THE AIR COMBAT SIMULATOR (ACS) : A REAL TACTICAL TRAINING TOOL

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ABSTRACT

The training requirements and the project schedule for the ACS (Air Combat Simulator) will be presented first. Then, after a brief description of the technical principles and components used in the simulator, will follow a more detailed presentation of the equipment, emphasizing the system features : high realism, versatility, variety of operational conditions, powerful and easy-to-use instructor's facilities, maintainability, flexibility for future modifications. Finally, last point to be presented will consist of comments about the visual environment generation system : general organization, horizon projector, target projector, computer generated imagery and missile projector. The simulator described herein is to be delivered to the French Air Force in the last few days of 1984.

ACS PROGRAM DESCRIPTION

General

In November 1982, the French Ministry of Defense issued an order for an air combat training device (see figure 1) for the Military Air Experimental Centre at Mont de Marsan. In its basic version (simulation of combat between two MIRAGE F1) this simulator is scheduled to be operational on-site at the end of 1984.

Objectives

Main objectives concern training and instruction for combat aircraft pilots in all air combat actions from radar detection and interception to missile firing and through dog fighting (up to the limits of the flight envelope) evaluation of firing envelope and evasive manoeuvres. These objectives need a representative (high fidelity target images), realistic and high performance training tool.

Who is to be trained

The simulator is designed to provide training for French Air Force pilots, training first specialized in MIRAGE F1 manoeuvrability and use of the weapon system.

In phase 2, MIRAGE 2000 pilots are scheduled to be trained on this simulator when it has been extended by the addition of two specific cockpits representative of MIRAGE 2000 aircraft.

In phase 3, this simulator will be capable of providing training for combat involving three aircraft and including mixed combat such as MIRAGE F1 versus MIRAGE 2000. The main purposes of the ACS are :

- to provide intensive training for already experienced pilots,
- to optimize use of sophisticated armament,
- to evaluate efficiency of conventional air combat figures,
- to validate new air combat tactics.

Ministry of Defense recommendations and requirements

a) Industrial design. The simulator must be designed and manufactured to ensure a high degree of reliability, an easy maintenance and a high degree of safety. Particular care must be given to the mechanical and electrical design of each simulator element. Design of the assembly and wiring of the various units must provide the equipment with the accessibility and interchangeability characteristics required to facilitate all maintenance operations.

b) Visual system. The landscape must be sufficiently luminous to provide realistic color rendering. Target images must have excellent definition, enabling the pilot to identify them and evaluate precisely their attitude at ranges up to 6000 meters. Target data base must be easily altered. Missile firing has to be represented.

c) Simulator use. The device must be fully utilized. To achieve this, the device must have the following qualities :

- simplicity of use,
- realism of scenarios, cockpit environment, aiming and firing sequences,
- reliability.

d) Simulator cost of ownership. The device must have reasonable acquisition and maintenance costs and provide :

- reduction of instruction and training time, accompanied by an improvement in missile firing training,
- savings in ressources such as aircraft lifecycle, fuel consumption, ammunition, etc.

e) Simulator readiness. The device must be set up as quickly as possible. Daily maintenance has to be reduced to a minimum.

f) Simulator modularity. The device must be capable of being easily modified and/or extended according to changes to the operational equipment and training requirements.

Organization of the analysis, design and manufacture

The French Ministry of Defense gave one of its technical services (STTE) the responsibility for providing the French Air Force with an air combat facility derived from an existing research facility already developed by a French Experimental Centre called the CELAR.

After a request for proposal THOMSON-CSF Division Simulateurs was chosen as prime contractor and had to assure the industrial management of the entire project, to manufacture the simulator (visual system and g-seat excepted) and to provide logistic support.

Then at STTE's request, THOMSON-CSF participated in a call for tender concerning visual system main equipment and won the contract pertaining to the whole visual system.

Simulator destination and schedule

Only one air combat simulator has been ordered but in three major stages.

The first one concerns the delivery of an air combat simulator equiped with two spherical domes and two MIRAGE F1 cockpits allowing combat MIRAGE F1 versus MIRAGE F1. A third dome (empty) is also to be delivered at this stage.

The second stage consists in adding capacity of combat between MIRAGE 2000 and also between MIRAGE F1 and MIRAGE 2000. Two MIRAGE 2000 cockpits are to be delivered in order to achieve this goal.

The purpose of the third stage is to extend capacity of the simulator to involve three pilots in the training exercises. To satisfy this requirement, the empty dome delivered in the first stage has to be completely equiped and some extensions on the rest of the simulator have also to be made.

The whole simulator (in its first stage definition) is scheduled to be delivered to the Military Air Experimental Centre at Mont de Marsan (south of France) in the last days of 1984 according to the schedule below :

- Request for proposal : November 1981
- Management proposal : January 1982
- Notification of THOMSON-CSF leadership for the simulator management : April 1982
- Visual system call for tender : June 1982
- Contract award : November 1982
- Notification of THOMSON-CSF for the whole visual system and finalization of technical specifications : December 1982
- 1st stage on-site acceptance : December 1984
- Notification of 2nd stage optional block : July 1984 to be confirmed
- 2nd stage on-site acceptance : June 1986 to be confirmed
- Notification of 3rd stage optional block : March 1985 to be confirmed
- 3rd stage on-site acceptance : March 1987 to be confirmed

ACS TECHNICAL DESCRIPTION

ACS will be at the present time the first genuine air combat simulator in daily use in France for training. Its innovative aspects lie both in general performance and in the technical designs of visual system.

This paper shall give subsequently :
- the ACS general description,
- the description of visual system.

ACS general description

The ACS achieves simultaneous basic and tactical training of combat aircraft pilots either in individual or in team mode.

The pilot has to react to tactical situations occuring in a very large field of view (about 330° azimuth and 180° elevation).

All the figures of conventional combat such as high speed yo-yo and barrel-roll (see figure 2) are allowed in the simulator and so are long range target visual detection and target attitudes identification.

Main features of the ACS are listed in table I. They confer to the ACS the following characteristics :

- high training realism,
- multipurpose simulation,
- variety of operational conditions,
- powerful and easy-to-use instructor's facilities,
- maintainability,
- flexibility for future evolution.

High training realism

A highly realistic environment was one of the major basic requirements. This realism concerns essentially mechanical and visual environment in fight phases.

a) Mechanical environment. Simulator cockpits faithfully reproduce the internal arrangement of real cockpits. This is achieved by means of well-known techniques using both real and simulated equipment. An important initial requirement was to provide the simulator with a good load factor simulation and buffeting cues. It is very important to train pupils to acknowledge the limits of their aircraft when they are engaged in a dogfight. For this reason the ACS includes a device called g-seat whose purpose is to act on human proprioceptive and tactile system. The design of this device is based upon jacks motion activating the seat pan and the back rest of a replicated ejection seat and upon pressure modulation of inflatable air cells. This device combined with an activated real g-suit gives onset and sustained acceleration cues.

b) Visual environment. The quality of an air combat simulator is closely linked to the quality of its visual system. Training in tactical operations such as target detection and identification against a sky-earth background, hostile attitude anticipation and missile firing requires a particularly high degree of realism in visual simulation. The basic requirements of this visual system are given in table II. System design is described in detail hereafter.

c) Aural environment. Although proposed by THOMSON-CSF, the French Air Force did not yet chose this additional simulation.

Versatility

The ACS is designed to meet all the training needs of the training centres :

- Operation in different modes : the instructor has the capability of programming simultaneous training of two pilots fighting each other (opponent mode) or facing a common tactical situation (team mode). In this case, each cockpit is involved in the combat progress either against the instructor or against a third pilot. Separate training can also be achieved (individual mode). In this case training of one cockpit against the instructor is played while tactical situation is duplicated in other domes in real time or in recorded time for pupils debriefing. In fact the instructor's station concepts (both hardware and software) authorize many other combinations according to the Customer desires.

- Training on any type of aircraft. The French ACS allows training on two different types of aircraft : MIRAGE F1 and MIRAGE 2000.

The ACS includes :
. 2 MIRAGE F1 cockpits,
. 2 MIRAGE 2000 cockpits.
Switching between MIRAGE F1 and MIRAGE 2000 training is achieved by :
. changing of the cockpits (not systematically),
. selection of appropriate software program by the instructor.
For other simulators, switching can also be achieved just by substitution of specific equipment in the simulated cockpits.

Variety of operational conditions

Another requirement was to provide a large number of exercises.
The reasons were :
- to have a set of progressively difficult lessons,
- to achieve effective training by preventing the trainees from being accustomed to repetitive tactical situations.

The ACS gives the following capabilities :
- infinite possibilities for aircraft initialization,
- some preprogrammed scenarios,
- possibility of modifying a set of parameters such as wind and temperature at any time,
- insertion of malfunctions in weapon and firing system (optional),
- several targets data base : initially units are delivered with two different kinds of targets. Simulator design makes it possible to change the target data base very easily.

Powerful and easy to use instructor's facilities

An ergonomic study by the users and manufacturer established two requirements.

Versatile instructor's station capable of :
- programming of various exercises,
- modification of main exercises parameters, supervision of trainees actions (perspective view of the combat, outside cockpit view, display of firing results),
- use of training aids (playback, freeze, memorization),
- trainees evaluation (optional).

Easy-to-use equipment : all these functions achievable by means of very simple operations.

Maintainability

Maintainability factors were taken into account at the very beginning of the design of the ACS. Proven technologies and a modular design have been used whenever possible. A full set of built-in tests are provided to achieve :
- quick tests to check the overall correct operation of the simulator,
- diagnostic tests isolating the faulty board (and often the faulty components on the board),

- adjustment test and associated tools for easy alignment of visual system.

Flexibility for future modifications

It was of great importance to provide the ACS with the capability of being modified as a result of changes in operational or technical requirements. Here we can give some examples of the possibilities of evolution which have been taken into account into the initial design :
- capability of the cockpit to be modified as well as the aircraft,
- simulation of sound effects,
- addition of other types of target in the data base,
- extensibility of computed image generator,
- installation of additional target projectors,
- integration of radar and HUD repeaters for third cockpit monitoring at the instructor's station,
- programming of exercises by the instructor,
- integration of a computer target control program.

Visual system description

General organization.

The visual simulation system is designed to provide independent images for the various viewing devices of each dome. These viewing devices are the following :
- Panoramic screen. It presents the entire field of view of a pilot in a real cockpit. Covered with suitable paint, it allows the perception of the simulated visual environment with sufficient brightness and realism.
- Horizon projector. This equipment provides in each dome a colourful but arbitrary background image whose purpose is to give the pilot first the perception of his attitude relating to earth, sky and sun and secondly knowledge of his height above the ground in order to acquire instinctive manoeuvers in air combat including ground avoidance.
- Target projector(s). In each dome the image (s) of the other engaged aircraft is (are) projected with the right size and attitude and at the right point of the simulated space with the precision, speed and acceleration required by all phases of an air combat up to the dogfight.
- Computer generated imagery. This system has to create in real time as many independent target images as target projectors are concerned. The design of the computed image generator allows the use of only one generation system for the three domes.
- Missile projector. The purpose of this device is to enable the trainee to take into account the first few seconds following a missile launch for starting vital evasive manoeuvers. It can also be used to simulate a very bright sun producing optical target masking.

Spherical screen and internal framework (see figure 3)

The dome, designed to be installed in a building, provides an eight meters diameter panoramic screen covering the pilot's maximum field of view. The operational environment is displayed on the screen.

The projection dome includes :
- the dome itself, the concave side of which, perfectly smooth and covered with suitable paint, is used as a screen,
- various openings allowing positionning of the internal structures such as projector supports and cockpit supports and the access for personnel,
- a removable panel allows the dome to be fitted with a ventilation system.

The dome is light and dust-tight. The doors are fitted with seals. An observer located near the centre of the dome cannot see any junctions between the parts of the screen. The spherical part of the dome is constructed in polyester resin bonded fiberglass (RFG). The entrance, floor and various openings (cable openings, ventilation ducts) are constructed in plywood covered on each side with a skin of RFG.

This rigid laminated dome has the following advantages over other dome constructions :
- stable and accurate geometry for the installations,
- fixed reference points permanently available for alignment of projectors,
- no aging,
- no upkeep apart from occasional dusting,
- repairs easy and invisible.

The internal arrangement of the domes includes the following :
- the cabin support structure,
- the pylon,
- the ventilation system,
- the safety equipment,
- the maintenance elevating platform.

a) The cabin support structure. This structure provides adjustment facilities for positioning the cabin and is designed to give easy access to equipment under the cabin.

b) The pylon. The pylon supports the missile, target and horizon projectors. It consists of a base section in the form a heavy gauge tube fitted with three feet anchored to the floor and a multi-tubular upper section providing support for the various projectors.
The pylon structural has been computed using the most recent structural computation methods in order to combine small size with the high rigidity needed to guarantee accurate projection of the images.

c) The ventilation system. The domes are ventilated into an air conditioned area (electronics cabinets are installed near each dome). The ventilation system renews the air in the domes and minimizes the difference of temperature between the dome and the hall.
Air is taken from and exhausted into the hall.
The ventilation system limits the difference of temperature between the dome and the hall to 5°C.

d) The safety equipment. Particular attention has been paid to the problem of safety in the domes.

Electrical safety. All mechanical parts in the dome are grounded.
As first choice, THOMSON-CSF selects equipment operating off low voltage. Otherwise, for direct voltage in excess of 50V and alterning voltage in excess of 30V rms, conspicuously placed notice warn of the hazard.

Lighting. The dome is equipped with three lighting systems :
- the main system provides general lighting for persons entering, leaving and working in the dome,
- a more powerful system provides strong local lighting around the maintenance work areas,
- an emergency lighting system comes into operation when the main power supply fails and during exercise preparatory phases (between the installation of the pilot in the cockpit and the start of the exercise) to avoid the pilot's remaining in darkness and being taken by surprise by the start of the exercise.

Personnel safety. A system of moving handrail on the forward gangway is provided for the access into the cockpit. When exercise is to begin, these handrails fold away out of the pilot's field of view (see figure 4).
The aft gangway and its fixed handrails are located on the maintenance elevating platform used for the access to the projectors. Before this platform is in upper position, a very secure system (electrical switches and sensitive carpets) checks presence of personnel and gives warning by appropriate lighting. When in upper position, safety nets prevent anyone from falling.

e) Maintenance elevating platform. In upper position an elevating platform provides access to the projectors for maintenance purposes. It is equipped with safety rails, electrical safety devices (low voltage controls, thermal cut out for the motor), hydraulic pressure limiter to control speed of descent. In its lower position this platform gives access to the cockpit.

Visibility problems were taken into account during the design of the dome (see figure 4). Much equipment has been miniaturized. All equipment inside the dome is coated with a mat black covering (oxide, anodic or paint depending on the material) to limit reflections and integrate dome effects (reduction of contrast due to multiple reflections within the dome).

Horizon projector (see figure 5)

The horizon projector is designed to display an image of the sky and the ground to an observer placed in the dome.
The junction of these two images of different brightness and colour is the horizon.
The projector, situated at the center of the sphere, gives a horizon movable in pitch, roll and yaw.

The altitude effects is produced as follows :
- change of slides (six for the sky, six for the ground),
- continuous variation of the horizon height.

The projection device makes use of two identical fish-eye lenses for slides projection with wide angle (225° for an object of 30mm diameter - F : 2).
The ground image is a real but fixed image of the ground viewed from various altitudes.
The sky image presents a blue sky with some medium altitude clouds.

The animation mechanism of the projection head is a device movable in rotation about three concurrent axes. It allows all aircraft attitudes including loop and barrel roll to be simulated without discontinuity.

The altitude effect is reproduced in two different modes :

- each pair of sky-ground slides is automatically changed at fixed altitudes. The six changes are quickly made and quasi-imperceptible for the pilot. The switching time between two slides is less than 150 milliseconds. Furthermore a digital damping system avoids induced oscillation at the limit fixed for slide switching,
- cylindrical masks concentric with the projection optics allow the relative variation of the horizon height to be simulated.

The dynamic performance of the observed image is shown below :

	Pitch rotation	Roll rotation	Yaw rotation
Angular displacemnt	360° without discontinuity		
Maximum speed	3rad/sec	10rad/sec	3rad/sec
Maximum Acceleration	10rad/ sec/sec	30rad/ sec/sec	10rad/ sec/sec

In theory three axes are enough to simulate the aircraft rotation. The horizon projector has a fourth axis which is useful to reduce to a minimum the projected shadows in some configurations.

The horizon height variation obtained with the mask motion simulates a maximum vertical speed of 300 m/sec and an altitude between 0 and 20000 m.

The optical performance is indicated below :
- maximum direct lighting (without slide) : > 10 lux at 4 meters near the centre of the field.
- lighting with slides (clear areas) : around 3 lux.
- without a slide the lighting variation in the field is less than 20%.

Target projector (see figure 6)

This projection device is designed to display to the pilot the simultaneous manoeuvres of friend or foe aircraft in an operational environment. The apparent size of the air target image is a function of the relative fighter-to-target range from 60 meters up to 6000 meters and its definition is such that target attitude knowledge is possible within the pilot's visual acuity limits.

The main elements of the air-target projector are as follows :
- a black and white video projector (625 lines 50Hz) reproducing the generated target,
- an optical device with variable magnification adapted to the source and fitted with an optical-mechanical deflector for target projection on every useful point of the screen-dome.

The optical device includes :
- an image relay,
- a screw zoom with motorized focal length,
- a second image relay,
- an opto-mechanical deflector with projection lens.

The performance associated with both deflector rotation axes is as follows :

	X axis	Y axis
Displacement	360°	360°
Maximum speed	50rad/sec	50rad/sec
Maximum acceleration	180rad/sec/sec	80rad/sec/sec

The apparent target size variation is made continuously from 60 meters up the limit of visibility by an optical zoom without any definition loss and by an electronical zoom, the definition loss being inferior to the eye resolution capacity.

Computer image generator

The computed image generator is able to process in real time the image of two three-dimensional targets, each composed from 300 basic polygons. It generates in real time the dynamic image of each air target sent to the target projectors. The computed image is refreshed every 40 ms (25Hz). The computed image generator forms a self contained assembly dialoging with the data processing unit at the beginning of the exercise to store the selected data base retrieved from a magnetic disc unit and to load the status matrix. This fast computation unit called VISA 10 is a computer especially developed by THOMSON-CSF for visual applications and is the first model of the VISA family characterized by microprogrammed processors and high capacity memories.

The image generator is composed of the following subsystems :
- geometric processor,
- segment processor,
- video processor.

The geometric processor computes the perspective of each element of the scene. This unit receives for each image a description of the scene to be displayed in terms of polygons and luminous points. It provides various functions such as rear face occultation, sun orientation, ambient luminosity and perspective projection.

The segment generator and storage modules are the interface between the geometric processor and video processors. They give a description of the image for video processing : the image is comprised of segments formed suitable by the intersection of the TV scanning lines with the different elements of the image to be projected.

The video processor operates line by line : it receives segment data and outputs the video signal to the display system. It also provides occultation, antialiasing and shadow effects to enhance the quality of the displayed image.

This computer generated imagery has a lot of advantages over the model board system, among them :
- extensive dynamic range of the projected target,
- special effects (sun lighting),
- no discontinuity in the attitude of the target,
- large extension possibilities (library of different types of targets),
- addition of special effects (display of stores, of kills, etc.).
- simplification of optical alignment.

Missile projector (see figure 7)

The missile projector displays a moving luminous point with a variable size simulating the trajectory of the missile fired.

The projector mainly includes :
- a light source and its power supply,
- an optical projection system,
- a two-axis opto-mechanical deflector of the same type as in the target projector.

The projection optical system allows projection of a highly luminous spot with a diameter variable between one and ten centimeters depending on the distance from the missile to the observer.

Three servo systems are required :
- one for the projected spot diameter,
- one for each of both rotations of the deflector.

	DIAMETER OF THE SPOT	X AXIS	Y AXIS
Range	1 cm/10 cm	360°	360°
Maximum speed	Full range in 1 sec.	15rd/s	10rd/s
Maximum acceleration		30rd/s2	30rd/s2
Accuracy	1 mm	± 3 mrd	± 3 mrd

ACS TRAINING POTENTIAL

Considering preliminary experiments done on a research prototype and availability objectives for this air combat simulator we can evaluate by an example the ACS training potential.

ACS TRAINING POTENTIAL (Example) (16 hours/day - 30 days/month)	
DAILY	. 96 exercises involving 2 or 3 pilots . an average of 10' for each exercise . an average of two missile firings per exercise
MONTHLY	. about three thousand exercises . about six thousand simulated missile firings

CONCLUSION

ACS appears to be an efficient tool to achieve basic and tactical training of fighter aircraft pilots.

Operational advantages of ACS lies on the fact that training is more effective and quicker than with conventional means because :
- all the pilot's actions are recorded, any error can be corrected using the playback facilities,
- continuous and detailed recording of firing results provides an objective evaluation of each pilot's performance, making a considerable contribution to student's motivation,
- as in combat, the large number of enemy attack scenarios make it impossible to remember target trajectories of previous exercises,
- finally, and this is an essential point, evaluation of new tactics in air combat can be experimented hundred and hundred times without any risk.

All these advantages don't suppress the necessity of conventional means. At the contrary the use of the ACS enhance the interest of actual air combat training by improving the efficiency of pilots already trained on a simulator and accustomed to the situations they will meet perhaps one day in the reality. For an insufficiently trained pilot, the first combat could well be the last.

ABOUT THE AUTHOR

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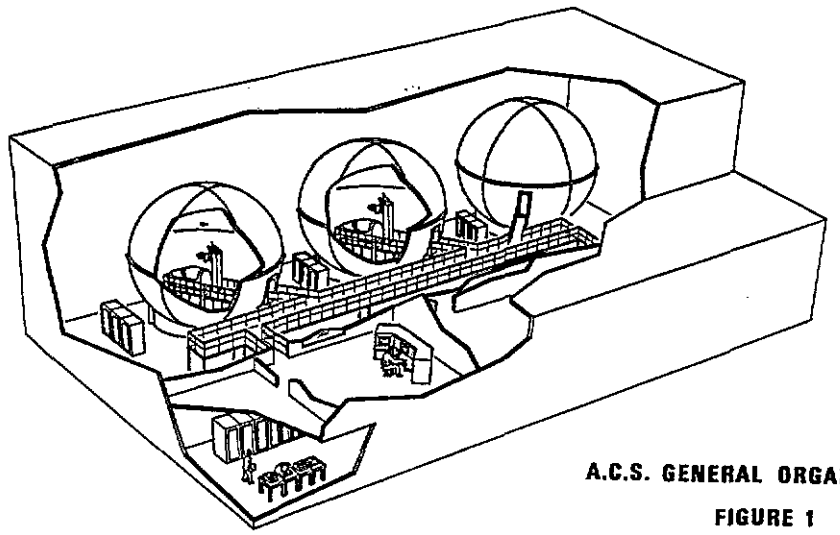
He received an engineer ESE degree in 1975. Then he worked on EMP simulation as a field engineer in the Ballistic and Space Missiles Division of AEROSPATIALE Company till 1981, when he joined THOMSON-CSF to take charge of the ACS project for the French Air Force. He is now responsible for all the military aircraft simulators.

TABLE I :
ACS MAIN FEATURES (BASIC VERSION)

- TRAINING AIMS : AIR TO AIR MISSIONS
  - . Radar detection,
  - . Interception,
  - . Dog fight up to the limits of the flight envelope,
  - . Evaluation of firing envelope,
  - . Missile firing,
  - . Survival (evasive manoeuvers),
  - . Validation of air combat tactics.
- TRAINING MODES
  - . Individual : one pilot against the instructor,
  - . Opponent : two pilots against each other,
  - . Team : two pilots against instructor (requires a second target projector in each dome).
- TWO STUDENT STATIONS - IN EACH
  - . 1 eight meter diameter dome and internal framework,
  - . 1 horizon projector,
  - . 1 target projector (2 on third stage),
  - . 1 missile projector,
  - . 1 MIRAGE F1 simulated cockpit with g-seat.
- ONE INSTRUCTOR'S STATION
  - . 3 colour CRTs,
  - . Radar indicator and HUD repeaters,
  - . 1 control panel with usual functions (freeze, playback, ...).
- OTHER SIMULATOR EQUIPMENT
  - . 1 CGI system,
  - . 1 computer complex hardware of the last generation with 3 processors,
  - . 1 modular interface system per dome,
  - . 1 central interface system with usual supplies.

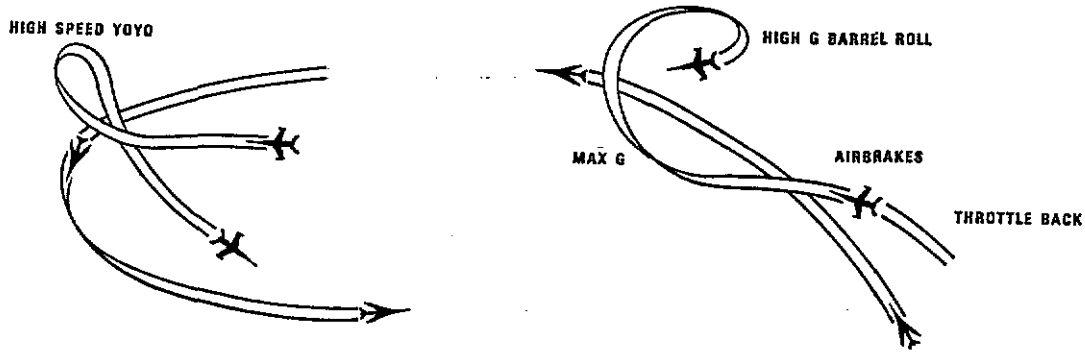
TABLE II :
REQUIREMENTS FOR VISUAL ENVIRONMENT SIMULATION

- BACKGROUND TERRAIN / SKY IMAGE
  - . must be arbitrary,
  - . must be realistic enough,
  - . must roll and pitch relating to aircraft movements,
  - . must vary against altitude,
  - . must have the sun as reference.
- AIR TARGETS
  - . must be realistic to be identified,
  - . must move realistically,
  - . must be seen from infinite to near range,
  - . must exist in different kinds.
- MISSILE IMAGE
  - . must vary in size relating to the range,
  - . must show the firing flash.



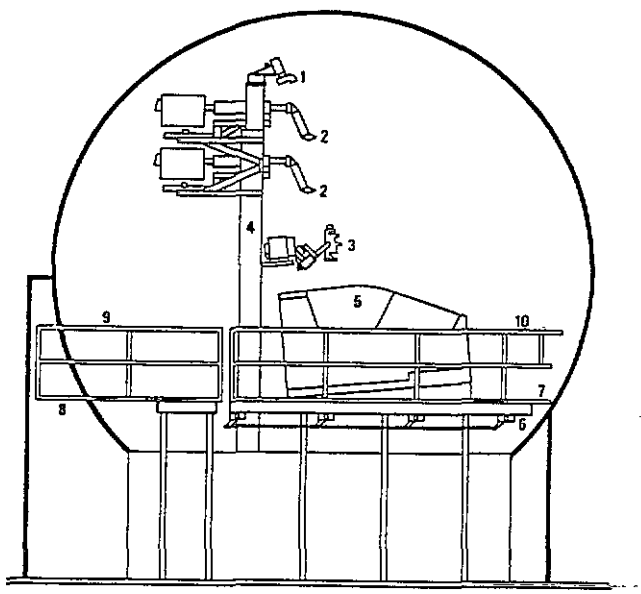
A.C.S. GENERAL ORGANIZATION

FIGURE 1



CONVENTIONAL COMBAT FIGURES

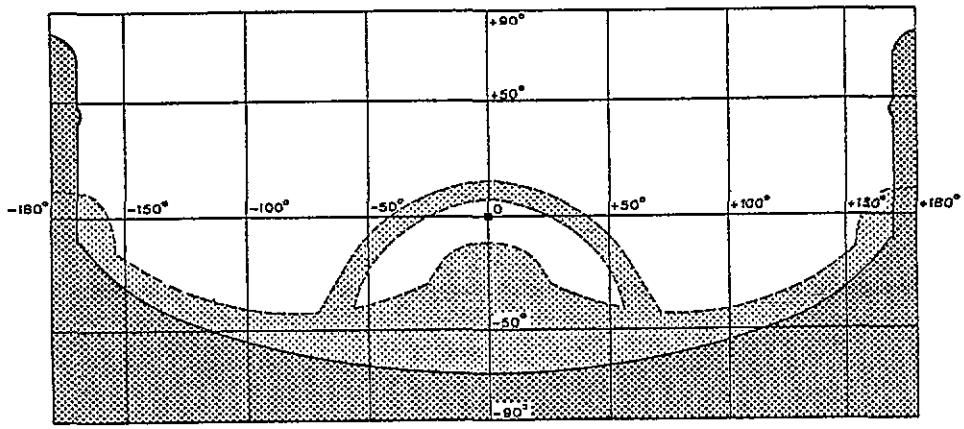
FIGURE 2



1 – MISSILE PROJECTOR
2 – TARGET PROJECTOR
3 – HORIZON PROJECTOR
4 – PYLON
5 – COCKPIT
6 – FORWARD PLATFORM
7 – FORWARD GANGWAY
8 – AFT GANGWAY ON ELEVATING PLATFORM
9 – FIXED HANDRAIL
10 – MOVING HANDRAIL

DOME AND INTERNAL FRAMEWORK

FIGURE 3



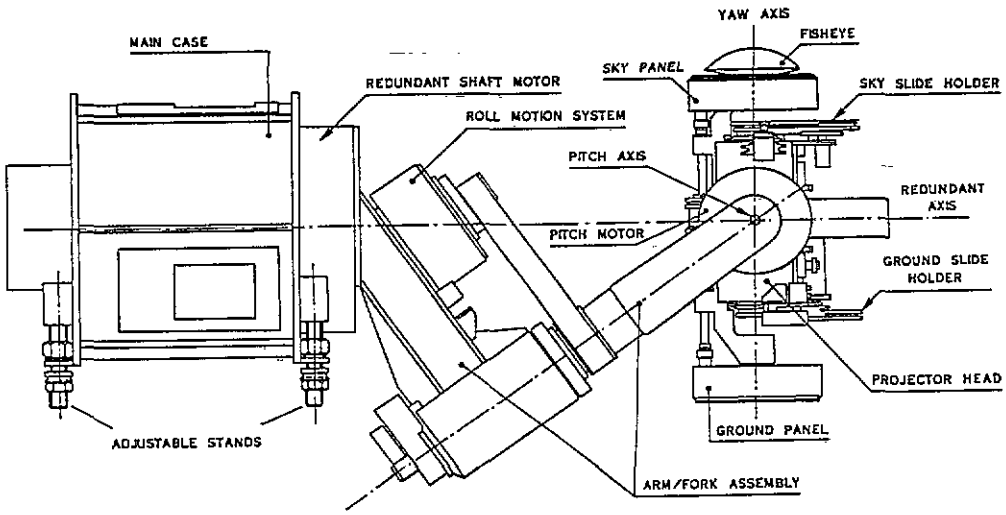
▨ — PERMANENTLY MASKED AREA

▭ — EXAMPLE OF PILOT'S THEORETICAL FIELD OF VIEW

▪ — PILOT'S EYE

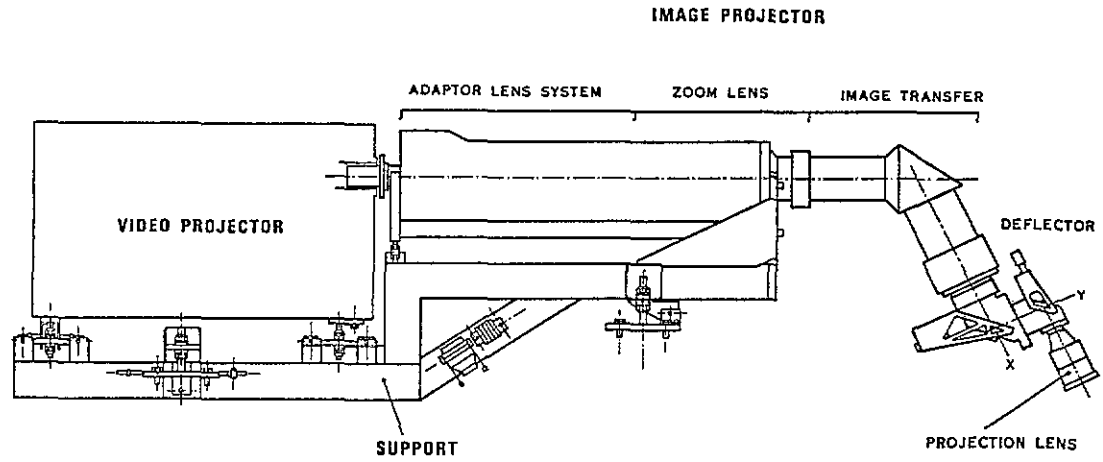
VISIBILITY DIAGRAM

FIGURE 4



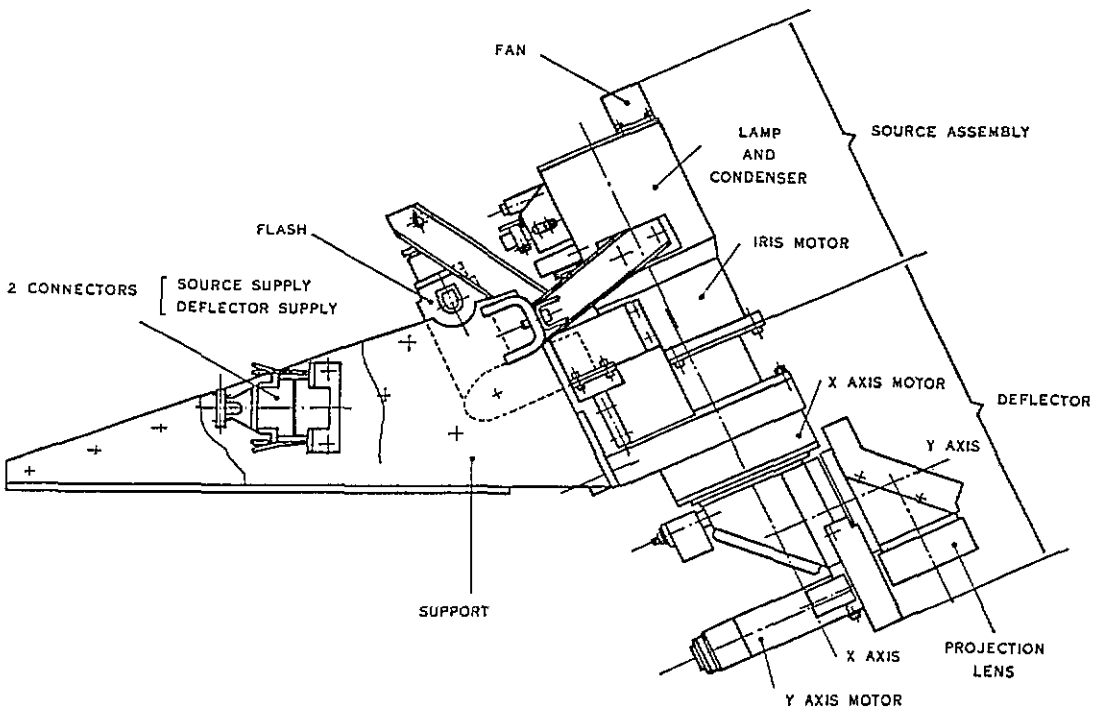
HORIZON PROJECTOR

FIGURE 5



TARGET PROJECTOR

FIGURE 6



MISSILE PROJECTOR

FIGURE 7