air Avancés" at Toul (France), is selected as the common basis for representing this training area.

FAC officer's are active in Close Air Support (CAS) missions performing precision, 'surgical' bombardments on enemy elements that are difficult or impossible to attack by land based weapon systems. Such targets are often small in size, camouflaged, and well protected. The principal units involved in CAS-missions are: the Air Liaison Officer (ALO), FAC-team(s), and pilot(s) of fighter aircraft. The ALO plans and coordinates the CAS-mission, involving the following activities: determining the target(s), assigning one or more aircraft to a FAC-team, and deciding upon the approach course. Prior to the mission, the ALO defines an Initial Point (IP), that is usually located 1-2 minutes flying from the target(s).

A FAC officer is member of a FAC-team, normally consisting of 5 people (2 FAC officers + 3 soldiers). The role of a FAC-team is to provide the pilot(s) with actual information and to assist him in his mission. In order to do this, the FAC-team moves forward into the "contact zone", close to or within enemy controlled area, and selects a strategic place for observation of the target (usually 3-5 km from the target). If possible, the FAC-team's position themselves on the straight line between IP and target, so that the aircraft flies directly over their heads. Especially in cases of attacking moving targets (e.g. convoy of battle tanks), the aircraft has to make a curve for an optimal approach. The FAC officers are responsible for communication with the pilot; the soldiers are responsible for protection of the team. The FAC officer and pilot communicate by means of radio.

The FAC officer informs the pilot about the terrain features, target characteristics and position (in relation to other marks in the environment), and about enemy's ground-to-air weapon systems. Depending on these factors, the FAC officer advises the ALO whether the attack should be carried out from a medium altitude (5000 ft) or from a low altitude (500 ft). The ALO usually complies to this advice, unless other information (possibly not available to the FAC officer) induces him to decide otherwise. The pilot gives a message to the FAC officer when he flies over the IP. Then, the FAC officer gives some final directions to verbally "guide" the pilot into the ideal approach route. The pilot must have the FAC officer's approval before releasing his weapons. The FAC officer is authorized to cancel the attack until the very last moment.

The time frame of the task of the FAC officer is as follows: After taking in a strategic position, a relatively long period of visually inspecting the environment (in order to re-actualise attack characteristics) follows (approximately 5-10 minutes). Then, when the aircraft is on its way, a period of interactive radio communication follows in which the FAC officer informs the pilot about the scene he is about to encounter. Then, when the fighter flies over IP, things are suddenly going very fast. The FAC officer gives some last minute directions, and authorizes or forbids weapon release. This part of the mission involves no longer than 1-2 minutes. Then, in case the target has been attacked, the FAC officer performs and reports battle damage assessment, and the FAC-team retreats as quickly as possible.

2.3.6.2 Selection of critical subtasks

According to the analysis of WP1b, the task of a FAC officer can be divided into four main subtasks: "to transmit the attack characteristics", "to guide the pilot to the target area", to "authorise/forbid weapon release", and "to transmit attack results" (battle damage assessment).

In "transmitting the attack characteristics", the FAC officer communicates the results of the visual inspection of the environment (including target description and enemy threat).

In "guiding the pilot to the target area", the FAC officer has selected the appropriate altitude and one or more approach routes.

The FAC officer has to approve or cancel the attack. Possible reasons for cancelling the attack may be: early detection of the planned attack by the enemy and subsequent operational air-to-ground fire, sudden and unexpected appearance of friendly forces in the direct vicinity, incorrect approach route taken by the pilot, etc.

In "transmitting attack results" the FAC officer must visually inspect the effects of the attack and communicate this to the ALO and to the pilot.

2.3.6.3 Functional requirements

Given the input of WP1b, the following principal knowledge and skills make a competent FAC officer. First, skill in visually inspecting the environment, and being able to comprehend how this environment will look like from altitudes of 500-5000 ft (mental visual transformations). Second, he must have knowledge of capacities and restrictions of: aircraft, air strike attacks, and air-to-ground defence weapon systems in order to advise about the best approach route and altitude. Finally, he must be able to exercise effective and concise communication protocols.

In the context of research into low-cost simulation opportunities, the accent is on simulating the static and dynamic visual scene. Adequate communication is evidently an inherent and important part of the task, but in terms of simulation requirements, this is not a major problem. The challenge is to specify visual requirements that can be accomplished with low cost simulation technology, but will nevertheless be sufficient to achieve high transfer-of-training. The remainder of this section therefore focuses on the visual aspects.

The training objectives directly related to this training area are that the FAC officer must be trained to visually inspect the environment, to select the attack altitude and one or more approach routes to guide the pilot onto its target, and to perform battle damage assessment. He must be trained to perform these tasks in different environments, including rugged or flat terrain, covered or open terrain, many/few/no objects similar to the target present in the scene, etcetera. In addition, the task must be trained under different tactical conditions (e.g. threat of enemy ground-to-air defence present or absent, friendly forces in the near vicinity, etc.).

Representation of environment

The FAC officer must inspect the target and its immediate and wider surroundings from a distance of 3–5 km. This requires high-resolution visuals, even with relatively big targets. Given the fact that the wider surroundings must also be inspected, this also requires a fairly wide horizontal field of view.

The FAC officer often uses his binocular to inspect the target zone. A training simulator representing the normal task situation, should allow for the use of this optical device.

When guiding, the FAC officer must be able to see the aircraft coming into the target zone, in order to verify whether the pilot has succeeded to follow the course communicated to him earlier by radio. If not, the FAC officer should suggest last-chance course corrections so that the pilot can come into the right approach track. This requires 360° FOV horizontally. Because the FAC officer has to be able to look up into the air to see the plane, a vertical FOV of approximately 50° seems to be necessary.

When performing battle damage assessment, The FAC officer must be able to determine the results of the attack (full kill, mobility kill only, miss, etc.). This requires a detailed visual inspection of the target and its immediate surroundings.

Furthermore, a simulator must be able to generate the visual cues that allows the FAC officer to be able to:
- detect and identify terrain features (land, grass, roads, hills, trees, rocks, bridges, cross-roads, etc.)
- detect and identify civil and military static objects (shacks, parked tanks, munition depots, artillery, etc.)
- detect and identify civil and military dynamic objects ((e.g. friendly or hostile) vehicles, animals, walking people, etc.)
- detect and identify the aircraft, to determine its position relative to the target, and to estimate its course
- estimate speed of objects, distances to objects and the distances between them.

Representation of operating environment

A FAC officer almost always use binoculars. These should be functionally present in full-fidelity. This may be achieved by using the actual instrument in the training environment. However, this may not be congruent with the other simulation technology used (looking at a screen with a binocular produces unrealistic views). There are, however, technological solutions to this problem.

Communication equipment should be present in its original form. In reality, radio contact is not always optimal. For initial training, crystal clear connections are recommended, because it is the content of the communication that is to be trained. For advanced training, scenarios may include blurred radio contact.

2.3.6.4 Conclusion

In the past decades, there is a increasing demand for performing precision air bombardments. This requires advanced aircraft (fast and difficult to detect by radar), skilled and brave pilots, advanced missiles, high quality intelligence information and effective communication between the forces involved. It is in this respect that the FAC missions are becoming increasingly important.

Because field training is very expensive and difficult to organize, practical training of the FAC officer currently involves scenarios in very symbolic learning environments (e.g. with maquettes). However, this type of training primarily focuses upon communication procedures; there is no interactive and valid link with the actual operating environment. A (low-cost) training simulator may provide the means to create a learning environment where practical (communicative and perceptual) skills may be trained in a more integral manner.

There is off-the-shelf simulation technology available that should be capable to generate a environment enabling trainees to practise their visual inspection skills, and to practise guiding an aircraft onto its target. An important task of the FAC officer is to detect course-errors of the incoming aircraft and to provide corrective instructions. Because the FAC officer is in stationary position, the projection of a simulated task environment can be kept constant. An already earlier suggested solution might be to create a (constant) visual environment, and to superimpose one or more targets and the incoming fighter. An aspect that makes it difficult to create an effective learning environment is that the task requires high speed action in a 360 degrees field of view. Furthermore, it may well be that the learning objective of acquiring skill in battle damage assessment is, at present, not feasible with low-cost simulator technology, because the required level of detail is too high.

2.3.7 Training area 7: Operating beyond-visual-range, non-guided, fire-and-forget, single-unit weapon systems

2.3.7.1 Introduction

The training of the aimer of the Howitzer M109 A2, provided at the artillery training centre at 't Harde (The Netherlands), is selected as the common basis training course for representing this training area. The aim of the course is to train aimers to load, aim and fire the Howitzer.

The aimer of the Howitzer is member of the Howitzer team, consisting of five people: the driver, the commander, a separate loader, and two aimers. In times of war one driver is added to this team. The Howitzer team operates in collaboration with two other Howitzer teams. They operate within visual range. The three teams form a unit, that is under command of a unit commander. Two units form a platoon, and four platoons form a section.

Howitzers are deployed in field artillery missions supporting the fire power of the combat units (tanks and armoured infantry) by providing indirect fire support. The platoon is under command of the command post that assigns the firing location for each Howitzer team. Once the teams, units, platoons, and sections are in position, all fire actions are controlled by a fire control centre.

Within the overall mission of the field artillery, the Howitzer team has to perform fire support actions to suppress, neutralize or destruct the enemy. They have to be able to provide fire support in all possible circumstances: day or night time, all weather conditions, in support of stationary or mobile forces, in a defensive or offensive battle situation, and in almost all terrain.

2.3.7.2 Selection of critical tasks

According to the task analysis that was performed for WP1b, the aimer of the Howitzer has four principal tasks: 1) to participate in taking fire position, 2) to execute fire commands, 3) check or change the gun's main direction, and 4) to fire with direct aiming. The first three are always performed during a fire support mission. The fourth task, however, is executed only in emergency situations.

The first task of the aimer, "to participate in preparing the Howitzer for firing" starts immediately once the Howitzer team has arrived at its assigned firing location. The result of this task is that the gun is aimed in the main direction of the most important fire mission.

The second task involves "executing fire commands". Fire commands are issued by the fire control centre, either by a direct line or by radio communication. On the basis of intelligence information, the control centre calculates the angles for the gun to strike an enemy target (on the basis of information provided by a forward ground observer), and subsequently provides the Howitzer commander with firing instructions. The Howitzer commander then passes this information verbally to the aimer, who adjusts the aiming devices accordingly. Before actual firing of the gun is allowed, the fire control centre has to give a final approval to the Howitzer commander, who passes this to the aimer.

The third task involves "duties on the firing position". Once the Howitzer is ready for action on its firing position, and the team awaits fire commands, then the gun's main direction will be checked or can be changed depending on the course of the ongoing battle. These activities are similar to the activities in the first task.

The fourth task, "to fire with direct aiming", is performed only in emergency situations because a Howitzer is not designed for direct firing. Because this ELSTAR training area is concerned with weapon systems for attacking targets beyond the visual range, this subtask of the aimer will be discarded in the analysis below.

2.3.7.3 Functional requirements

Given the input of WP 1b, the following skills make a competent aimer:

- comparing the angle of the gun, as indicated by the calibrated angle measuring device, with the angle indicated by the aiming devices of the Howitzer
- setting the compass aiming device in direction and elevation, by using panoramic sight and the reference cross of the compass aiming device
- setting the gun in elevation and azimuth by using panoramic sight and focus on reference points in the environment, beacons, or the collimator
- adjusting the aiming device
- compensating for movements of the vehicle (e.g. as a result of an earlier fired grenade) by turning the gun until the reticule of the panoramic sight meets the reference point of the collimator.

The skills to be trained are procedural (predetermined, stereotypical sequence of actions, discrete movements). The procedures to be executed require three types of input:

- visual information (e.g. displays on instruments; beacons and reference points in the environment)
- verbal information (commands with firing coordinates and firing orders)
- events (e.g. a shot fired triggers certain actions).

The output of the procedures consist of physical responses (mainly tuning devices). Below is a brief discussion on the nature of the information required to initiate and maintain the procedures.

Visual information

The aimer has to read his equipment (e.g. the compass aiming device, the calibrated angle measuring device). Furthermore, he has to use distant reference points in the visual environment for aiming. When aiming with the use of beacons (positioned closely in front of the Howitzer), the aimer has to take the parallax into account, because the panoramic sight of the aimer is not located in the centre of the turret of the Howitzer.

Verbal communication
The firing orders, verbally passed down by the Howitzer team commander, is very important input for the aimer. The nature of this communication is fairly simple and standardized. The aimer simply receives instructions from the Howitzer commander and acts accordingly. Therefore, the training of the communication between Howitzer commander and aimer will probably not be a difficult problem in developing low-cost simulator training solutions.

Events
In a few cases, the aimer has to initiate a procedure autonomously after a certain event. For instance, after a firing session, the aimer has to fine-tune his aiming devices. In order to create a simulated task environment, the disrupting effect of firing sessions on the settings of the aiming devices must be simulated. The disruptive effect need only to be present; exact simulation of it is not required for training purposes.

Representation of the environment

The aimer comes into action after the Howitzer has taken in its (stationary) position. Therefore, the visual scene is static, with no or very few dynamic objects. The aimer only uses reference points in the visual environment. He positions the reticule of the panoramic sight either using distant reference points (e.g. a church tower), beacons installed at close distance from the Howitzer, or on the collimator, also installed at close distance. Thus, in order to create a simulated task environment for training of aiming tasks, a simple visual scene will be sufficient. The simulated scene should allow the identification of distant reference points (approximately 2 km) as well as the identification of nearby beacons and collimator. Furthermore, the simulated task environment should mimic the phenomenon of parallax realistically.

Representation of the operating environment

The task of the aimer is relatively simple and involves mainly the reading of instruments and to use the obtained information for setting other equipment. The primary skill is to read this information correctly, and to copy it without errors. High-fidelity simulation of *physical display features* is probably not crucial for skill acquisition. However, for reasons of transfer it is advisable to simulate the dynamic characteristics of the equipment as closely as possible. In sum, it seems not necessary to simulate the operating equipment with high fidelity. A simplified training environment may yield good transfer to the operational situation.

2.3.7.3 Conclusion

The tasks of the aimer of the Howitzer M109 A2 consists of executing procedures, requiring relatively simple visual, verbal, and event information. The output consist of discrete motor actions (setting equipment).

The visual requirements are not very demanding. A simple static visual scene with few objects, a low resolution, and a small field of view is sufficient to create a simulation in which effective skill acquisition can take place. Such a simulation can probably be generated by a low-cost visual system.

The nature of field artillery missions requires the aimer to perform his tasks under time critical circumstances (rapid firing). The aimer therefore needs to be able to cope with time stress. In order to practice this aspect, training should occur in real time. Apart from this, there are very few constraints on the mathematical model, since there is no interaction between the aimer and objects in the environment.

To conclude, the technologies required for developing a low-cost simulator for training a Howitzer aimer are rather simple. Given the fact that field training using the real equipment is expensive and restricted, suggests that there exist good opportunities for cost-effective simulator training, even though the number of trainees per year is rather low. It is unlikely, however, that developing low-cost simulator training for this type of tasks will generate new knowledge on achieving cost-effective simulator technologies. The problems to overcome will be more related to instructional and training design rather than to simulation technology.

2.3.8 Training area 8: fault diagnostics and maintenance of complex, composite systems

2.3.8.1 **Introduction**

The training of mechanics of ARBR21, ARBB36, and DAGAI1C systems, provided at the "Centre d'Instruction Navale" in St. Mandrier (France), is selected as the common basis for representing this training area.

The "Centre d'Instruction Navale" in St. Mandrier is a large naval training centre, providing over 100 different training courses. The centre has two main departments: "weapon systems" and "platform, mobility & logistics". The common base training course belongs to the department of "weapon systems".

Until a few decades ago, ships had only mechanical, hydraulical, and electrical systems on board. The maintenance and repair required mechanics with a high level of understanding of these systems, and with knowledge of the functions and structure of all parts. An important concept in describing the task of a mechanic is the "Line Replaceable Unit" (LRU). It refers to the nature and size of the system component that is to be replaced in case of malfunction. In the older systems, the LRU generally involved small parts, like wires, switches, pot-meters, plugs, etcetera. In order to train the mechanics, the navy commonly had an exact replica of the system available in a training centre on shore.

In the past two to three decades, the systems on board have become more and more complex as a result of technological developments in electronics and computers. Due to the increased complexity, the functionality of systems has become less transparent. Components have been integrated (e.g. multiple elements and their connections on one electronic component board), thus leading to larger LRUs. This development made that detailed knowledge of a system's structure, and their constituent parts, has become less important, although maintenance and repair still requires mechanics to have a high level of system understanding. The utilization of advanced electronics, and the fact that they are produced in lower numbers, have made new systems, in general, more expensive. This makes the purchase of an extra copy for training purposes often not feasible.

The mission of the mechanics is to perform maintenance, trouble shoot, and repair of ARBR21, ARBB36, and DAGAI1C systems. They do this by visual inspection, by running system-integrated tests (self-tests), by consulting technical documents, and by utilizing standard or system-specific measuring instruments and tools.

2.3.8.2 Selection of critical subtasks

According to the analysis of WP1b, the task of a mechanic can be divided into the following main subtasks: "to check", "to detect", "to identify", "to interpret", "to solve", "to plan", "to follow technical orders", and "to repair".

2.3.8.3 Functional requirements

Inferring from the input of WP1b, the following principal knowledge and skills make a competent mechanic:

- knowledge of system principles
- knowledge of the structure of the technical documentation
- skill in using system knowledge for maintenance, diagnostics and repair tasks
- skill in the use of technical documentation for maintenance, diagnostics and repair tasks
- skill in the selection and use of measuring instruments and tools.

As argued earlier, understanding the functional principles of electronic war equipment systems is very important. In order to diagnose a malfunction, mechanics have to understand the functionality of each LRU, and how a failure in such a unit affects the functioning of other components, and of the whole system. This can best be explained using multi-media instruction, including, for instance, photos, video, and animations to demonstrate system processes. This requires elementary system simulations only; no real-time simulation is required. Likewise, the structure and use of technical documentation can best be explained in a computer based instruction (CBI) environment. If the technical documentation is still in the form of traditional books, this CBI has to be separate from the technical documentation itself. However, recently technical documentation tends to be more and more made available in electronic form: Interactive Electronic Technical Manuals (IETMs). There is much interest to integrate computer based instruction into these electronic manuals for training purposes. Once again, this does not directly require real-time simulation.

Mechanics need to have skill in applying internal (mental) and external (documentation) knowledge for maintenance, diagnostics, and repairs of the equipment. Maintenance task involve fully prespecified procedures requiring no or little system simulation. Actual repair requires hand-on experience with the real equipment. Diagnostics, however, requires inspection, hypothesis forming and testing, and interpretation of results. Acquiring this skill requires experience with many possible system malfunctions. Some (or perhaps all) of these malfunctions may be simulated on the actual equipment. However, using a low-cost training simulator representing the system in a symbolic and dynamic manner, may be more flexible and cost-effective, and may provide a deeper understanding of system processes. Therefore, the focus should be on determining the requirements of low-cost simulation of system behaviour in order to provide a satisfactory training environment.

Representation of environment

The skill of interest is "diagnostics", involving the utilization of (internal and external) knowledge to isolate a system fault in a logical and correct manner. Principal processes to be trained are: combining information sources, hypothesis forming, and testing of possible causes. These are cognitive processes, and do not require a high-fidelity simulation of the task environment.
In order to develop a simulator to train diagnostic skills of a mechanic, the output of the system does not need to be simulated, only the interface between equipment and operator. Evidently, the interface reading, as the result of the operator's input, should be consistent with the functioning of the system.

2.3.8.4 Conclusion

The training need of mechanics of ARBR21, ARBB36, and DAGAI1C systems can for a large part be realized with traditional classroom instruction, or, more advanced, with computer based training programmes. Training the actual procedures for maintenance and repair requires hands-on experience with the real system or exact replicas. For acquiring these skills, there seem to be no opportunities for low-cost simulators. Training in trouble-shooting (fault finding), however, may be more effectively and efficiently realized with the use of low-cost training simulators, representing the system and task environment in a symbolic and dynamic manner (e.g. through 'desk-top' simulation, see deliverable WP1A). The most significant problem in developing such solutions is to specify the training scenarios and to determine the associated level of system modelling required.

2.3.9 Training area 9: Mission planing and implementation at the (Army) staff level

2.3.9.1 Introduction

The training of 2nd Staff officers, provided by the Belgian Army Training Centre (CHKO: "Cursus Kandidaat Hoger Officier"), is selected as the common basis for representing this training area.

The army staff officers are being trained to plan and command the operations of armoured infantry and of tank battalions. The trainees have an academic level of education and at least 10 years of military experience.

The staff officer has to be able to fulfil his mission under all types of tactical conditions (defensive, offensive), in low- and high intensity conflict situations. He should take into account the limitations and possibilities of the environment and of the enemy. Based upon a careful analysis of all factors, the staff officer has to formulate a tactical plan, direct his lower-level commanders into adequate mission implementation, to keep higher-level officers informed about mission progress, and -if needed- to make proper mission plan adjustments.

2.3.9.2 Selection of critical subtasks

According to the analysis of WP1b, the planning and executing of army missions involves four principal tasks: "time management", "tactical planning", "tactical field briefing", and "command & control". Each of these can be subdivided. Below is an abridged version of the task structure, see deliverable WP1b for details.

<u>Time management</u>

- Inventorise critical moments (e.g. time-of-twilight; time-of-attack, etc.)
- Calculate time to move to staging area (e.g. distance, speed of vehicles, etc.)
- Generate mission time table (prepare, evaluate, fine-tune)

<u>Tactical planning</u>

- Perform tactical analysis (environment, own means, enemy means)
- Choose best solution (generate possible solutions, evaluate, select)

<u>Tactical field briefing</u> (instruction in the field to lower-level command)

<u>Command & Control</u>

- Observe activities
- Adapt the mission plan (e.g. because of enemy threat, new higher-level orders, etc.).

2.3.9.3 Functional requirements

Inferring from the input of WP1b, the following principal knowledge and skills make a competent officer:

- knowledge of capacities of own forces, and the possible impact of environment and enemy forces upon performance own forces (in order to develop a realistic tactical plan and a feasible time frame)
- knowledge of capacities of enemy forces (in order to anticipate upon this in the tactical plan)
- knowledge of military warfare techniques and history (in order to prevent "classic" mistakes in the tactical plan)
- skill in preparing comprehensive and logically consistent mission time tables
- skill in producing and evaluating alternative mission plans and to select the best
- skill in briefing lower-level control in a comprehensive manner (communication skills)
- skill in mission management (requesting and providing information from lower- and higher level control, (rapidly) evaluating incoming information, developing and issuing plan adjustments on-line, information exchange with same-level control in coordinated missions, etc.).

Because the knowledge and skills identified above are different in nature, they require different types of learning environments. These will be discussed below.

Extensive *knowledge of military material and warfare* is very important to (become) a good staff officer. In order to make a realistic tactical plan, an officer has to be able to assess the possibilities and limitations of his troops on all kinds of aspects (e.g. speed of transportation, fire power, prior cooperation between units, etc.). As a result of their prior military experience, trainees are usually very well informed about these aspects. Furthermore, he should be acquainted with the literature on military warfare. The practical and theoretical background knowledge is necessary for developing mission plans. The planning of missions does not require advanced training aids. It can be trained very well in a traditional learning environment, simply with a map, paper, pencil, etc. This type of learning environment is suitable for training in: mission planning, preparing mission time tables, producing and evaluating alternative mission plans, selecting the best alternative.

Skill in *briefing lower-level control* includes the selection of a proper briefing spot and to effectively and efficiently communicate the selected plan, and to discuss "what-if" scenarios (tactical briefing). Given the task descriptions, low-cost simulation seems not the appropriate approach for meeting the training needs. Communicating plans need to be practised with a real public (role playing instructors, or representative soldiers), and training to select an appropriate briefing spot can best be trained in the field.

There are very few missions that are executed exactly the way as planned. Adjustments (major or minor) are almost always necessary. Skill in *managing the mission* while it is being executed is therefore of central importance. The commander has to be the focus of communication lines to obtain complete and reliable information about the situation in order to make any appropriate adjustments. Field training in the form of full troop exercises is one possibility to train officers, but that is very expensive in terms of money and effort. Another possibility, that is currently the most practised, is to use symbolic exercises, where the troops are represented as symbols on a map. The officer has the normal communication lines to command his lower level control in the conflict situation. The instructor controls the scenario and has to implement the outcome of the officer's action on the situation. Drawbacks are that this type of practice is not very flexible, the instructor can not always judge the nature of a certain situation (e.g. is a unit within or outside the visual range?), and that the consequences implemented by the instructor may not reflect the situation in real combat.

There exist promising opportunities for training *mission management skills* using low-cost simulation. The challenge is to specify the requirements for simulating the behaviour of friendly and enemy forces. The focus of developing such training simulators should be on the construction of scenarios (including peace enforcing missions, applying (and violating?) international Rules of Engagement, etc.), the modelling of the behaviour of military units involved (fire control, air defence, logistics, transport, etc.), and the instructional facilities (scenario generation and control, feedback, performance measurement, etc.).

Representation of environment

The skill of interest is "mission management": the officer is required to utilize military knowledge and procedures in order to deal adequately with expected and unexpected events. He should do this in such a fashion that the preplanned mission will (is most likely to) succeed. Principal processes to be trained are: obtaining and providing information, combining information sources, acknowledging events that may threaten mission success, unfolding adequate responses, and implementing and directing plan adjustments. These are cognitive processes. The tools and instruments that the officer has in real life at his disposal (a (digital) map, communication lines and reconnaissance information) can be implemented easily in a low-cost simulator training environment. For reasons of scenario control one or more instructors are needed to provide the trainee-officer with requested information and to implement his commands into actions. Furthermore, the model (containing data on many battle field factors, like: terrain, time-of-day, geographical information, vehicle movement characteristics, etc.) should be able to recalculate the impact of actions upon a situation in (near) real-time, and should reflect the real situation as closely as possible (e.g. containing single shot kill probabilities, detection likelihoods).

2.3.9.4 Conclusion

Field training in the form of full troop exercises in order to train officers are becoming too expensive and are no longer socially accepted when they take place outside the military training grounds. In order to maintain an acceptable degree of operational readiness, and in order to be able to give efficient instruction, low-cost training simulators may provide an adequate alternative. The training analysis reveals that it is sufficient if such simulators represent the task environment and participating parties in a symbolic manner. The most significant problem in developing such training solutions is to model participants' (units, platoons, etc.) behaviour, their inter-reactions, and the effects of events in a realistic manner. In addition, solutions need to be developed for specifying training scenarios, and to find ways for adequate instructor facilities.

2.4 *Discussion*

The purpose of conducting the training analyses is to identify the *critical* task variables and cues for the training programmes of the earlier selected 9 training areas. This is necessary to specify the global functional requirement for developing simulator training solutions. In this paragraph, the main results of the analysis of the investigated training programmes will be discussed in relation to each other, and in relation to simulation requirements. It is beyond the scope of this work package to be complete in our elaborations. Therefore, we will address the main issues only.

2.4.1 Representation of natural environment

In general, creating learning environments requiring simulation of a natural task environment is more difficult than creating learning environments requiring simulation of a man-made task environment only. The majority of training programmes representing the training areas require some sort of representation of the natural environment (all with exception of training areas 8 and 9). The complexity and detail that is needed, however, differs substantially among the different programmes. Because the completeness and quality of environment simulation has direct implications for the simulation technology needed to create an adequate learning environment, the functional requirements are briefly discussed with respect to the principal components of training simulators.

Visual database

The training programmes differ considerably with respect to the size and complexity of the visual environment. For instance, learning to drive (and to participate in traffic) requires a large and complex visual database. The database has to cover several square miles, many stationary objects (roads, signs, houses, trees, etc.) with a sufficient level of detail, and many moving objects (other traffic participants). Because the driver interacts with the environment (i.e. moves through it), a three-dimensional model is needed. The training of the aimer of the Howitzer is at the other end of the continuum. The operator is stationary within his visual environment, and requires few visual references in order to carry out his task. Therefore, the visual database can be very simple.

Image generation and presentation

The visual aspects of the environment, stored in the visual database, need to be displayed to the task operator(s) in such a fashion that it enables the perception of task critical cues. The quality of image presentation can be expressed in terms of field-of-view (horizontally and vertically), resolution, update frequency, refresh rate, image delays, contrast ratio, stereo, luminance, etc. Again, the demands on the image quality varies from training programme to training programme. For instance, generating a simulation of a task environment for learning to navigate during low-level flight imposes very high demands upon an image generation system. It requires detection and identification of close and distant objects. Because of the aircraft's high speed (with high angular speed of objects), the outside image changes constantly and quickly, and has therefore to be recalculated and refreshed at a high frequency rate. In contrast, simulating video images for a UAV internal pilot would be much less of a problem, because such images of the outside world are already degraded in terms of field-of-view, resolution, and, sometimes, update frequency. Finally, generating a simulation of a task environment for learning to aim a Howitzer, should be very simple. Because of the aimer's stationary position, low end image systems should be capable to produce the (relatively meagre) visual scenes.

There are several possibilities for projecting visual images. A possibility is to use one or more computer monitors for displaying the scene. This may be adequate for some, but not for all training programmes. For example, computer monitors are likely to be suitable for displaying simulated images of thermal image equipment. In contrast, the Stinger team commander and, to a lesser extent, the FAC officer have to be able to perceive objects at great distances. This requires very high resolutions that are unlikely to be produced by computer monitors. Another possibility, but usually less flexible are projection screens (e.g. flat, panorama, dome). For some purposes, collimated image systems may be appropriate. Because collimated images prevent perception of depth, they are not suitable for tasks in which nearby objects have to be perceived, like driving, for instance. If the task requires scanning a large part (or the entire) environment, like, for example, a FAC officer, then a Helmet Mounted Display (HMD) may be a good solution. The HMD should be equipped with a head tracker in order to present a small high-resolution instantaneous field-of-view, and a large total field-of-view.

Mechanical database, and simulation of motion

For some tasks, perception of the movements of a system is necessary to perform the task. In order to create a simulation of the task environment in which the task can be learned, simulating the critical mechanical movement cues is necessary. For the training programmes investigated, this seems only to be required for learning certain subtasks of "driving a wheeled-vehicle". In order to generate vehicle movements in a valid way, highly accurate models are required of the vehicle's behaviour, and of the mechanical characteristics of the (surface) environment. However, sometimes adequate training may be obtained by using only the transient components of the accelerations and decelerations by using vibrations rather than real movements.

Sound database, and the generation and presentation of sound

For some tasks, perception of sound is necessary to perform the task. The sound cues to be simulated may come from several sources, like: engine (rpm, gear-switching), tires, wind, etc. The required sounds need to be stored in a database. The samples should be correctly related to the real sounds in terms of intensity, pitch, and timbre. For some tasks, the sounds may provide the cues for direction (e.g. FAC officer). If that is the case, this property should be adequately simulated in the learning environment. Another important aspect is that the sound generation is synchronized with the visual and motion information.

The challenge for developing simulations is to acquire adequate sound samples, with all their relevant properties. The *generation* of the sounds is technically not a big problem. They can be presented in high-fidelity using a multi-channel 3D presentation.

2.4.2 Representation of operating environment

In a training simulator, a trainee learns to perform a task by interacting with a model of the real task environment. In order to be able to interact with this model, the trainee is placed in an operating environment. This is the hardware through which the trainee is informed about the system's status (by meters, indication lights, etc.), and through which he enters his responses into the system (by switches, levers, pedals, etc.). A learning environment using simulation requires some sort of representation of the operating environment. For some training programmes, using the actual system may be the best solution, because the real system is relatively simple, and can easily be connected to other aspects of the simulation. For instance, for developing a simulator to train the Stinger gunner, the actual weapon (or an exact replica) can best be used for learning to perform weapon operations. In other cases, including the actual system in the simulation may unnecessarily inflate costs. For example, including the full range of equipment into a simulation of the task environment of a Howitzer aimer may not be needed in order to obtain the desired learning effects.

It is important that the characteristics of the operating instruments are correctly simulated (control loading), with respect to position, force, and motion.

A special case is the training of staff officers in command & control (area 9). The heart of the simulation is a model of participants' (units, platoons, etc.) behaviour, their inter-reactions, and the effects of events (enemy fire, obstructions, etc.). Although such a model can be developed by using available knowledge of military warfare and of history of military warfare, the validity of the model can not be evaluated easily.

2.4.3 Instruction facilities

It is important to make a distinction between a simulator and a training simulator. A simulator is simply a dynamic model of a system and a task environment. The purpose of a training simulator is to provide a learning environment in which trainees can acquire effectively and efficiently the skills required for successful task performance. A training simulator is therefore the combination of a system model, task scenarios and instruction facilities. The system's behaviour is defined as a function of possible operator inputs, usually in the form of a mathematical description of input-output relations. Task scenarios are a description of the conditions under which the task has to be performed. Instruction facilities are added to the simulator in order to enhance the learning processes. They include, for example, specifying learning trajectories, conducting and recording performance measurements, providing demonstrations, providing feedback about task performance, and providing help and hints.

3 GENERAL CONCLUSIONS

The purpose of conducting the training analyses was to identify the *critical* task variables and cues for the training programmes of the earlier selected 9 training areas. The results are necessary to establish in more detail the possibilities and restrictions for developing simulator training solutions. This information is, in turn, necessary to intelligently narrow down the selection to 3-5 training areas, in the next stage of this work package (WP1d).

Each training area includes many military training programmes (e.g. "wheeled-vehicle control" includes training of passenger cars, of light trucks, lorry-trucks, etc.). It was therefore not possible to analyse all of them. A pragmatic solution was required. The approach taken in the ELSTAR project was to select one representative training programme for each training programme, and to subject that programme to further analyses. The results of the analyses should then be generalized to the whole training area. Whether such generalization is justified depends upon the homogeneity of the training area, and upon the representativeness of the selected training programme.

It can be concluded that the homogeneity, and the number of associated training programmes (broadness), differs substantially among training areas.

It can be concluded that the training areas are not always comparable with respect to homogeneity, and the number of associated training programmes (broadness). Some of the tasks of the investigated training programmes have very specific characteristics, having limited relevance for other programmes within that training area (e.g. when actions pertain to a specific operating console). Furthermore, some training areas are broader than others in the sense that they cover more related training programmes. For instance, using infrared and image intensifier equipment are tasks in many branches of military operation, while operating a "beyond-visual-range, non-guided, fire-and-forget, single-unit weapon system" (e.g. Howitzer) is restricted to artillery missions only. It is therefore important to note that the results of the analyses can not always be automatically generalized to other training programmes belonging to a training area.

Notwithstanding the earlier mentioned limitations, it can be concluded that the results demonstrate the appropriateness of the 9 selected training areas for low-cost simulation research and provide insight into the global functional requirements for developing simulator training solutions. The data provide the information necessary to intelligently narrow down the current selection in the final phase of this work package.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTES))

The objective of the EUCLID RTP11.8 ELSTAR project "Low-cost simulators" is to develop guidelines for the specification, development and application of low-cost training simulators. Low-cost simulators are trainers that, through the use of commercially available and emerging technologies, provide superior benefit-to-cost ratios when compared to full fidelity simulators.
First, the full spectrum of military tasks is screened on their potential for cost-effective simulator training. Next, 9 training areas were defined covering those task domains for which further investigation of low-cost simulator training solutions seemed promising. Then, field research was conducted on actual training programmes in order to verify the initial selection. The data of the field investigations were used for analysing the training programmes to determine global functional requirements of training simulators. The present report presents the methods and results of those analyses.
The goal of the analyses is to identify the *critical* task variables and cues for the training programmes of the defined 9 training areas. First, the principal subtasks of the training programme are identified and the nature of the task-specific skills are characterized (e.g. cognitive, perceptual-motor). Then, the functional requirements of learning environments in which the necessary skills can be learned, are addressed. Finally, for each training programme, the opportunities and restrictions for developing low-cost training simulator solutions are discussed. It is concluded that the results provide the information necessary to intelligently narrow down the current selection in the final phase of this work package.

16.	**DESCRIPTORS** Simulators Task Analysis Training Analysis		**IDENTIFIERS**

17a.	**SECURITY CLASSIFICATION (OF REPORT)**	17b.	**SECURITY CLASSIFICATION (OF PAGE)**	17c.	**SECURITY CLASSIFICATION (OF ABSTRACT)**
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