# TACTICAL MISSION TRAINING,

# DESIGNING THE VISUAL SYSTEM TO PILOT PERCEPTUAL REQUIREMENTS

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## ABSTRACT

To determine visual requirements for ground-based tactical trainers, it is necessary that system designers understand how the aircrew perceives the real world in a tactical situation including what and how various cues are used to accomplish the mission.

Visual simulation system performance requirements are often based purely on visual perceptual data collected under laboratory conditions. Such data tends to overstate the requirement since it has no real world or training need modulation and does not reflect the effects of the aircraft and mission environment on human performance. It also does not address factors such as target obscuration or occulting nor how supplementary pointer cues and avionics may be used to locate a target. Data is also needed as to where a pilot looks within the field of view during each element of a mission in order to define field of view requirements of the display.

It is important that the system designer understands the missions and likely conditions and environment that affect the pilot in the real world so that the simulation can reflect these conditions. He must also understand the cues used by the pilot to detect targets, waypoints, SAMS, etc., in order that the data base reflects the proper conditions and supporting cues.

This paper briefly addresses the visual trade process, vision requirements, and the process of collecting and applying pilot perception data to support visual simulation requirements for tactical training in a USAFE type of environment.

## INTRODUCTION

### Background

United States Air Force Europe (USAFE) together with other members of NATO have been under increasing pressure to reduce low altitude training flights in Germany and other Western European countries because of the potential hazard of such flights to the local population.

With the coming down of the Berlin Wall and the reduction in the Eastern threat, the pressure to restrict low altitude flights geographically to smaller areas and higher altitudes reduces USAFE's ability to train in order to maintain readiness. The European topography makes low altitude terrain following a key tactic for avoiding enemy threats during a USAFE mission such as air interdiction. Training for such missions is a key area of USAFE's defense strategy.

At the request of USAFE, the Training Systems Program Office (SPO) at Aeronautical Systems Division (ASD) contracted with JWK of Annandale, VA. to conduct an indepth Training Systems Requirements Systems Analysis (TSRA). The purpose of the analysis was to define changes and alternatives to the current low altitude mission training program which will allow USAFE to maintain readiness under the flight restrictions that are being imposed. The TSRA was completed in May of 1991. It covered all aspects of both airborne and ground-based training. A key element of the TSRA was a Technology Assessment (TA). Although the TA included a review of technology to support all aspects of ground-based training such as computer based training, procedural training, and part-task training, the most critical area was to assess the ability of visual simulation to support critical aspects of low altitude mission training.

### Statement of Problem

The visual system is the most important element of a fighter simulation. The visual system is made up of two principle subsystems, the visual display and the image generator. Low altitude flight and air to surface weapon delivery are the most difficult flight envelopes to simulate. Simulation of air-to-air combat is much simpler because it involves specific high resolution airborne targets and limited ground or surface simulation. Tactical air-to-surface on the other hand, requires detailed terrain simulation over a large gaming area for both low altitude flight to a target area and to perform the attack on a target. It includes the simulation of other aircraft, SAM missiles, etc. It also involves flying behind or below terrain features that afford masking from enemy radar and threat forces. Low altitude flight subjects the pilot to high work load including a great deal of image scanning. Selecting a display and an image generator which will meet training requirements and at the same time is affordable is extremely difficult. The current high-end image generators under development may meet a good share of the training needs, however their affordability may be questionable. Selecting a display system is even more challenging.

To resolve the problem of providing an affordable solution to tactical visual simulation, pilot perception must be a key consideration in the parametric analysis and trade process.

Purpose of the Paper

The purpose of this paper is to describe for the user and the systems designer some of the representative considerations to choose a visual system for tactical simulation and a process to gathering mission related pilot perceptual information. The paper shows how such data may be applied to the visual system selection process with factors such as theoretical perceptual and training effectiveness data.

Approach

The approach taken to conduct the assessment to support mission training was unique. A systems engineering approach was adapted where system performance requirements were first defined from: (1) mission training tasks, (2) human perception requirements and (3) known training effectiveness data. Each major subsystem of a training simulator was first addressed separately and then as part of the trainer system. Data collection included visits to: (1) existing tactical training facilities to gather data on system utility, (2) government R & D facilities to review trainer and training research programs and (3) simulator development contractors to review latest state-of-art in simulation technology. Finally, operational tactical fighter pilots were interviewed to tie together theoretical perceptual requirements with real world pilot experience.

## METHOD/PROCESS

Visual Trade Analysis Process

Visual system performance requirements must be based upon low altitude mission training requirements. Therefore, the analysis and recommended configurations were made based upon technology which would support a general set of mission training requirements, training tasks and a base line suite of media. Training effectiveness and perceptual requirements were defined to be part of the data gathering and analysis process. Specific mission training requirements or descriptions such as battle air interdiction (BAI), tactical reconnaissance, and close air support were used as a basis to form the training system performance requirements. These performance requirements together with human perception considerations and training effectiveness considerations provided the basis to define training device subsystem. Later, subsystem trades were conducted to define the most training/cost effective training systems. Human perception and training effectiveness data formed a part of the trade process. This was a highly iterative process involving state-of-the-art technology, various trade parameters, together with mission requirements and perceptual and training effective information.

Initially, the human perception data used was theoretical laboratory data. Later pilot perceptual data was incorporated in the trade process in order to modulate the result to account for a real world pilot perception. The pilot inputs turned out to be a key factor to provide a system which includes the proper trades and compromises. The paragraph which follows on human vision and pilot perception discuss some of the more important perceptual factors to be considered for tactical mission training.

Human Vision and Visual Simulation

The human eye is an extremely sensitive high resolution sensing device that even in todays world of exotic high performance electro-optical sensing devices is highly impressive. It is capable of operating under extremely wide ranges of light levels from starlight to a bright day on a beach. It can resolve extremely small details over a wide field-of-view and range of distances. Visual simulation can not duplicate the resolving power or the range of brightness and contrast within which the eye can operate. For that reason we must provide a system which stimulates the eye as similar ranges and level of difficulty that a pilot is expected to experience in a real world tactical situation. However, the limitation in system resolution and brightness will preclude the simulation of conditions such as a clear bright day with very high brightness and contrast. It also means it may not be feasible to train target identification and recognition with a complete range of conditions. However, simulation of enough conditions for visual mission training should be possible.

To develop visual simulation requirements including trading off system performance requirements for an optimum training system, one must first understand the anatomy of the human eye, its performance, and how it perceives information under different conditions.

Eye Characteristics

Several human eye performance characteristics were given careful consideration to develop visual system requirements. Some of the most important include:

(1) Resolution

The central portion of the human eye or foveal region has very high resolution. This area extends roughly only 1.5 to 2 degrees. Human vision beyond the central foveal region is extremely poor.

(2) Field of View

The field of view of human vision with both eyes extends to approximately 200 degrees. Perceptual data indicates that perception of speed and altitude are greatly enhanced by peripheral information. This conclusion was born out by the pilot interviews. Perception of motion is also highly affected by peripheral vision.

(3) Brightness Sensitivity

The human eye is highly sensitive over a wide range of brightness levels. However, very low brightness levels can reduce the resolution of the eye. This should be a concern in the visual system design.

(4) Eye Dynamics

The movement of the eyeball is very important in scanning for and tracking targets and other objects of interest. For certain conditions the eyeball may move as fast as 1,000 degrees per second. Head and body movements may also occur at speeds as high 500 degrees per second. These dynamics must be given careful consideration in the design of the visual display system.

## Perception Factors

Although the pilot's eye may perceive detail far better than the visual simulation devices are able to provide such detail, conditions seldom exist in the aircraft which make it possible to achieve such perception. The following factors affect pilots perception during a tactical mission:

(1) Contrast

Contrast is the ability to perceive a lightness or brightness difference between two areas. Generally missions in the real world involve relatively low contrast scenes. Contrast may be enhanced in the simulation to compensate for lower resolution.

(2) Atmospheric Conditions

Atmospheric conditions usually limit the distance at which a target or other object can be perceived in the real world. In a European environment both target contrast and atmospheric clarity will tend to be low. Coupling of low contrast and poor atmospheric conditions can have a significant effect on the pilot's perception of targets and other detail.

(3) Object Occulting

In addition to the effects of low contrast and atmospheric attenuation, a pilot must deal with the obscuration of a target caused by it being occulted by objects in the foreground. This is especially true when dealing with the rolling hilly environment with large amounts of tree cover found in Europe. Flying at low altitudes causes this problem to be extremely severe. Often a pilot may not see a target until such time as he pops-up to perform his attack on a target. Occulting may cause pilots to rely heavily on avionics systems such as radar and FLIR to locate a target.

The factors just discussed together with the human eye characteristics were all taken into account during the analysis of the visual system requirements. Later, their effects on system design were modified and expanded to reflect the inputs received from the pilot interviews.

## Rationale and Process Used to Collect Data from Pilots

To determine potential applications, utility, and system requirements of ground-based tactical trainers, it is necessary that system designers understand how the aircrew perceives the real world in a tactical situation. This must include what and how various cues are used to accomplish the mission. It is important that the system designer understands the likely conditions and environment that can affect the pilot in the real world so that the simulation can reflect these conditions i.e., visibility, clouds, overcast, etc. He must also understand the cues used by the pilot to detect targets, waypoints, SAMS, etc., so that the data base properly reflects the proper conditions and supporting cues. Some of the more important factors explored with the pilots in the interview process included (1) the role of peripheral vision, (2) cues used to maintain altitude over terrain, (3) means of tracking over a ridge, (4) effects of weather on performance of a mission, and (5) the role of avionics in a visual mission.

## Interview Questionnaire

A questionnaire was prepared which provided structured questioning of the pilots relative to visual cues used in a typical tactical mission in USAFE such as an air interdiction mission. The questionnaire was used as a guide for the interview process. Deviations were made as appropriate during the interviews to assure adequate coverage of issues. Typical of the questions used for the interview are as follows:

(1) How would you fly a wartime air interdiction mission in a high threat environment under different weather conditions in USAFE? (Specific weather conditions were given).

(2) At what range would you expect to be able to detect and recognize different types of targets in USAFE while flying in a high threat environment at an altitude of 300 feet? (Specific targets were given).

(3) How would you judge a ridge crossing in terrain similar to southern Germany?

(4) How much time and how often is the pilot's head in the cockpit while flying low altitude?

(5) How important is peripheral vision and the ability to see the 3-9 line (3 o'clock, 9 o'clock) during a low altitude mission?

(6) What are the cues used to maintain a tactical formation?

(7) What visual cues are used to judge and maintain altitude during low altitude flight? (At 300 feet?, At 500 feet?).

(8) What are the visual responsibilities of the F-15E WSO (weapons systems officer)?

(9) How are air-to-air aircraft targets visually detected and recognized?

Interview Procedure

The questionnaire was validated by interviewing F-16 Air Force reserve pilots from Wright Patterson AFB, Ohio, who had experience flying low altitude in USAFE. Interviews were then conducted with operational F-15E pilots at Seymour Johnson AFB, N. Carolina, and F-16C pilots at Moody AFB, Georgia. There were 20 pilots interviewed at Seymour Johnson AFB and 18 pilots interviewed at Moody AFB. Interview sessions included from 1 to 3 pilots. Interview lengths varied from 45 minutes to 1 hour and 15 minutes. The interviews were recorded in order to insure maximum objective data was collected. Pilots were assured that only background experience level information would be kept and that names would not be kept for record. Recordings appeared to have no affect on pilot responses. The pilots were asked to respond based upon what they would do or possibly experience in a wartime mission. They were asked to ignore peacetime rules of engagement which would probably not exist in a wartime situation.

INTERVIEW RESULTS

Although there was a wide variation in the different points made by the different pilots, there was a high degree of correlation in the responses with very few contradictions. There were some points made by almost every pilot. This high degree of correlation may be due to similar training experiences both on the ground and in the air. The value of an interview did not differ greatly with the degree of experience of the pilot. Experienced pilots made points which the inexperienced pilot did not have the background or exposure to contribute. However, inexperienced pilots often provided better descriptions of certain conditions. This may have been because certain situations had become second nature to the experienced pilot. Also, it was apparent that pilots tend to use different cues as they reach a higher level of experience. As an example, in order to judge altitude, inexperienced pilots will rely more on three dimensional objects to judge altitude, whereas more experienced pilots will rely more on the ground rush (flow field) perceived in his peripheral vision.

Some of the representative responses to the questions are included below in order to provide a feel for the type of information which can be extracted from this type of an interview process:

(1) Question - How would you fly an air interdiction mission in a high threat environment under weather conditions?

Answer - The worse the weather, the fewer the options especially with respect to the type of delivery. Delivery affects the type of ordnance which can be used. Delivery, together with ordnance affects the ability to destroy the target. Generally speaking, as the weather gets worse, pilot task loading and task management requirements go up. Also, situational awareness goes down, and in the case of a multi-ship engagement, confusion goes up. Under very poor weather conditions, the avionics play a much larger part in the mission.

(2) Question - At what range would you expect to detect and recognize different types of targets in USAFE while flying in a high threat environment at an altitude of 300 feet?

Answers -

(a) Airfields - All pilots agreed that it would be very difficult to detect and recognize a airfield at this altitude because of large trees.

Without vertical development it is possible to fly over an airfield without recognizing it if one approaches the runway other than being parallel to it. More often than not, it may not be visible until one pops-up. This may be anywhere from 2 to 3 miles with some haze or 4 to 5 miles on a clear day. On-board systems such as the radar and/or INS/GPS can help locate it.

(b) Bridges - A bridge may be a very difficult target to locate unless it is very large. At low altitude, the pilot may be required to depend more on his systems than on his eyes. Mission planning is very important. Large pointer cues such as a river and/or road which crosses the bridge and possibly a tree line may be used to pinpoint its location. The bridge may be hidden in a valley in the trees.

There seemed to be a general consensus that bridges would be visible at a distance of somewhere between 1 and 3 miles while flying at low altitude depending on the amount of vertical development, its contrast with the background and the degree to which it was obscured by surrounding vegetation. As an example, a 100 foot long bridge with little vertical development, may be visible at less than a mile. However, with a 30 foot vertical development, it may be visible 2 to 3 miles. A bridge may be visible on the radar if it is in the line of sight. If a bridge has a metal structure, it would provide a very good radar return. If the TD box in the HUD is locked to the bridge, it will help direct attention to the bridge to visually identify it. FLIR could also be useful to identify a bridge, if there is a temperature differential between the bridge and its background.

(c) Moving ground targets (tanks, trucks, etc.) - Individual moving targets such as a tank or truck are extremely difficult to detect or recognize. If the vehicles are intent on not being seen from the air, they could successfully hide under trees in a forest. In this case, the one potential clue remaining would be any tracks they would leave from torn up ground and vegetation next to the forest. With some amount of contrast such as being on a road or in an open field they may be visible 1 to 2 miles. Coordination from a FAC (forward air controller) may be useful to find tanks. Also, such effects as dust kicked up by their tracks, track marks in the ground, tracers, smoke, and flashes may be useful cues for their detection. With FLIR, under the right conditions, it may be possible to detect such vehicles out to several miles.

The pilots consistently talked about pre-planning in order to find their way to a target during a mission. They stressed situational awareness which included using large pointer objects which would lead to smaller pointer objects and finally to the IP and the target. They also mentioned that pointer cues should include objects that are permanent and not rely on objects that may have disappeared such as a tower. If FLIR is used, objects should be chosen which will have a temperature differential from the background at the time of day that the mission is to occur. Consideration also needs to be given to picking up pointers which have large amounts of vertical relief that would be visible at low altitude. Visual perception of an area can be affected by the relative positioning of the aircraft, the object interest, and the sun.

(3) Question – What visual cues are used to judge and maintain altitude during low altitude flight?

Answer – A great deal of information was obtained on the different cues that the pilot uses to maintain altitude. These cues tend to be highly altitude dependent and to some degree, experience dependent. They also vary as a function of the type of terrain which the pilot is flying over. All of the pilots said that they use the flight path marker and/or altimeter to set up and calibrate what they see visually. Experienced pilots tended to rely more on the rush of terrain information in the periphery to maintain low altitude. Inexperienced pilots on the other hand tend to rely more on the size of the trees and other objects on the ground. All pilots expressed concern that the use of trees to judge altitude can be a problem since they vary in size in different areas and this can create a false cue. As an example, one pilot said that he had been calibrated flying over large trees and then found himself flying over small brush. This condition was not recognized until a moose appeared which was about the same height as the trees. Although the rush of information in the periphery may appear to be a constant cue, it appears that as the pilot becomes more comfortable at a particular altitude the apparent speed of the rush seems to decrease. If the pilot has not flown at low altitude for a period of time, the speed of the rush appears to be greater until such time as he becomes more comfortable flying at that altitude. Generally the perception of the terrain in the periphery, is not very apparent much above 300 feet. Some of the pilots felt that ground rush goes up exponentially as one flies below 300 feet.

Pilots consistently stated they observed the terrain at low altitude out to about 60 degrees to each side of center line of the aircraft. There were several things discussed that indicate that flying low altitude in rolling terrain is much more difficult than flying over flat terrain. In rolling terrain the pilots must have to keep making a mental picture of what appears right. Also, in rolling terrain, the lower you are, the less you have of a real horizon.

Flat terrain creates another set of problems. Comments were made that it tends to "suck you down." Flying over a desert can be extremely difficult because of the lack of any vertical development or texture information. In some cases it may be difficult to tell the difference between 100 and 300 feet. Shadows from sand dunes may help with this problem. Fresh snow is another area which provides almost no cues and is very difficult to judge altitude. One comment made by an experienced pilot with respect to flying at 500 feet was that it helps to fly at that altitude initially in order to learn task management. They said that at this altitude you have more time to do things and that you may only have to spend one fourth of the time concentrating on looking at the terrain than you would at 300 feet.

Inexperienced wingmen appeared to rely heavily on looking at their lead in order to maintain altitude. This is done by placing the lead on the horizon. More experienced pilots said that depending on the lead for altitude maintenance, when weather obscured their horizon or while flying over rolling terrain would not work. They also stated that even over relatively flat terrain, the wingman could not judge his altitude by looking at the lead at 300 feet whereas he could judge his altitude by looking at the lead at 500 feet. It appears that less experienced pilots have not refined their ability to judge altitude at the lower altitude using peripheral flow field information.

(4) Question – How much time and how often is the pilot's head in the cockpit while flying low altitude?

Answer – All the pilots interviewed including F-15E and F-16C, said they spend less than 10% of their time looking in the cockpit at 300 foot altitude. Almost all the pilots said that at 300 feet they would glance in no more than 1 to 2 seconds. At 500 feet, pilots said that they may glance in from 2 to 3 seconds up to 3 to 5 seconds. They all seemed to agree that at 500 feet the lower task saturation made it easier to look in the cockpit.

(5) Question – How important is peripheral vision and the ability to see the 3-9 line during low altitude flight?

Answer – All agreed that peripheral vision is very important for a tactical mission. They said that they needed to see somewhere beyond the 3-9 line in order to maintain line abreast formation and back to the 6 o'clock position in order to visually detect threats. Most pilots mentioned that they required peripheral vision in order to perceive ground rush and judge altitude. There was also a feeling that peripheral vision played an important part in having a "seat of the pants feeling" similar to being in the aircraft.

(6) Question – What are the cues used to maintain a tactical formation?

Answer – Both F-15E and F-16C pilots provided similar responses. They said that it was important for mutual support to see what the other is doing at all times. The distance that they operated varied from 6 to 12,000 feet depending on the aircraft and the weather conditions. As weather conditions became poorer, the tendency was to move in closer and in some cases drop back to a "wedge formation." The bottom line was that a tactical formation was performed at what could be considered eye limiting resolution.

These comments are only a small portion of the responses obtained from the pilots. This includes both the number of questions responded to and the length and breadth of the responses.

## INTERVIEW CONCLUSIONS

Although there were variations made in the different points made by the different pilots, there was a high degree of correlation of the information provided. Pilots with different levels of experience and different backgrounds provided different perspectives of how visual perception plays in the performance of a tactical mission. As an example, a former RECCE pilot provided detailed information on how targets are visually located.

Several of the same factors kept coming up in the discussions which seemed to have a large effect on mission success. Some of the most important were situational awareness, task management, and team work. Some of the external forces discussed which affect the performance of the mission are weather, topography, and the threat environment. Weather reduces situational awareness and increases task loading. It also can affect the flight plan, tactics, and the type and way in which the delivery is performed. Rough and rolling topography can also reduce situational awareness, increase task loading and affect the flight plan.

Although, flying in a very low altitude may improve survivability by helping avoid threats, it reduces situational awareness and makes task management more difficult. It also makes visual navigation and target identification more difficult. Whereas, younger pilots sometimes seem to be able to express the way in which different problems are handled, it appears evident that experience and training made such problems much easier to deal with. It also appears that indepth pre-mission planning which anticipates and prepares the pilot to deal with many of the problems that may be encountered can greatly improve situational awareness once into the mission.

Ground rush in the peripheral is the most dependable cue to maintain altitude. However, all pilots indicated that they used vertical development such as trees, buildings, etc. where it exists.

All pilots believed that peripheral vision was extremely important in flying low altitude. They felt that the ground rush came principally in peripheral vision. Several said that it seemed as though they needed about 120 degrees horizontal vision, or visual field-of-view. They also said that during formation flight, they need to see somewhat aft of the 3-9 line and to be able to check 6 for threat aircraft.

Key concerns for any low altitude training should be to facilitate pilot survival ("avoiding the rocks") and accomplishment of the mission.

### Impact on Visual System

The conclusions reached from the interviews appear to track well with the perceptual data obtained from various sources. It also appears to mesh well with training effectiveness data which has been generated principally by the Air Force Human Resources Laboratory.

Some of the more important conclusions reached with respect to the implications this data has on visual simulation for tactical mission trainers were as follow:

(1) Avionics including INS/GPS, RADAR, and FLIR must provide the correct real world related cues to the pilot. These systems must closely correlate in content and position with the out-the-canopy visual.

(2) Highly enriched ground information together with three dimensional objects are required to provide the pilot altitude cues for low altitude flight. Also, an instantaneous horizontal field of view of at least 120 degrees together with a full field of regard is required.

(3) Since the pilots periodically make quick glances in the cockpit at low altitude, the visual display should be designed so as not to impair such glances.

(4) A trainer visual system should be designed to provide controlled simulation of illusions. The trainer must also be designed so as not to inadvertently produce illusions which are not related to the real world.

(5) For full simulation of a daylight tactical mission, the instantaneous field of view of the display should at least be 120 degrees and the display should have preferably a full field of regard. A lesser capability display may suffice for a night mission. The visual system must include eye limiting resolution for formation and target aircraft detection and tracking. If necessary this may be done with target projectors.

(6) The WSO has an important visual role in the F-15E. He must have visual display information of the formation aircraft, threats and the terrain. This could drive the overall display system design.

## GENERAL CONCLUSIONS

Pilot interviews should play a key role in the definition of a visual system design. Past experience in conducting such interviews has often been less than satisfactory. Many analysts have said that it is impossible to extract such information from pilots. Our experience on this effort was better than we had originally anticipated. Pilots were extremely cooperative, perceptive and articulate in their responses.

We believe that there are several keys to successfully conduct such an effort. To be properly prepared, it is best to first accomplish a preliminary systems definition using mission and task requirements, theoretical perceptual data, and training effectiveness data as available. Once an initial cut is made to define alternative candidate visual subsystems, the analyst should have a better understanding of what is needed from the pilots and the questionnaire can be prepared. The questionnaire should first be validated with interviewees who are representative of the audience to be interviewed. This provides the analyst with the opportunity to fine tune the questionnaire prior to the final set of interviews. Recording of the interview is also extremely helpful. This takes the heat off the interviewers to record every last detailed remark. Some analysts have expressed concern that the use of a recorder will restrict the interviewee responses. In our case it appeared to have no real impact on the responses which were received. Although we offered each interviewee the opportunity not to use the recorder or turn it off any time they requested us to do so, none of the interviewees made such a request.

Once the interviews are completed and the data has been reduced, the results can readily be incorporated into the visual system analysis.

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Mr. Heintzman has authored many papers on aircrew training and devices. He was one of the original authors of the Air Force Simulator Master Plan and the Systems Engineering Plan for Manpower, Personnel, and Training. He has been an advisor to the Air Force scientific Advisory Board, the FAA, and foreign Air Forces.

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