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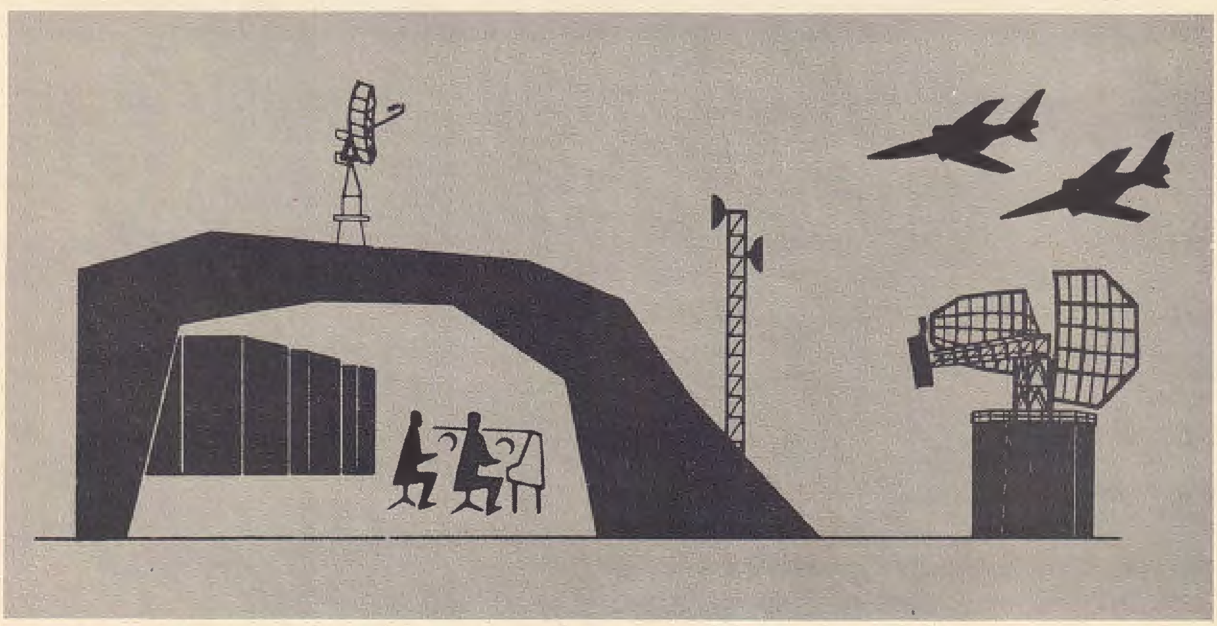
Surveillance and Operational Control in Air Defence

Examples of activities in creating a national air defence system



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Surveillance and Operational Control in Air Defence

Examples of activities in creating a national air defence system

Introduction and Acknowledgements

From time to time prospective customers from abroad have asked if AB Teleplan (formerly TUAB and TALAB), an electronics consultancy company working mainly for the Swedish defence authorities, might assist them in planning radar surveillance and weapons command and control for air defence. There has also been a demand for a condensed presentation giving general information on the main parts and functions of a command and control system and on such activities as are inherent in air defence planning.

Since our company has been engaged in such planning for the Swedish air defence for more than ten years we have found it appropriate to make a presentation of what we consider is essential in this field. We have made a picture-book in which symbolic pictures and telegraph style sentences are presented in much the same way as in a lecture accompanied by overhead projected transparencies. We would indeed have been well justified in writing a complete text-book on the subject which is quite extensive and of great importance for defence planning but such a book would be too large an undertaking. In this booklet we have emphasized systems analysis, systems layout, radar technique and telecommunications, as well as implementation activities such as site planning, project management, reliability planning, testing, and evaluation.

We wish to thank the Swedish Air Materiel Department for making this presentation possible. Teleplan has had the privilege of working on air defence contracts implying studies and design of various parts of radar surveillance and command and control systems, and we gratefully acknowledge the permission to use results and material from these assignments in preparing this document.

Stockholm,
July 1972

Tord Wikland
Technical Director

Contents

1 Elements of Air Defence Planning

Threat

- High Altitude Bombers
- Low Altitude Attack Aircraft
- Air-to-Surface Missiles
- Surface-to-Surface Missiles
- Nuclear Weapons

Targets

- Mobilization Depots
- Air Bases and Missile Bases
- Radar Stations. Command Centres
- Troop Concentrations and Staff Headquarters
- Ships and Marine Bases. Coast Artillery Installations
- Railways, Bridges, Transports, Civil Telecommunications
- Plants for the Supply of Energy and Goods

Defence Weapons

- Interceptor Aircraft
- Attack Aircraft
- Surface-to-Air Missiles
- Anti-Aircraft Guns

Air Surveillance and Operational Control

- Early Warning and Alerting
- Command and Control of Fighters, Missiles and AA-guns
- Closed Control. Modified Closed Control
- Dispersal of Bases
- Identification of Friend and Foe (IFF)
- Air Traffic Control (ATC)
- Air-raid Warning. Alerting of Civil Defence
- Resistibility against Attack
- Integration and Decentralization
- Separate Defence Levels
- Electronic Counter Measures (ECM)
- Electronic Counter-Counter Measures (ECCM)
- Protection and Warning against Atomic, Bacteriological, and Chemical (ABC) Weapons

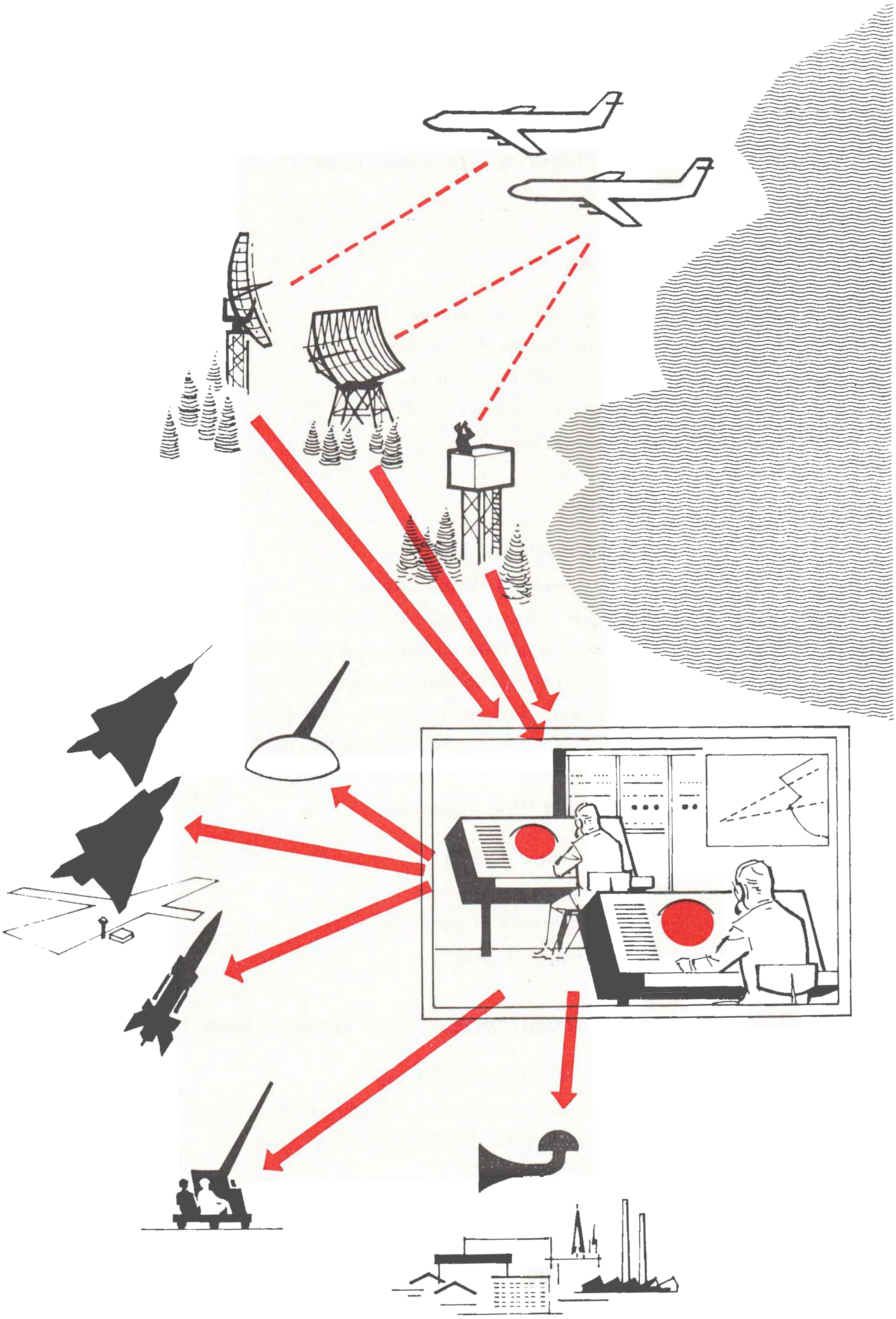


Figure 1. Components of a command and control system

2 System Analysis and Design of an Air Surveillance and Operational Control or Command and Control System (C & C System)

System Analysis - a Closed Loop Study

In most cases system analysis is an iterative process as is indicated by the feedback lines in the following list of activities.

General Ideas about Objectives
Examining Objectives and Assumptions
Formulation of Objectives and Problem Definition
Collecting Technical and Tactical Data
Finding Limiting Conditions and Criteria
Building Models
Testing and Improvement of Models
Using Models for Analysis and Simulation
Examining Results of Analysis
Evaluation of Performance, Cost, and Effectiveness
Drawing Conclusions
Making Recommendations and Presentation

Objectives for an Air Command and Control System

The possibility of successfully intercepting modern strike aircraft is dependant upon the ability of the defence to make good use of every available second of warning before attack. Air defence systems are therefore based upon early warning and quick-reacting computer command and control. The objectives can be formulated in a general way as follows:

- Provide a basis for making decisions and taking actions:
  - Derive information about the actual air environment from sensors, and from weather and other status reports (threats and targets evaluated, available resources matched to objectives)
  - Clarify the possibilities of interception in the actual threat (calculation, display)

- Control of the available resources:
  - Aircraft and missile vectoring
  - Anti-aircraft fire control
  - ECM-ECCM-control

- Report and warn:
  - Data communication with other parts of the total defence system
  - Air-raid warning etc

Essential Functions of a Command and Control System

(See fig 2)

A C & C system should be capable to:

- Evaluate threat
- Advise a controller whether an interception is practical or not
- Advise a controller as to a suitable fighter base and a suitable fighter/weapon or S A M system
- Provide all the command instructions necessary to bring the fighter on an optimum flight path to within aircraft radar range of the target, and provide information on the relative position of target and fighter during the final phase
- Indicate the predicted interception point
- Provide command instructions to guide the fighter to the designated landing base

Modelling and Simulation

The essence of systems analysis is to create and operate a model. Experiments with actual systems are often too expensive and sometimes even impossible since they are not available or too complicated.

A model is a representation of reality which abstracts the characteristics of the situation relevant to the problem being studied. The representation may vary from a set of mathematical equations or a computer program to a verbal description of the situation in which judgement alone is used to assess the consequences of various alternatives. Simulation is a process by which a model is used to obtain quantitative information on system capabilities and limitations (see fig 3).

For simulation of a C & C system the most suitable model is of the Monte Carlo-type and consists of a great number of subroutines simulating different functions To get significant results every intercept is repeated several times under identical conditions but with random numbers for the systematic and random errors in the model (see figs 4 and 5).

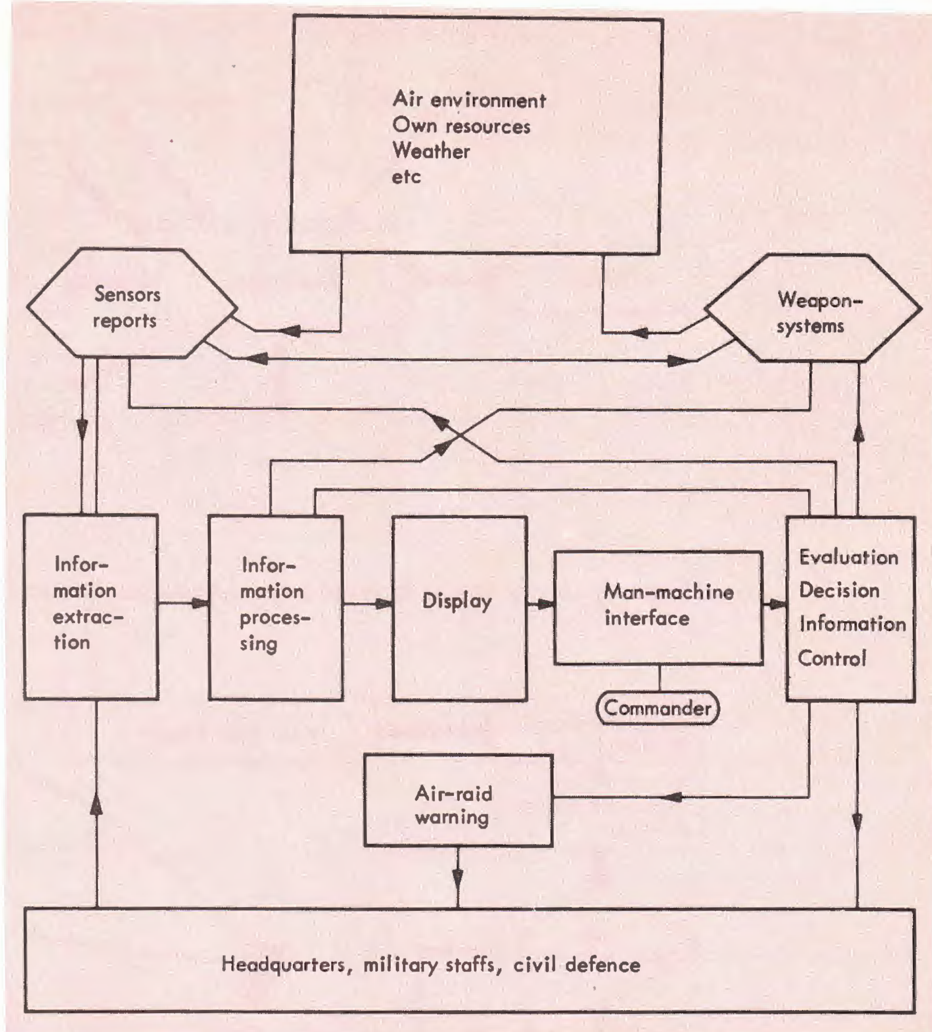


Figure 2. Command and control functions

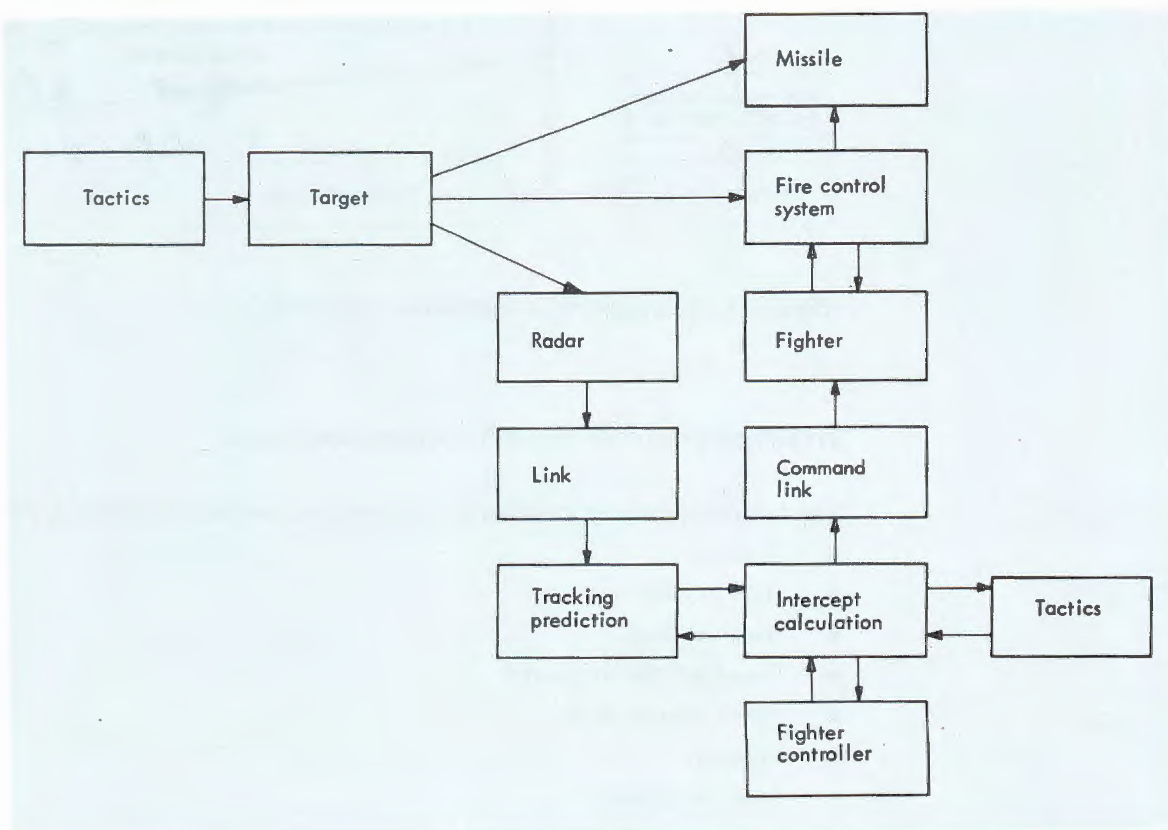


Figure 3. Simulation, block diagram

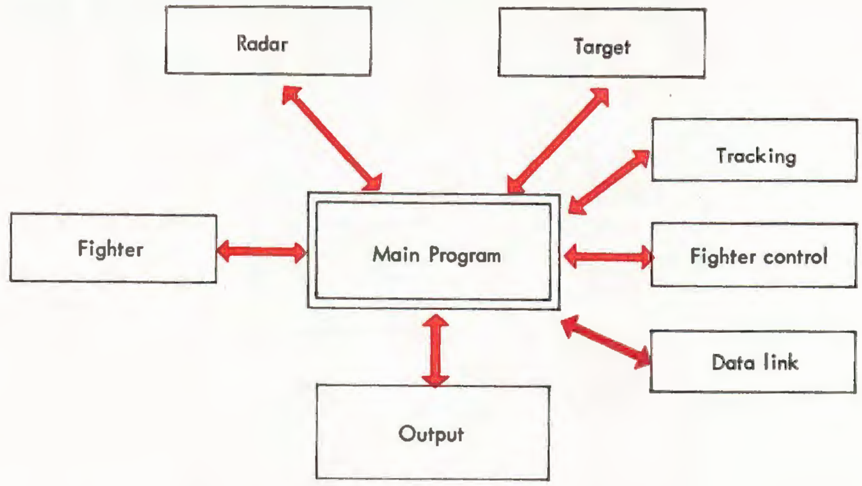


Figure 4. Basic block diagram of a simulation program for intercepts

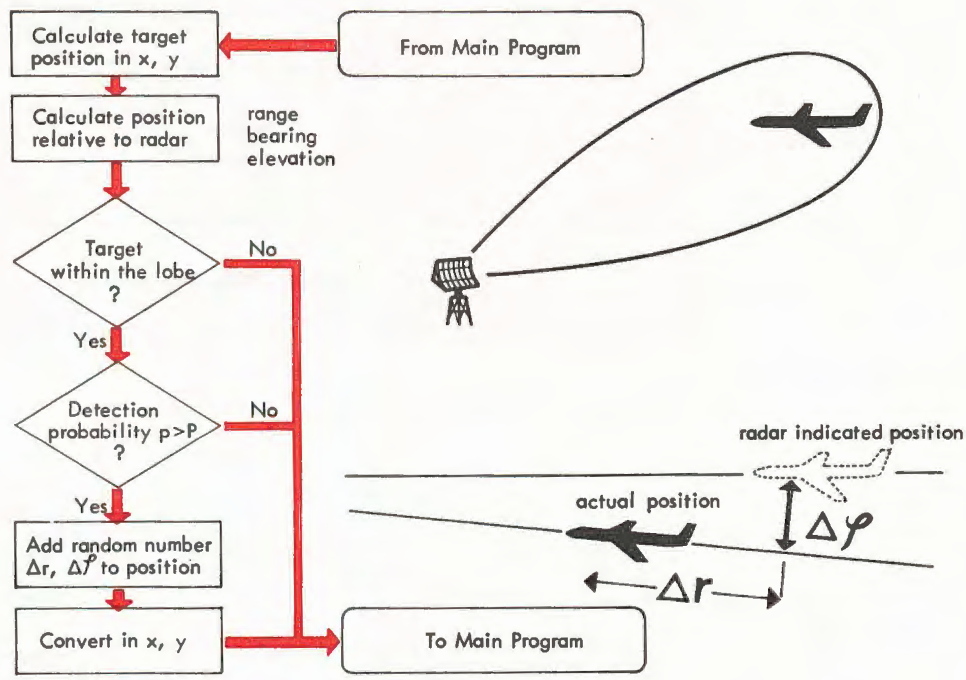


Figure 5. Example of a subroutine for radar

Interceptor Aircraft Calculations

The following data are calculated for interceptor aircraft (see table 1 and fig 6):

- Position
- Rate of turn
- Rate of climb
- Speed relative to ground
- Speed relative to air
- Heading
- Angle of attack

The calculations are based upon

- Radar performance
- Base locations and base conditions
- Scramble conditions
- Fighter performance as a function of atmospheric conditions, load, weapon alternative etc
- Atmospheric conditions (wind, pressure, temperature)
- Heading order etc given from Sector Operations Centre (SOC) or Operational Subcentre (OSC)
- The response of the pilot and the aircraft on orders from SOC etc

Every computation run results in an intercept track which is plotted (see fig 7). All the runs are plotted on the same paper and with marks for elapsed time in order to illustrate speed and time relation. Simulation with different interceptors, bases, radar and attack parameters make possible the construction of diagrams of defended areas (see fig 8).

Table 1. Printouts controlled by relative range and time

	Printouts controlled by relative range	Printouts controlled by time
TIME	Real time	Real time Calculated time to go until turn
FIGHTER	Position Speed	Position Speed
TARGET	Position Speed	Predicted position (Predicted speed and heading)
RELATIVE GEOMETRY	Relative range Relative velocity Intercept angle Lead angle Aspect angle	Relative range Intercept angle Lead angle Aspect angle
ERROR IN TARGET POSITION INDICATION	Bearing Elevation Relative range	
HEADING OF THE FIGHTER	Command heading Accumulated number of corrections	Command heading Real heading
PROBABILITY OF DETECTION	Any reconnaissance equipment at the same time	
PROBABILITY OF ACQUISITION	Any reconnaissance equipment at the same time	
EVALUATION	Statistics (means and standard deviations) Criteria (kill probability etc)	

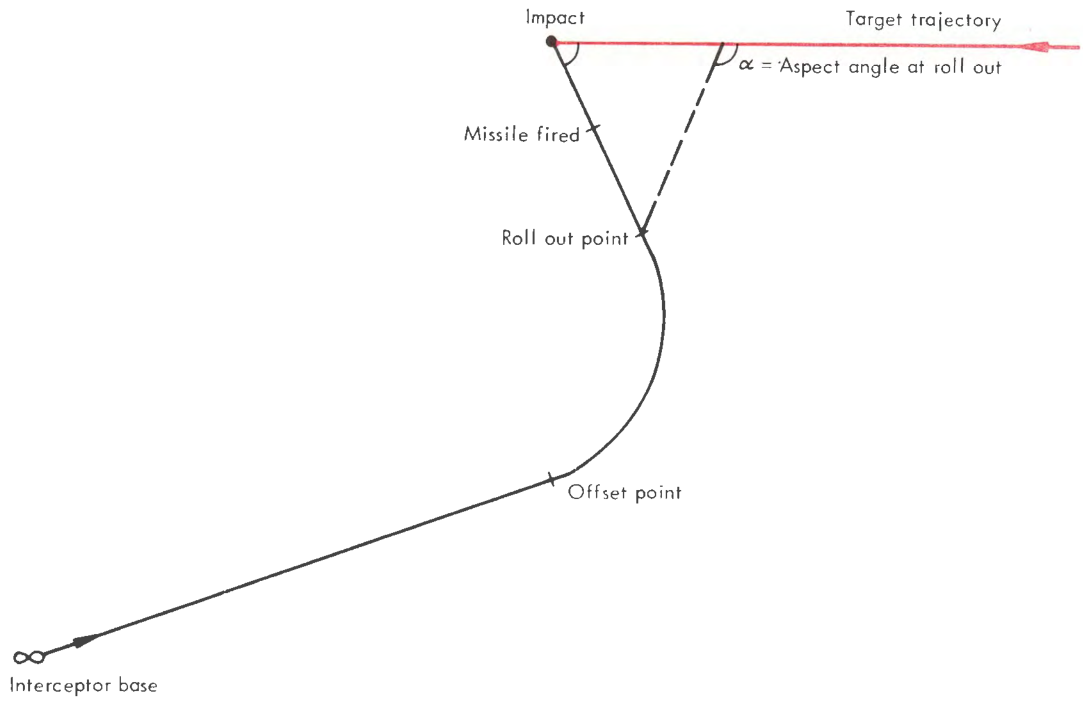


Figure 6. Sketch of mission geometry for ideally controlled interceptor

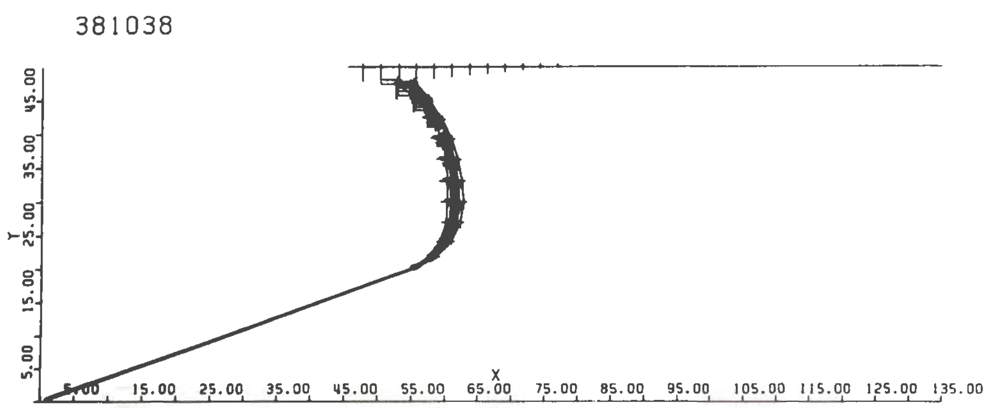


Figure 7. Example of plotted intercept tracks

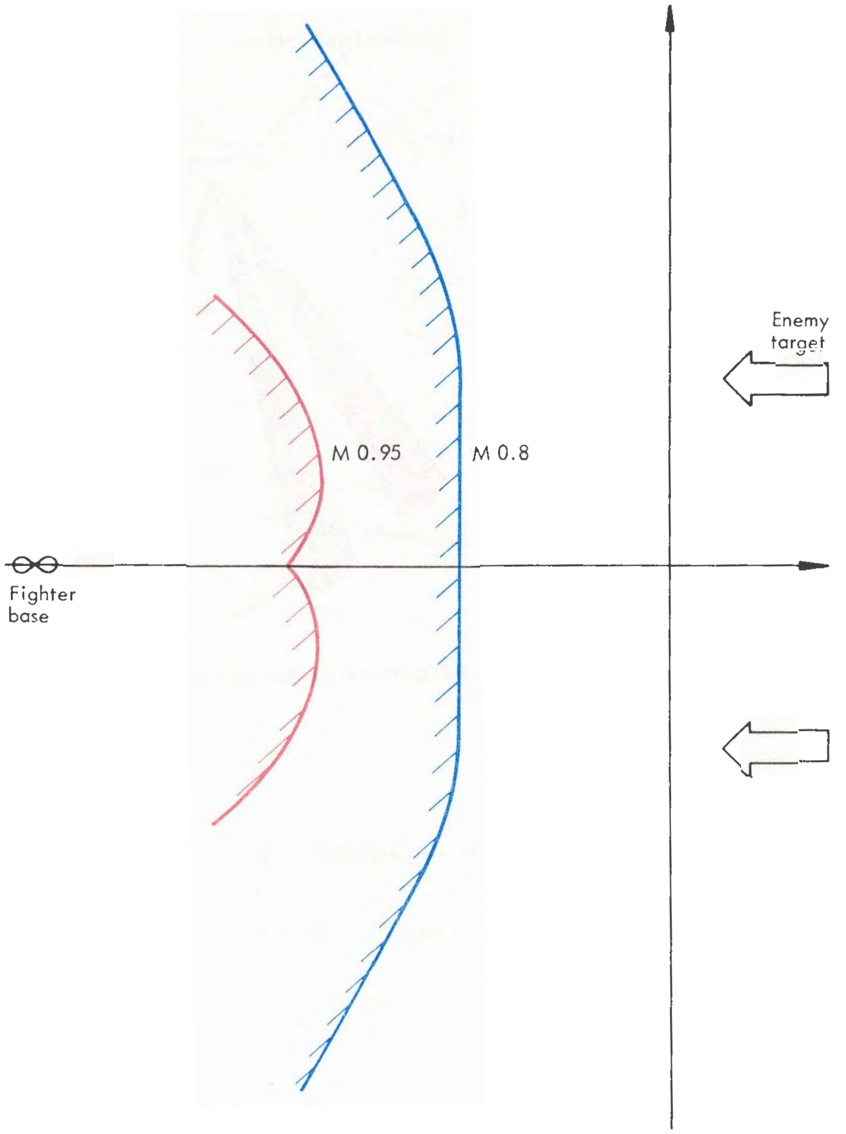


Figure 8. Defended areas at different target speeds

Interceptor Aircraft Guidance, Navigation, and Landing

Main components and functions (see fig 9):

- Command data link
- Air data navigation
- Doppler navigation
- Inertial system
- Distance Measuring Equipment (DME)
- Airborne computer
- Landing aid
- Air Traffic Control (ATC) radar

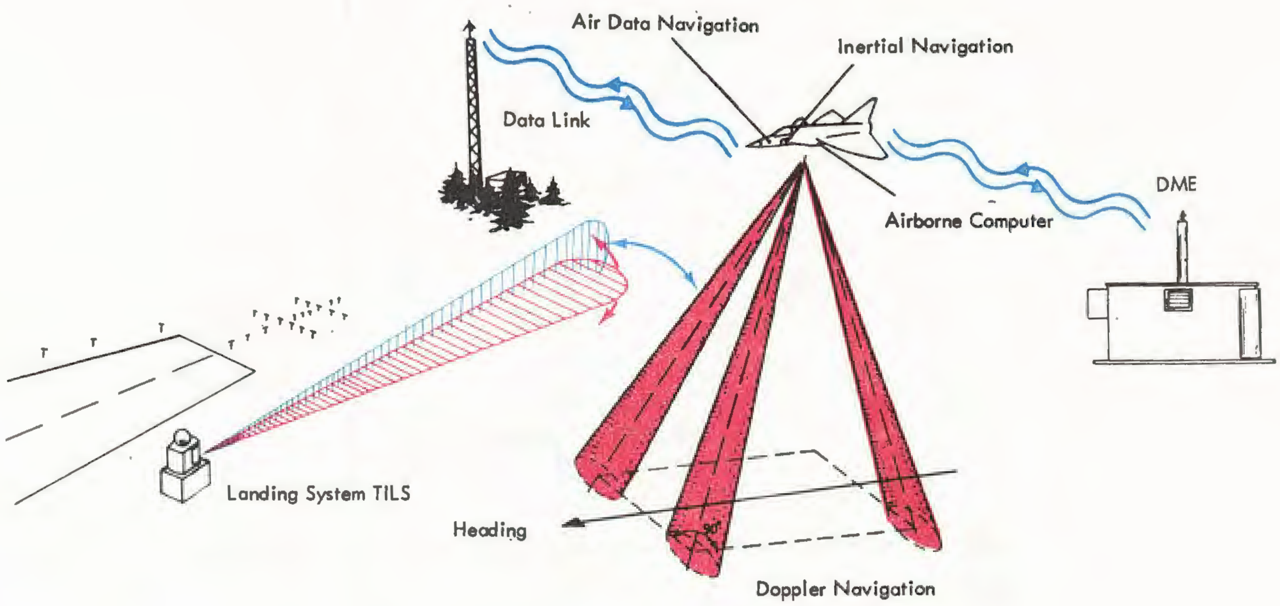


Figure 9. Aids for aircraft navigation and landing

Anti-Aircraft Missile Systems

Main components and system functions (see fig 10):

- Radar
- Infra Red (IR)
- Laser

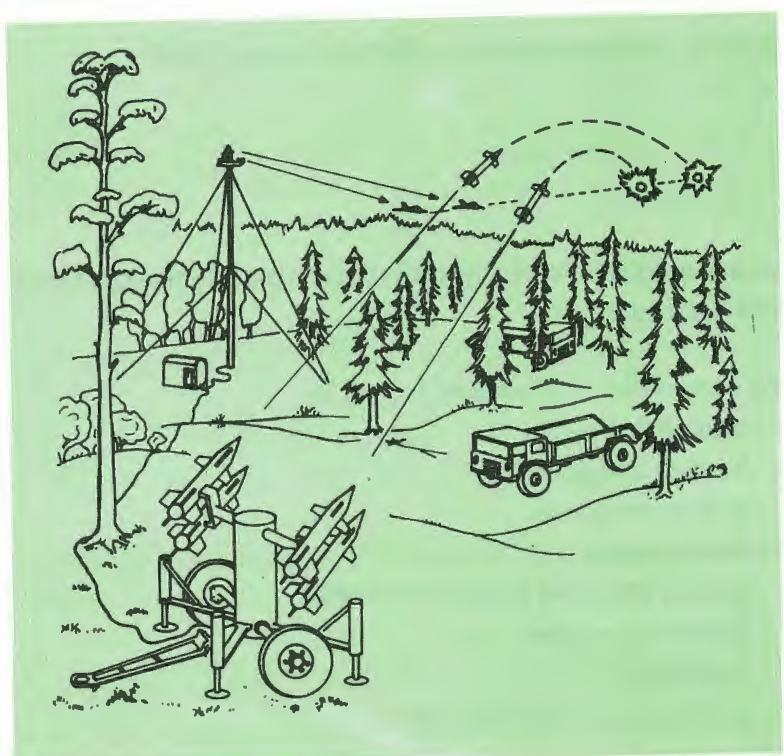


Figure 10. Anti-aircraft missile system

- Television (TV)
- Signal processing
- Data processing
- Data communication
- Guidance and control

Target selection, command and control tasks, and system studies:
- Targets at great height and high speed
- Early warning and bringing fire-control radars to bear on target
- Identification of targets
- Coordination of missile fire with fire from AA-guns and aircraft intercept missions
- Performance studies including model building and simulation

Anti-Aircraft Guns

(See fig 11)

Target selection, command and control tasks:
- Targets at low and medium heights and subsonic speed
- Protection against attack on ground targets and troops
- Early warning and bringing fire-control radars to bear on target
- Identification of targets
- Coordination of gun-fire with missile fire and aircraft intercept missions

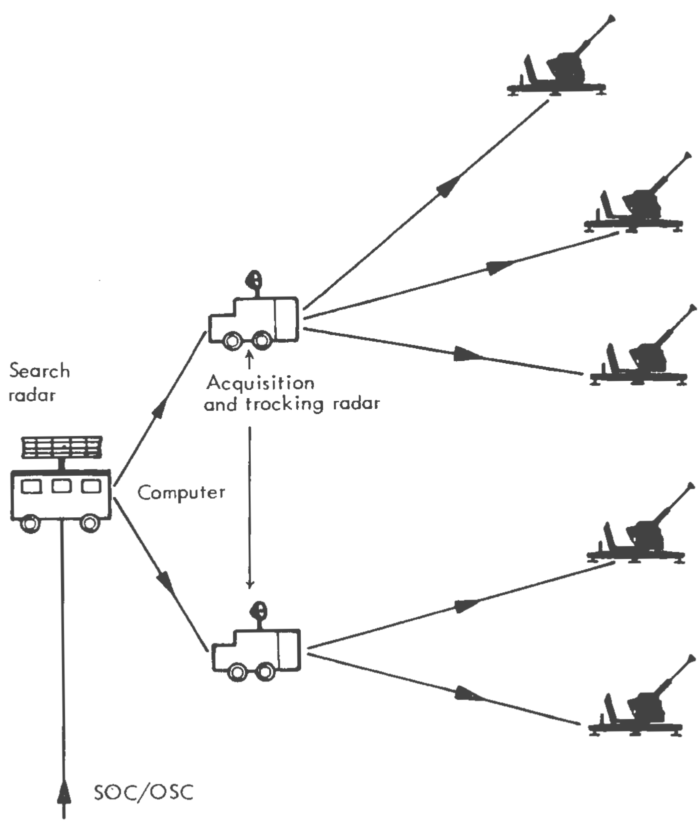


Figure 11. Anti-aircraft guns

Command and Control System Layout

(See figs 12, 13, 14)

The layout of the system with its main components, its communications and flow of information is based on threat analysis, demand analysis and system analysis.

After defining the defence levels, subsystems can be identified such as

- Sector Operations Centre (SOC)
- Operational Subcentre (OSC)
- Radar Station with Command Function (RSC)
- Communication Network
- Computer Systems and Installations
- Display Systems

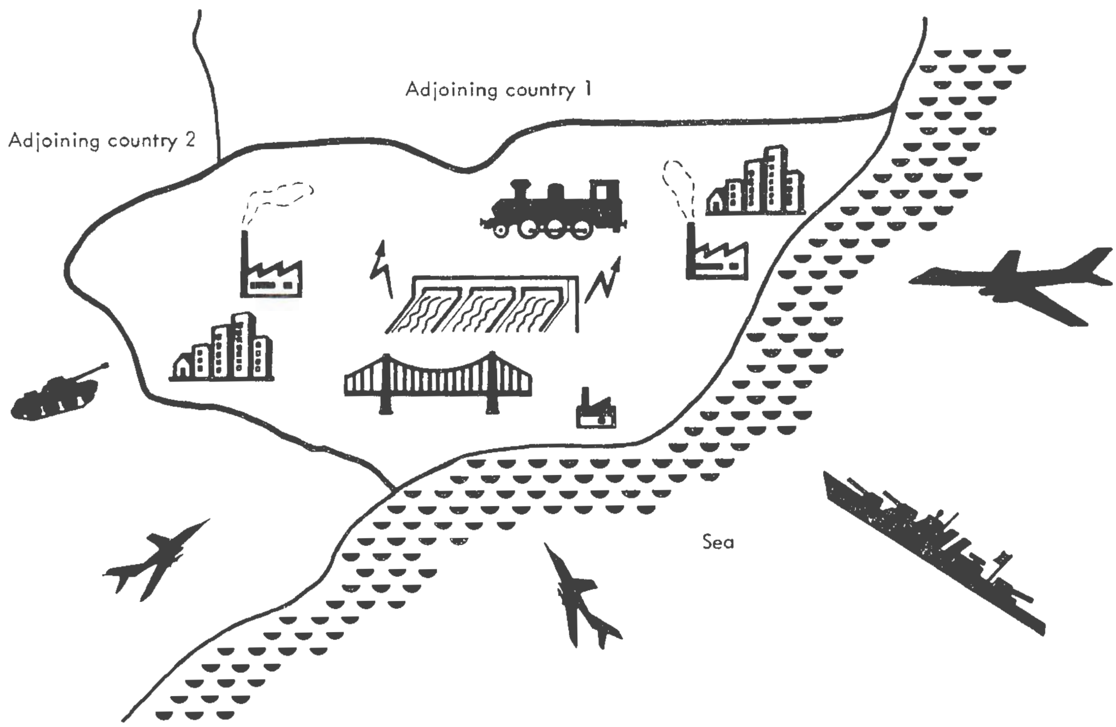


Figure 12. Threats and targets

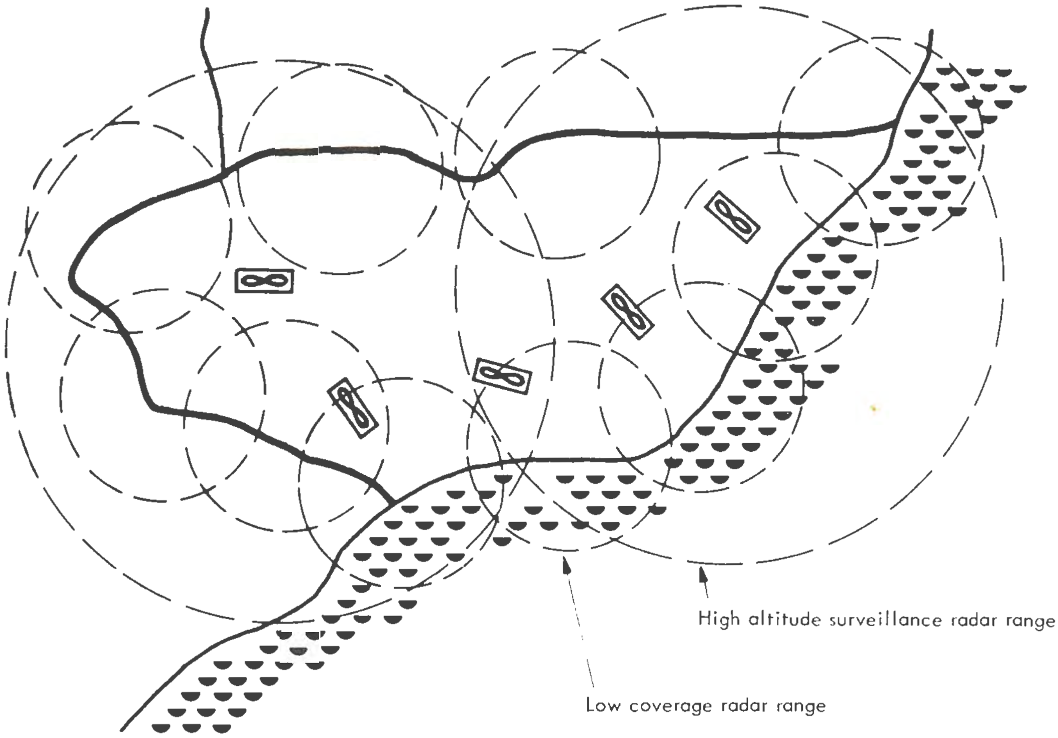


Figure 13. Air bases and radar coverage planning

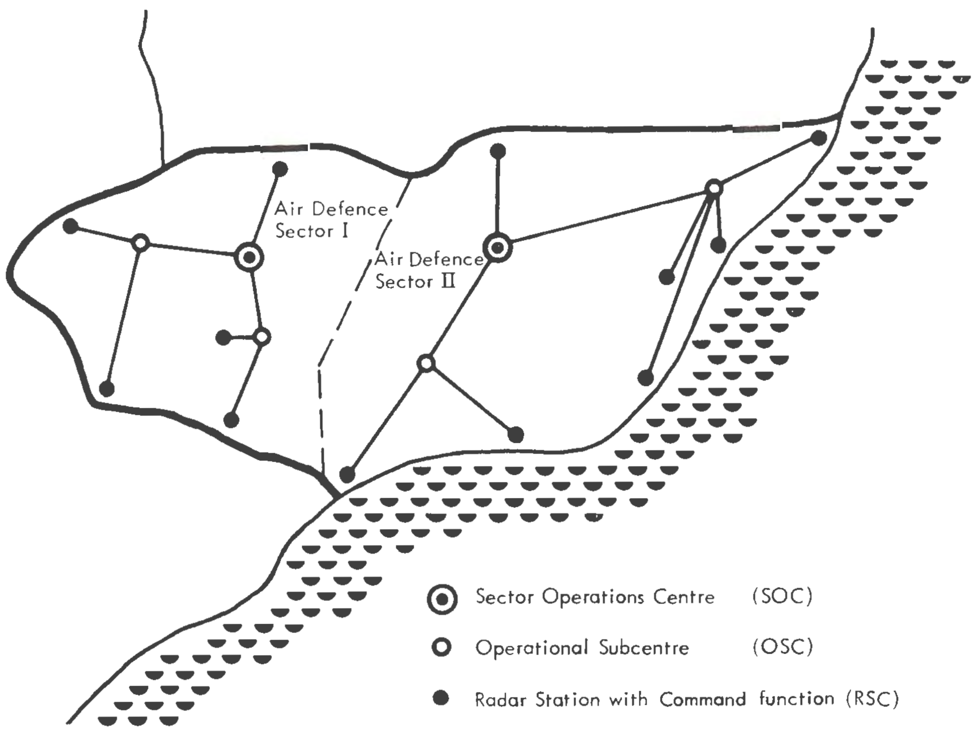


Figure 14. Command and control centres

Man-Machine Interfaces

(See figs 15, 16, 17)

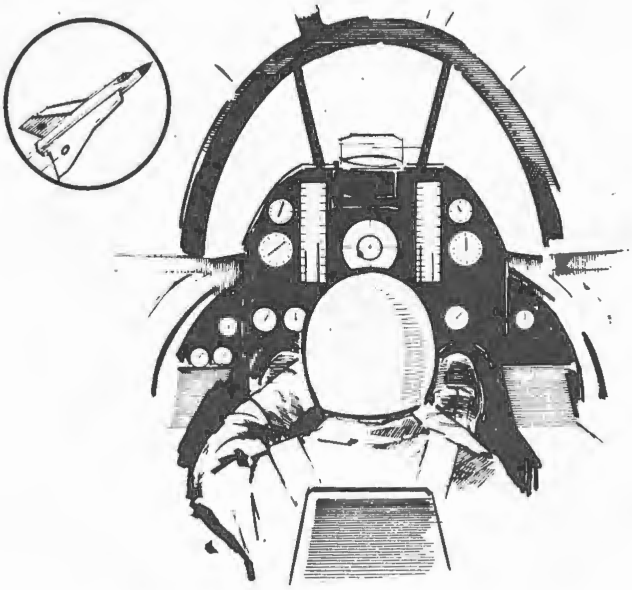


Figure 15. Pilot - aircraft interface

Figure 16. Operator in ground environment system: Interceptor controller - display console

Examples of Special Studies

- Analysis of the tracking function
- Analysis of the operational value of new equipment and new procedures for command and control
- Analysis of the capabilities of emergency systems (e. g. use of visual observation)
- Analysis of special ECM and ECCM situations

- Analysis in order to design new fighter systems
- Technical and tactical system testing by means of simulation
- General analysis and evaluation of the air defence system. (Example: Defended areas for different target speeds).

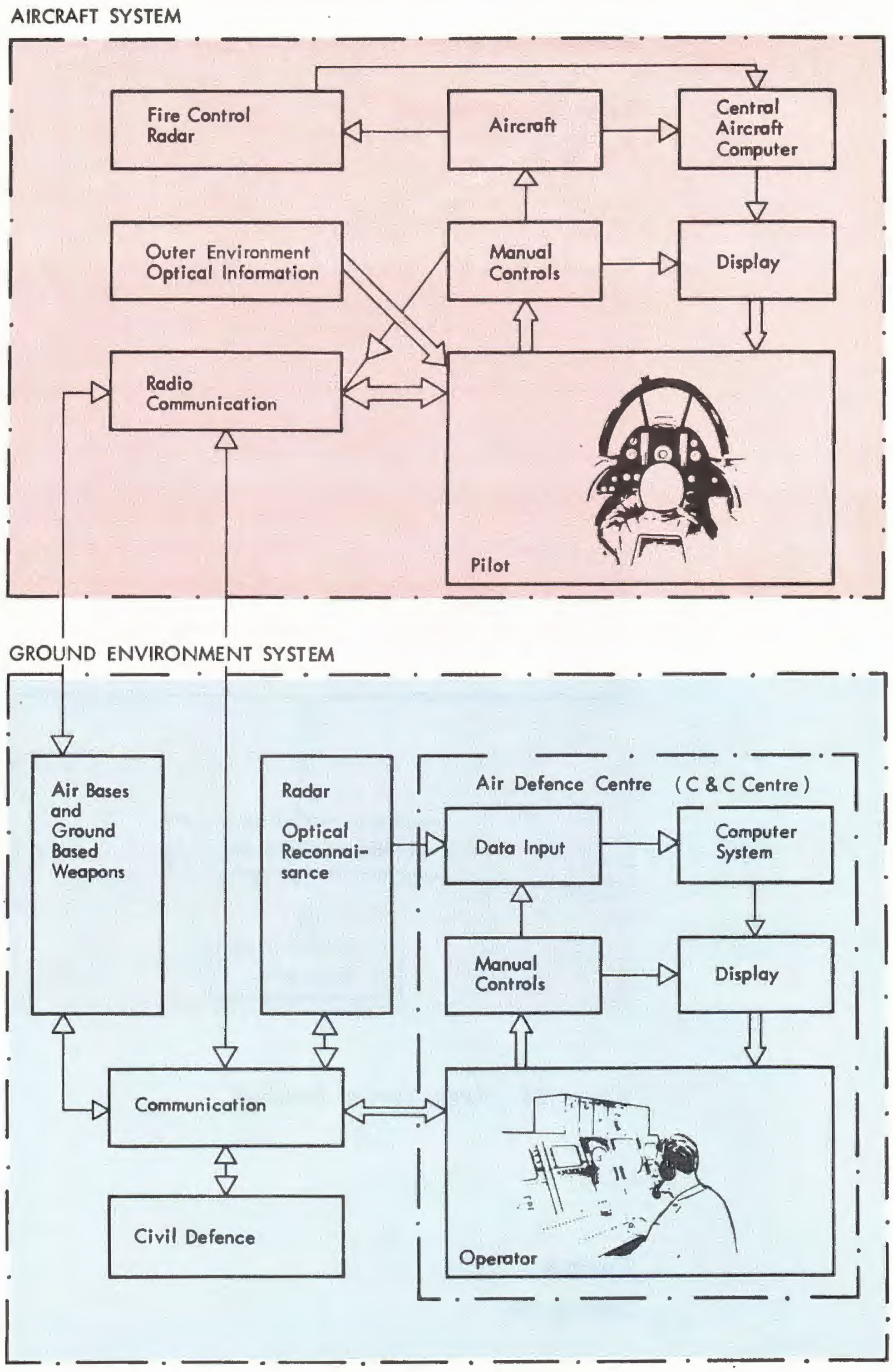


Figure 17. Man - machine interface, systems diagram

3 Radar

Radar Systems and Techniques

Radar Systems Analysis

(See fig 18)

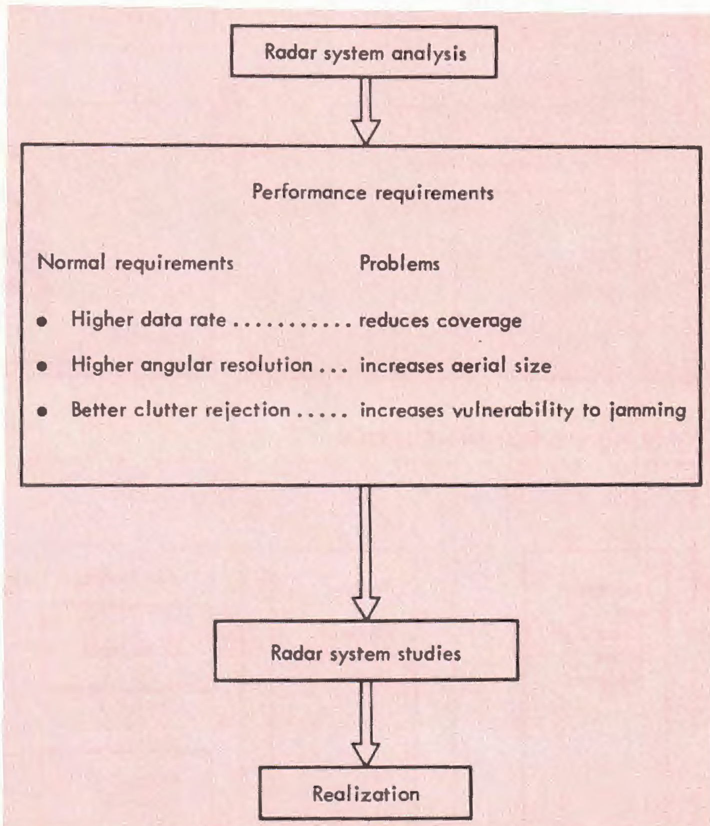


Figure 18. Radar system build-up

Coverage

(See fig 19)

- Target Scattering Area
- Detection Probability and False Alarm Rate
- Relationship between Radar Parameters
- Propagation Problems

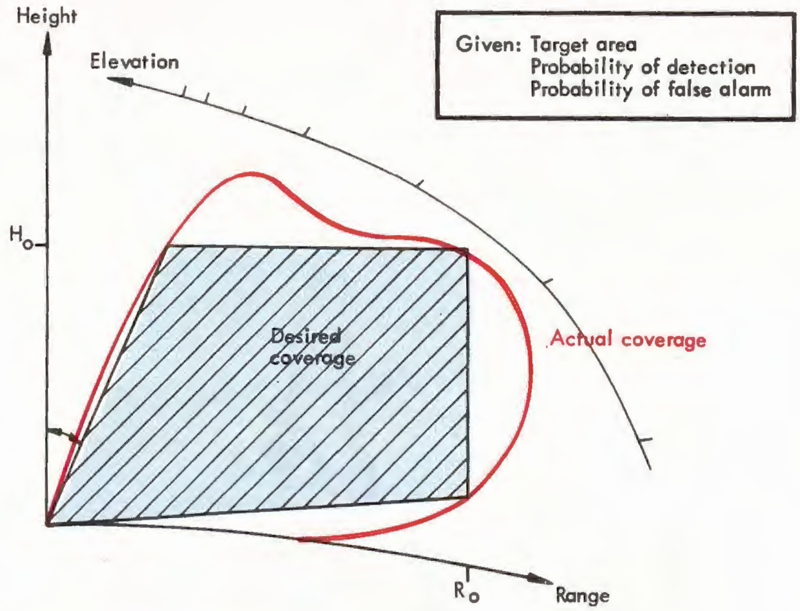


Figure 19. Example of unjammed radar coverage

Height Measurement

(See figs 20, 21, 22, 23)

- Basic Requirements:
  - Accuracy
  - Capacity
- Methods:
  - Nodding height finder
  - 3D radar

Figure 20. Nodding height finder measurement ("azication" or bringing to bear on target in azimuth from 2D surveillance radar)

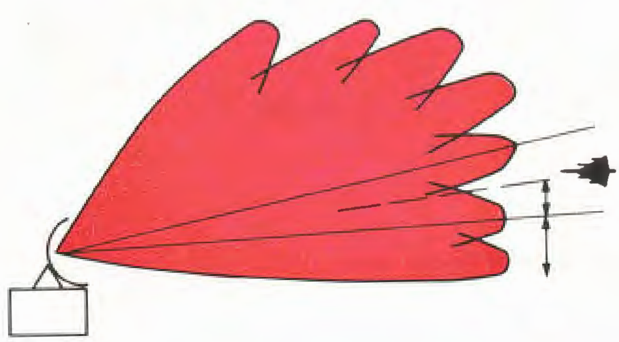


Figure 21. Multi-beam 3-dimensional radar antenna diagram

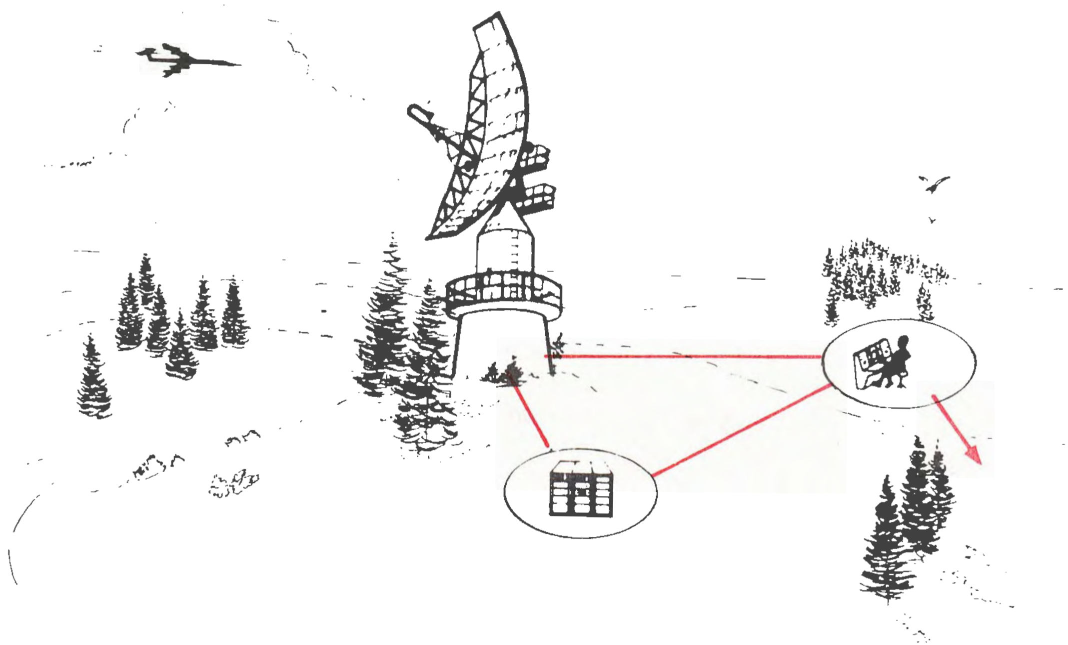


Figure 22. Nodding height finder site

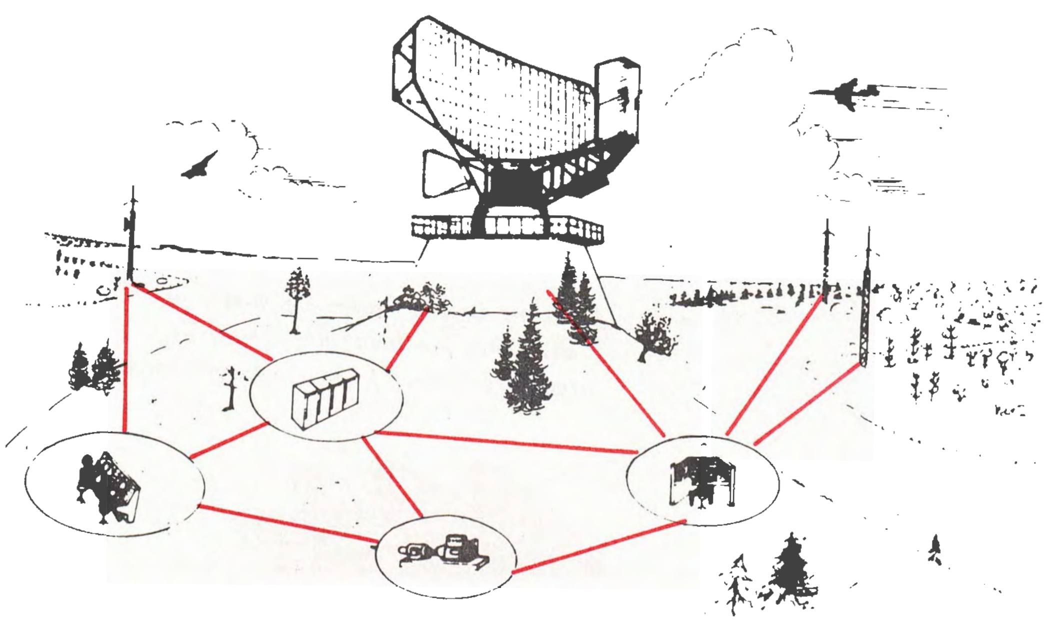


Figure 23. Surveillance radar site

Protection against Electronic Countermeasures (ECM)

ECM Techniques

(See figs 24, 25, 26)

Active jamming:

- Creating confusion or masking targets
  - Noise jamming
  - Barrage jamming
  - Sweep-through jamming
  - Self-screening jamming
  - Stand-off jamming

- Deception
  - Repeater jamming
  - Range-gate stealer

Passive jamming:

- Chaff
- Decoys
- Radar cross-section reduction

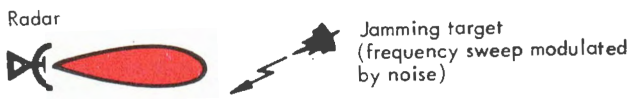


Figure 24. Self - screening jamming (low power)

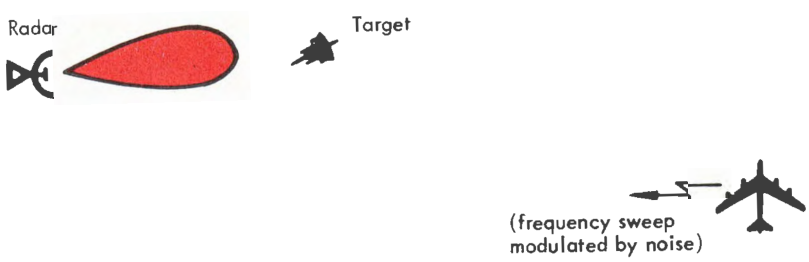


Figure 25. Stand-off jamming (high power)

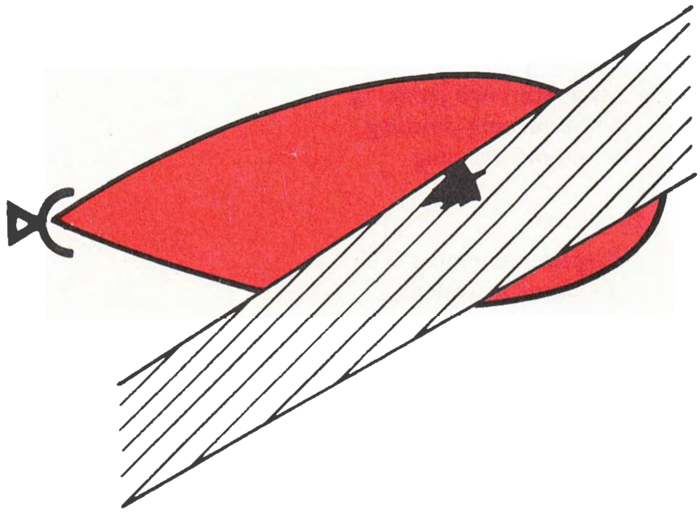


Figure 26. Chaff corridor

Important Radar Characteristics in a Jamming Environment

- Output power
- Bandwidth
- Aerial gain
- Sidelobes
- Signal processing

Electronic Counter-Counter Measure (ECCM) Methods and Techniques

- Signal Processing

Processing:	Types of jamming:
- Constant False Alarm Rate (CFAR) receiver	- Noise
- Dicke Fix	- Frequency sweep
- Dicke Fix and video correlation (see fig 27)	- Pulsed (interference)
- Moving Target Indication (MTI)	- Chaff
- Pulse compression	

- Passive Detection

Philosophy

- Design to counter stand-off jamming and chaff
- Protection against deceptive ECM methods
- Use of passive methods to localize jamming targets

Triangulation (see fig 28)

Necessary radar characteristics:

- Narrow beams
- Low sidelobes
- Facilities for jamming strobe extraction

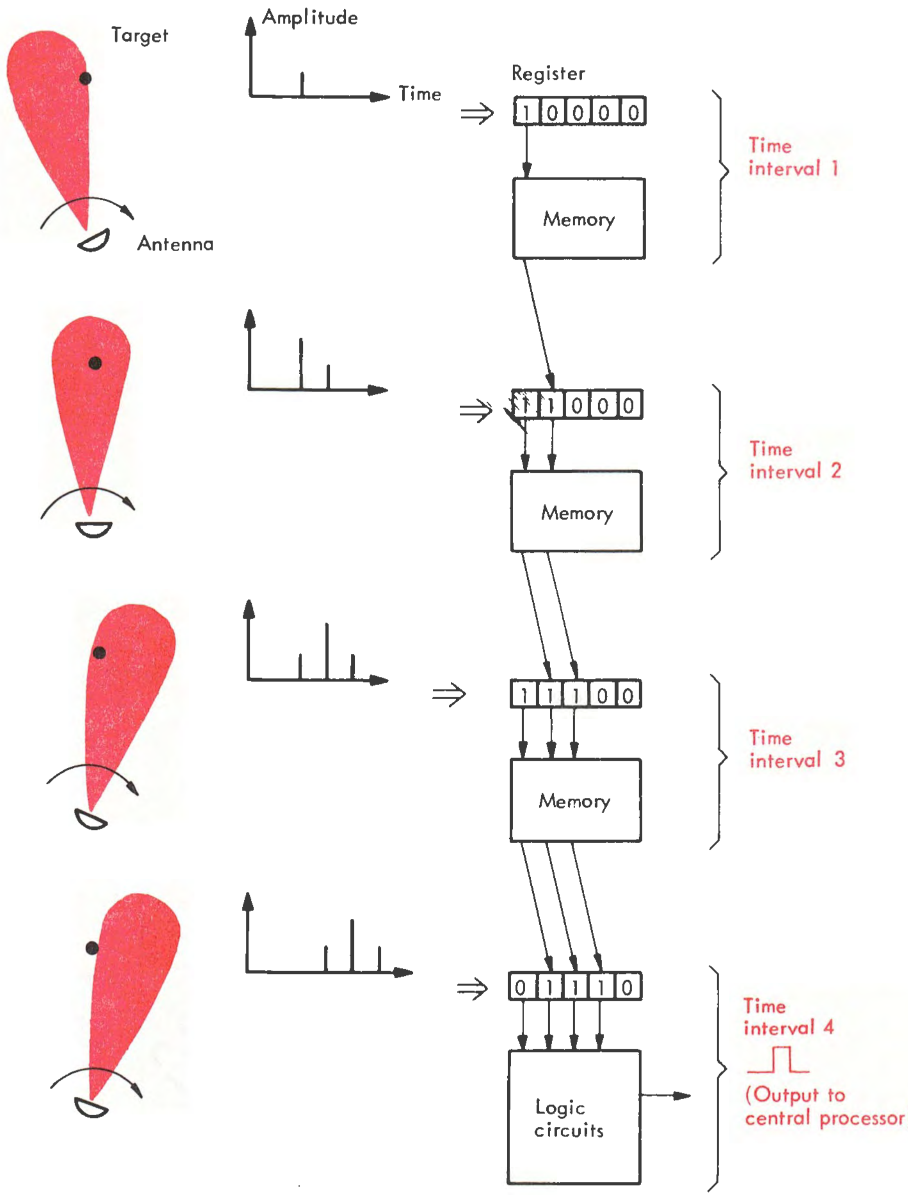


Figure 27. Signal processing with video correlation

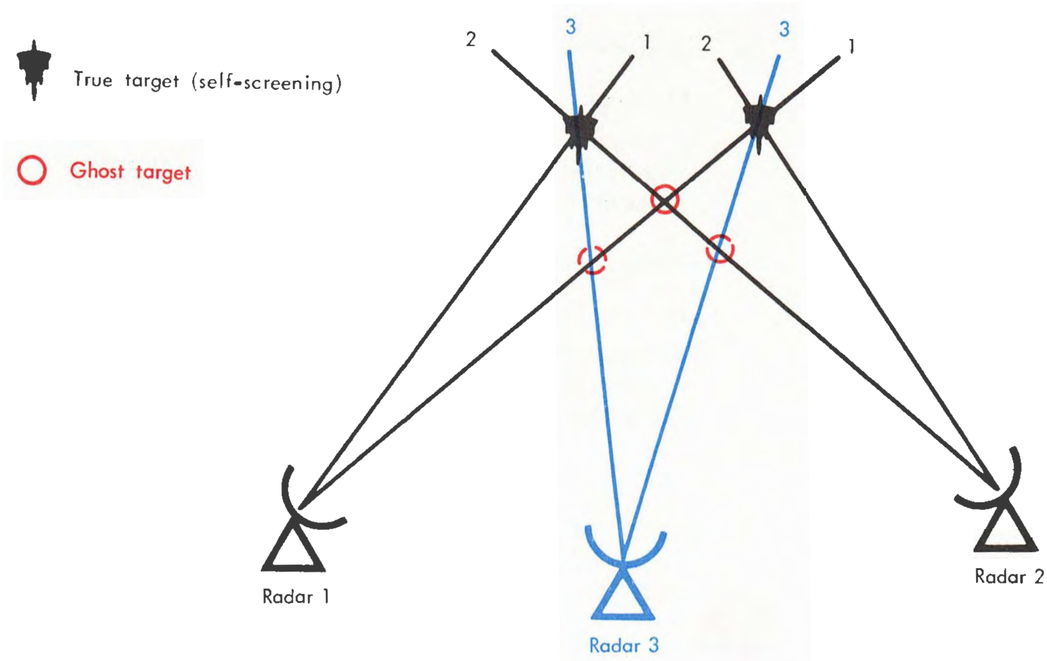


Figure 28. Passive detection by triangulation

Coverage in a Jammed Environment

Range and height coverage decreases substantially under jamming conditions (see fig 29).

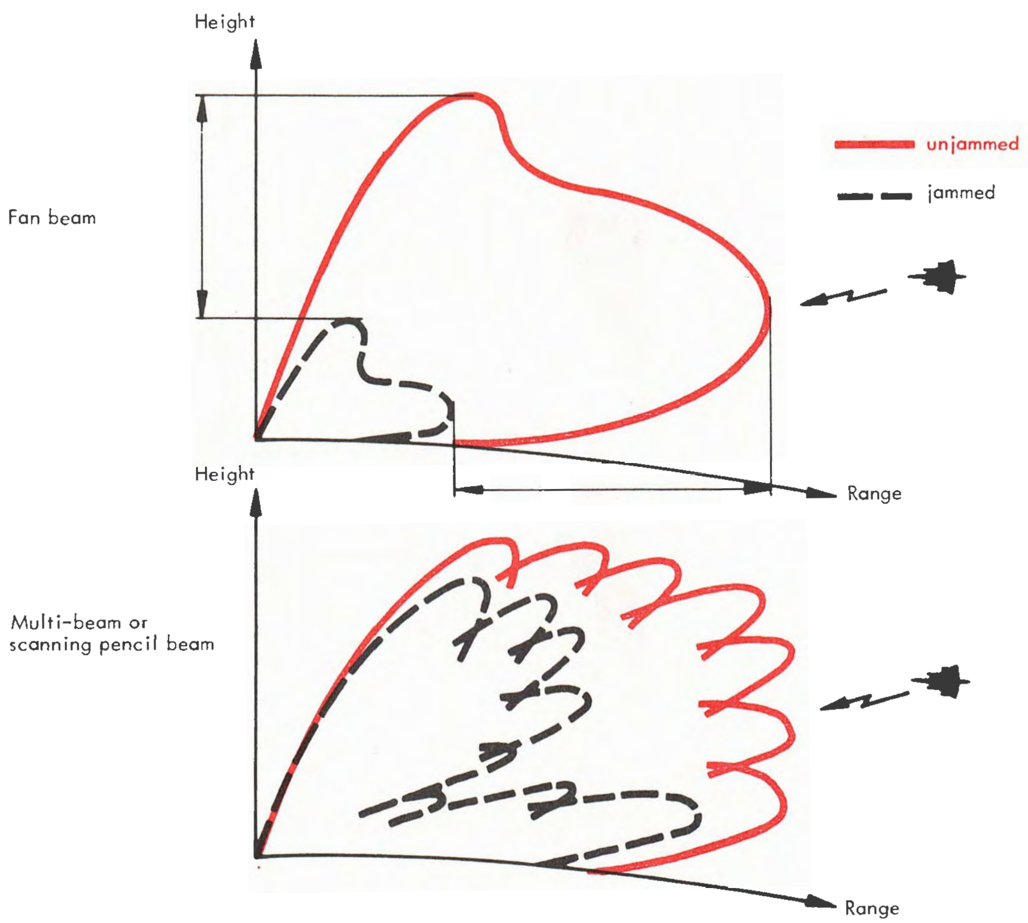


Figure 29. Decrease in coverage due to jamming

Height Measurement under Jamming

Jamming situation:	Accuracy:
- Self-screening jammer	- Fairly good (provided the target can be detected)
- Stand-off frequency sweep jammer	- May be substantially decreased depending on antenna characteristics and signal processing methods

Detection of Low Altitude Targets

Radar Horizon

Antenna and target height have great influence on range in microwave region of spectrum. (See fig 30).

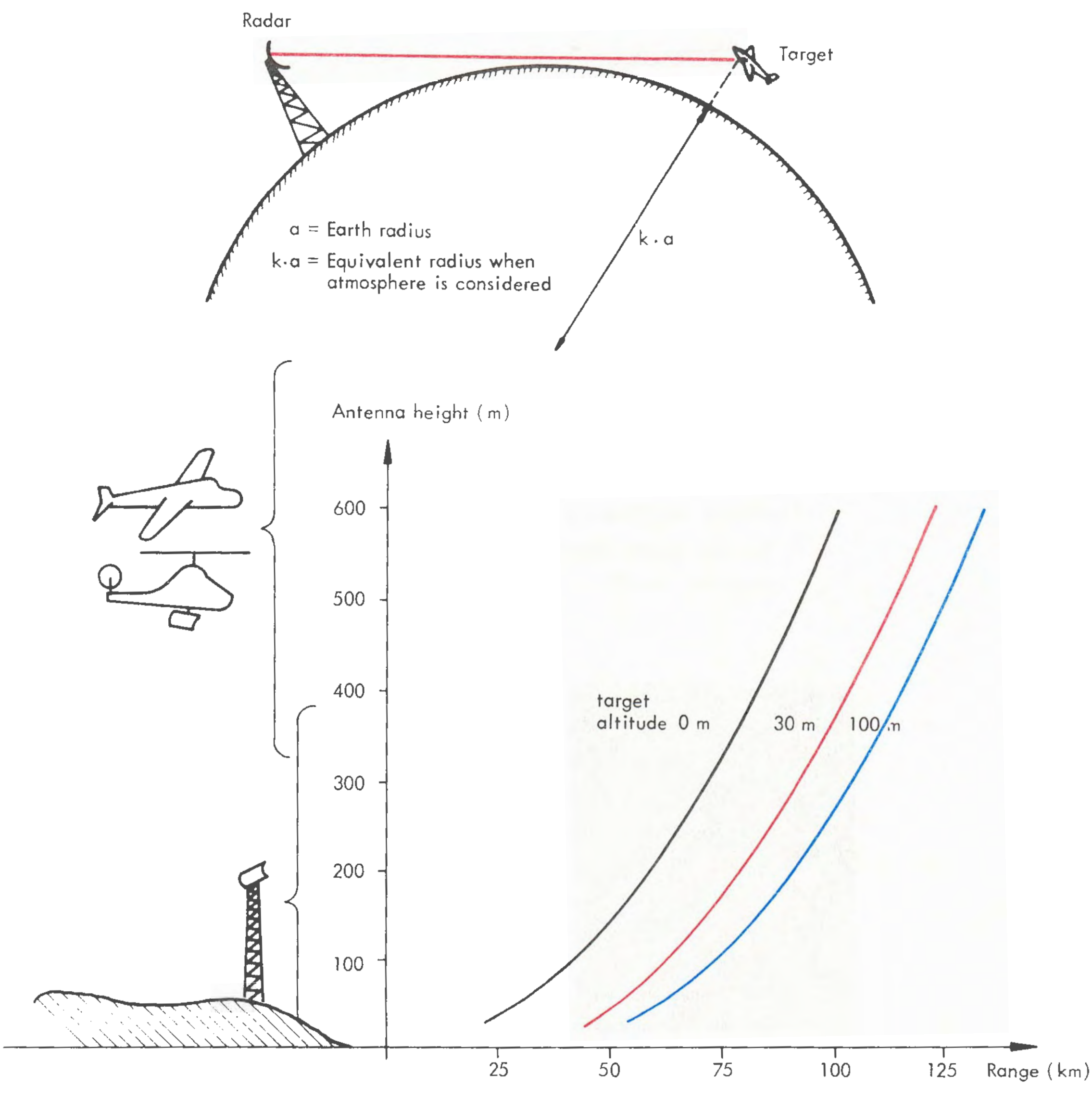


Figure 30. Antenna height and radar horizon

Anomalous Propagation and Lobing

Drastic changes in radar range can occur. (See figs 31 and 32).

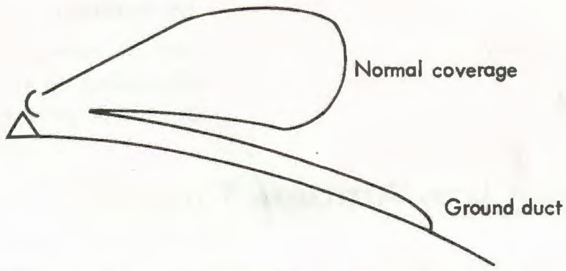


Figure 31. Increased low altitude range appearing during superrefraction

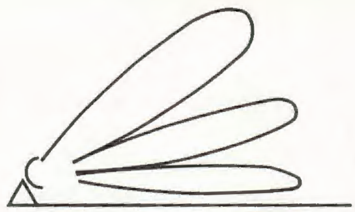


Figure 32. Lobing due to ground reflections

Computation from Maps of Masked and Cluttered Areas

- Coverage Diagrams with masked areas (see figs 33, 34, 35).

  Inputs to computer program:
  - Terrain points (from topographical maps)
  - Antenna height
  - Target altitude

- Clutter Diagrams (see figs 36 and 37).

  Inputs to computer program:
  - Terrain points (from topographical maps)
  - Antenna height

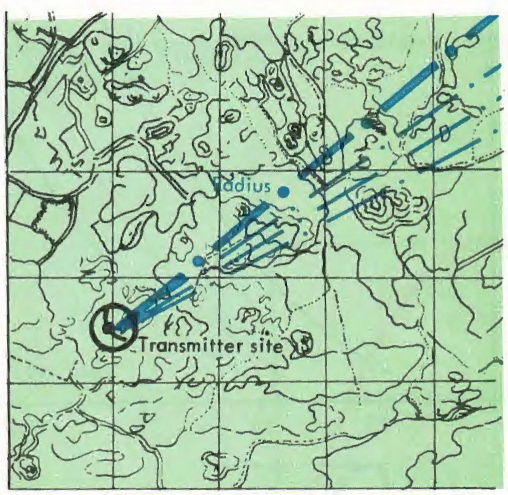


Figure 33. Topographical map with transmitter site

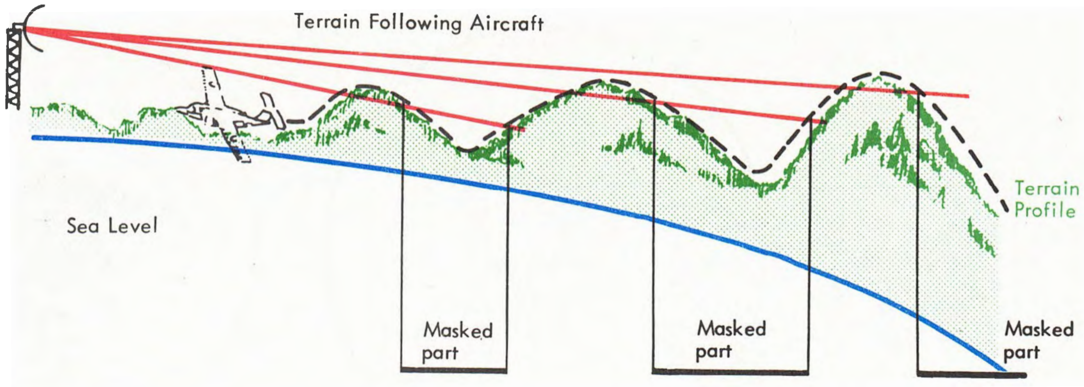


Figure 34. Profile of terrain following aircraft

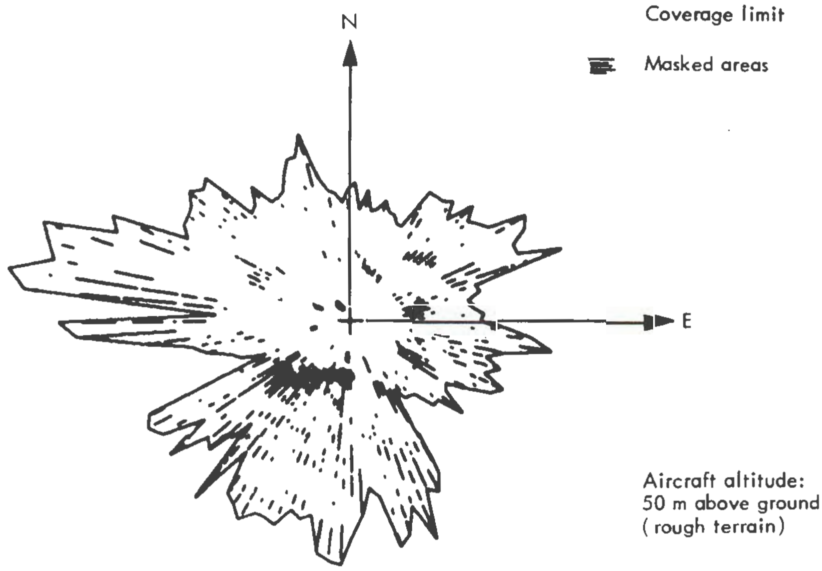


Figure 35. Ground clutter areas calculated from maps

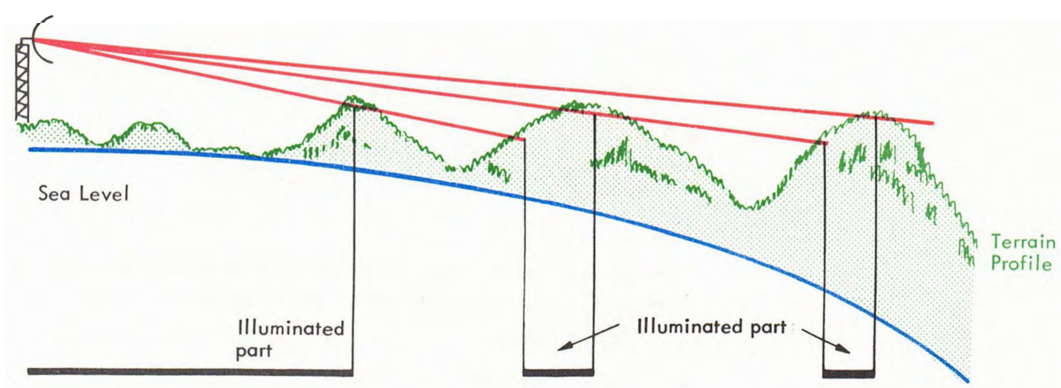


Figure 36. Radial profile of terrain showing ground clutter

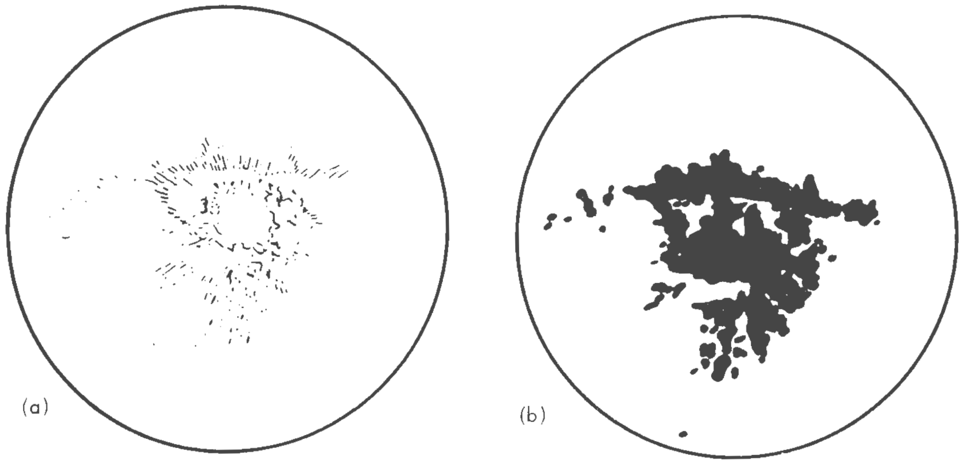


Figure 37. Computed (a) and real (b) ground clutter

Protection against Ground Clutter

- Signal processing including pulse compression
- Pulse doppler technique
- MTI techniques, analog and digital (see fig 38)

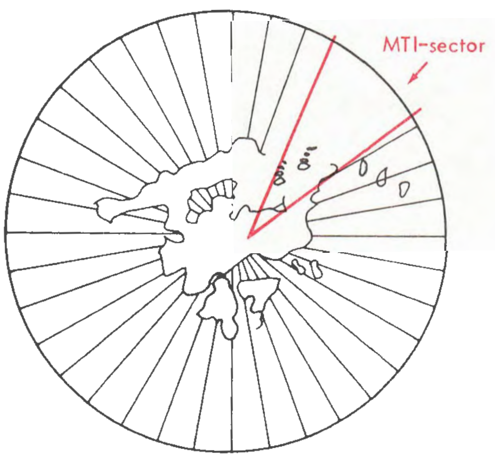


Figure 38. MTI display

Low Cover Ground Based Systems

Systems can be built according to two principles: antennas at great height and antennas at low height (see figs 39 and 40).

Antennas at great height offer great geometrical horizon ranges and need few stations but have the following disadvantages:

- Many lobes
- Easy to detect
- Easy to destroy
- Reduced coverage at low target altitude above rough terrain

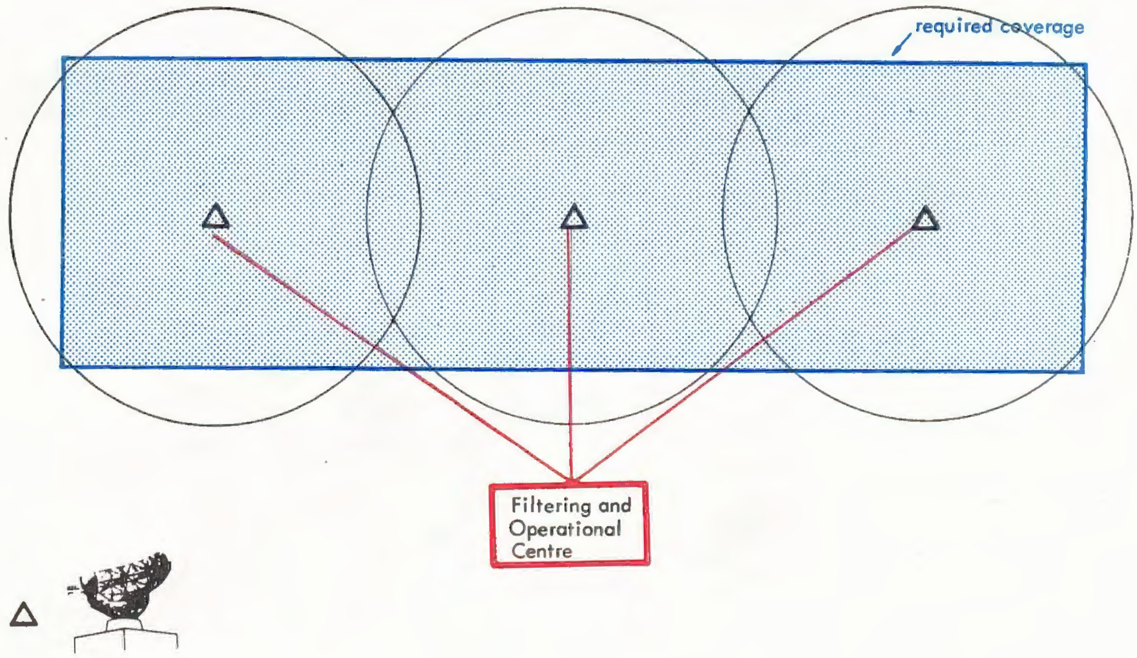


Figure 39. System with antennas at great height

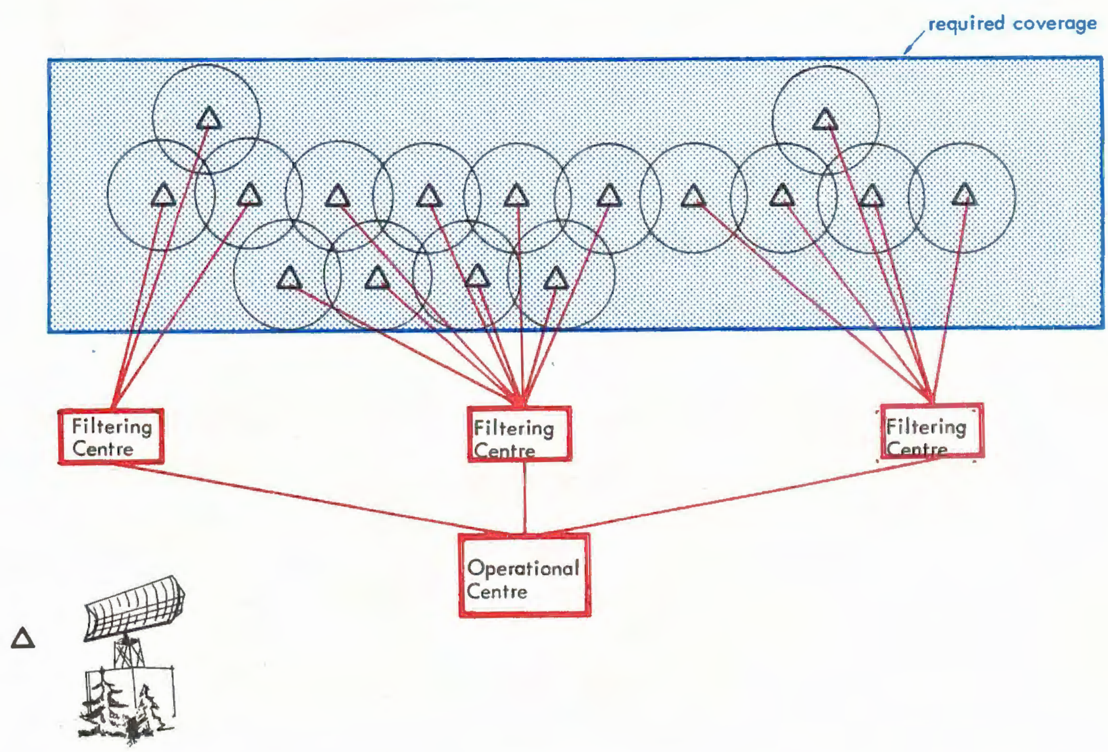


Figure 40. System with antennas at low height

Antennas at low height mean little lobing but also the following disadvantages:

- Need of many radar stations
- Interference and ambiguity problems
- Communication problems
- Height coverage limitations

Low Cover Airborne System

An airborne radar system provides great horizon range without many of the disadvantages of a ground based system with antennas at great height but is more complicated. (See fig 41).

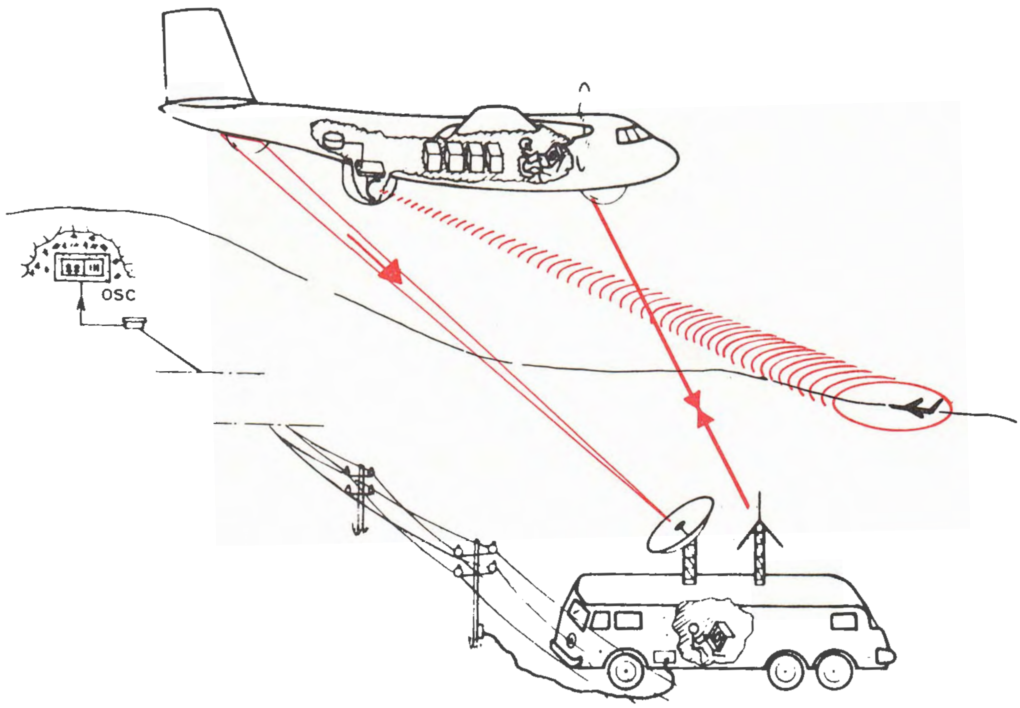


Figure 41. Airborne early warning system including aircraft, radar, communication, computer and display

Protection against Anti Radiation Missiles (ARM)

- Detection of ARM and transmitter turn-off
- Variation of the signal characteristics such as frequency, pulse repetition frequency, (PRF)
- Spoofing (radar decoys, see fig 42)
- Camouflage
- Weapon action against missile carrying aircraft or missile itself

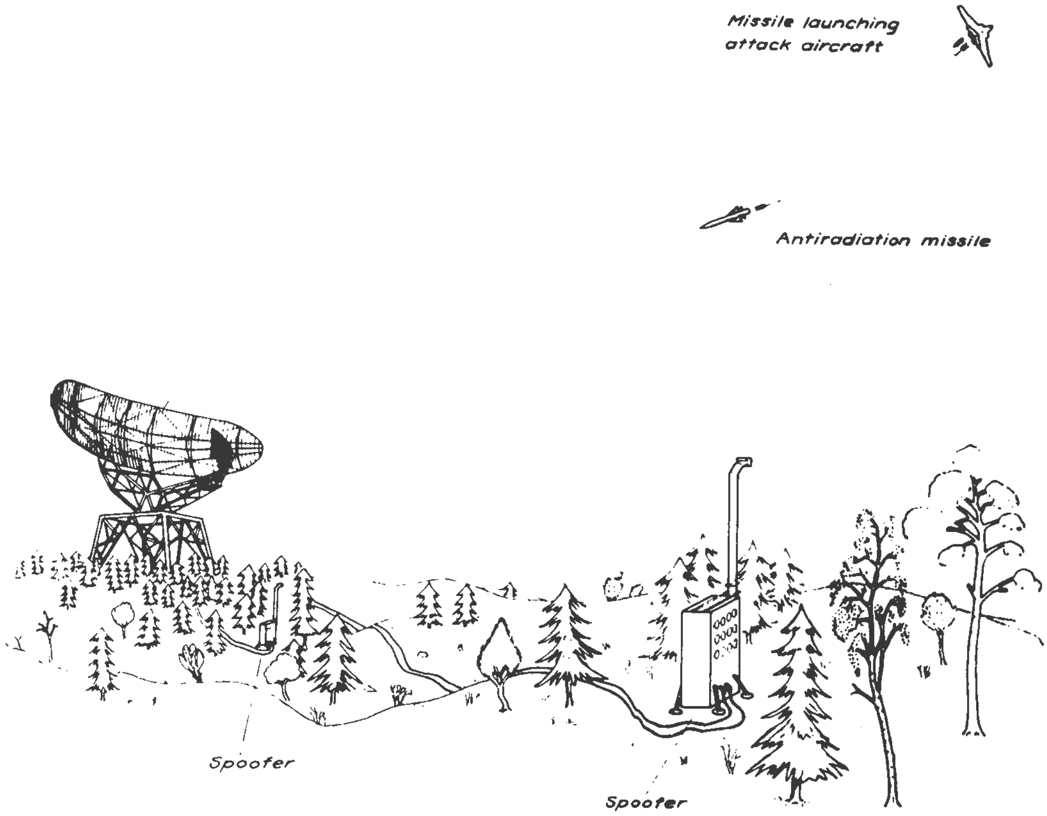


Figure 42. Example of ARM protection

Realization of Radar Systems

Main Activities

(See fig 43)

- Technical Specifications
- Evaluation of Technical Offers
- Factory Acceptance Procedures

Gradual Build-up of an Integrated Nationwide Radar Network

- Increasing Area Coverage
  - »single coverage» over total area
  - »double coverage» over important parts of the area
- Broadbanding
  - C-band
  - S-band
  - L-band
  - P-band
- Improvement of Signal Processing
  - CFAR receivers
  - MTI with velocity compensation
  - Video correlators (plot generation)
  - Automatic detection (track generation)

- Use of Radar Stations in Passive Detection Systems
- Integration with Civil ATC
- Possibility to Up-grade Basic Building Blocks
- Possibility to Integrate at Different Levels

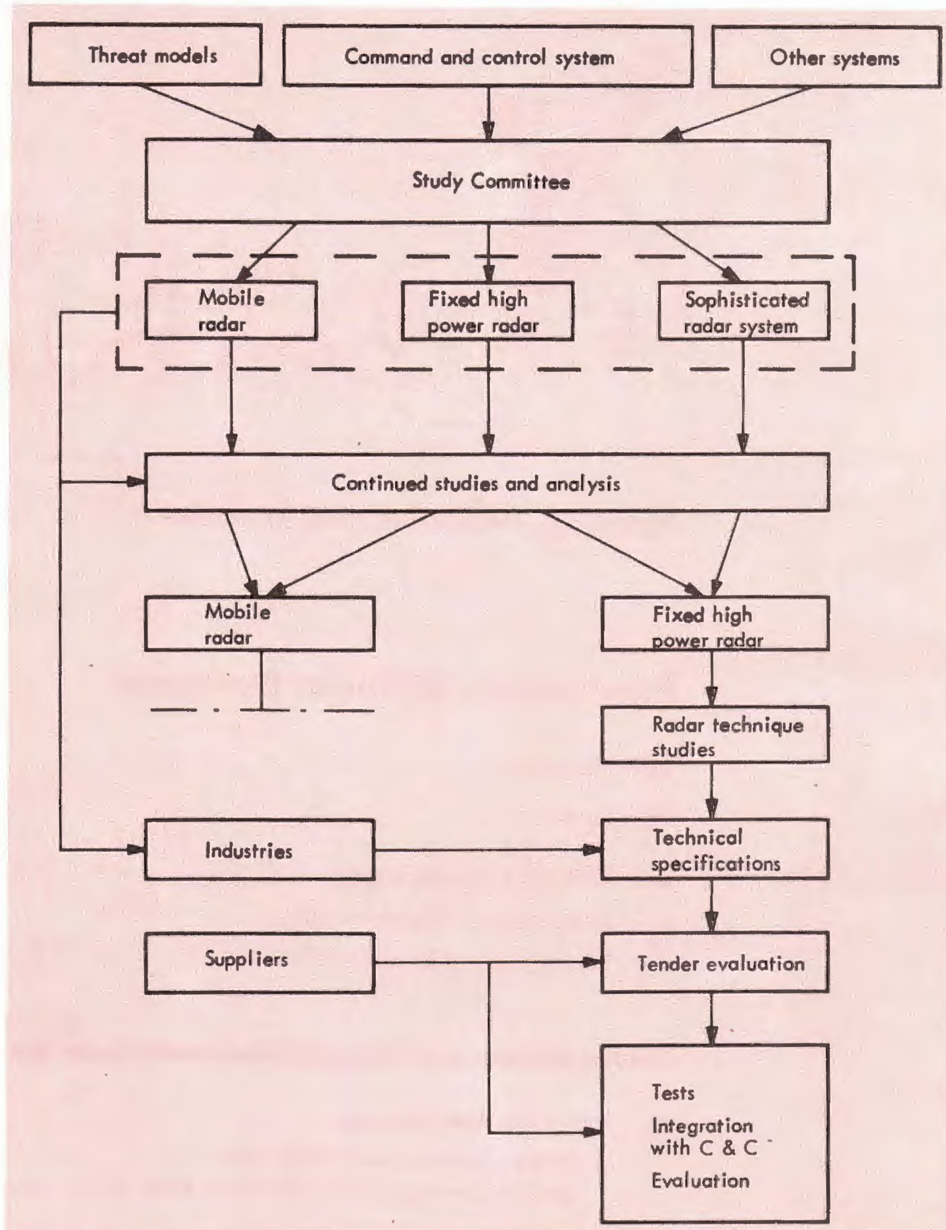


Figure 43. Flow diagram of radar system build-up

4 Command and Control Centres

Different types of centre

(See fig 44)

- Sector Operations Centre (SOC)
- Operational Subcentres (OSC)
- Radar Stations with Command Function (RSC)

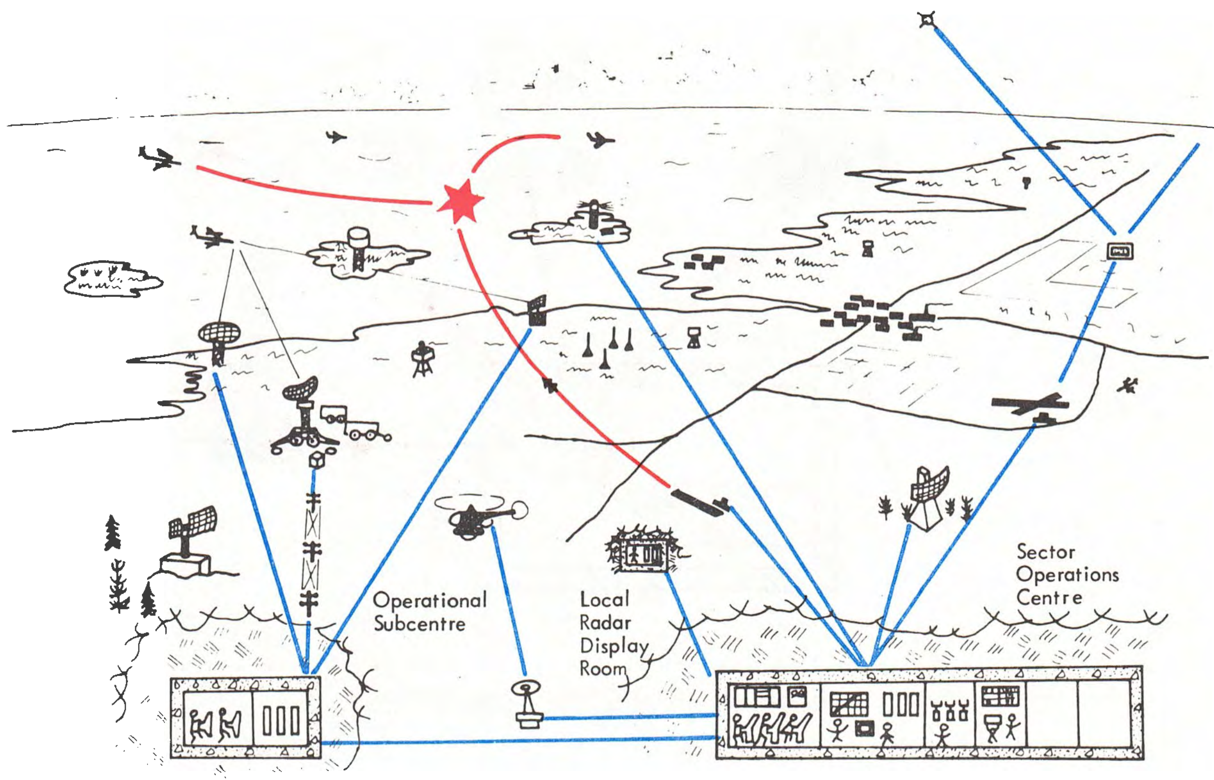


*Figure 44. Command and control systems
Deployment and installation*

Functions

(See figs 45, 46, 47)

- Manual and Automatic Tracking
- Height Measuring
- Intercept Calculation
- Air Traffic Control (ATC)
- Weather Forecast Service
- Alarm (Civil Defence etc)

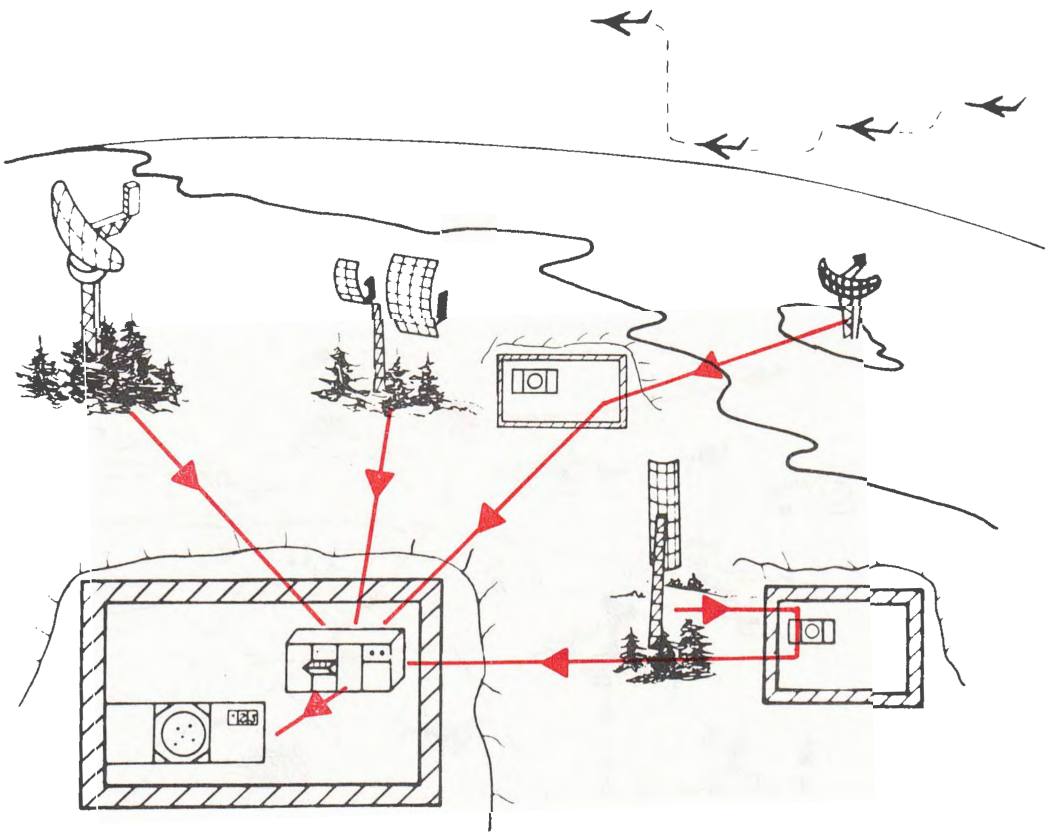


Figure 45. Height measuring system

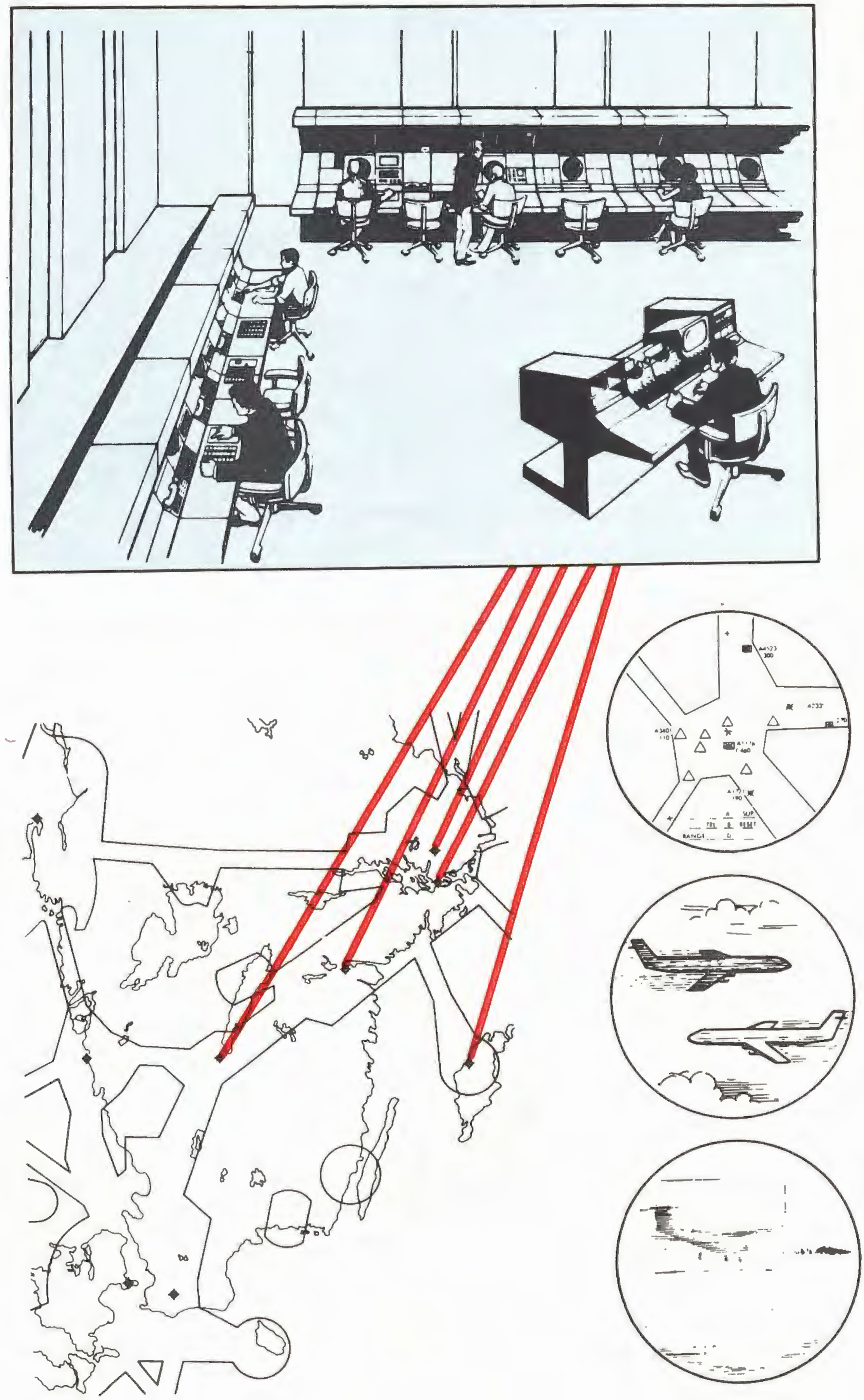


Figure 46. ATC system

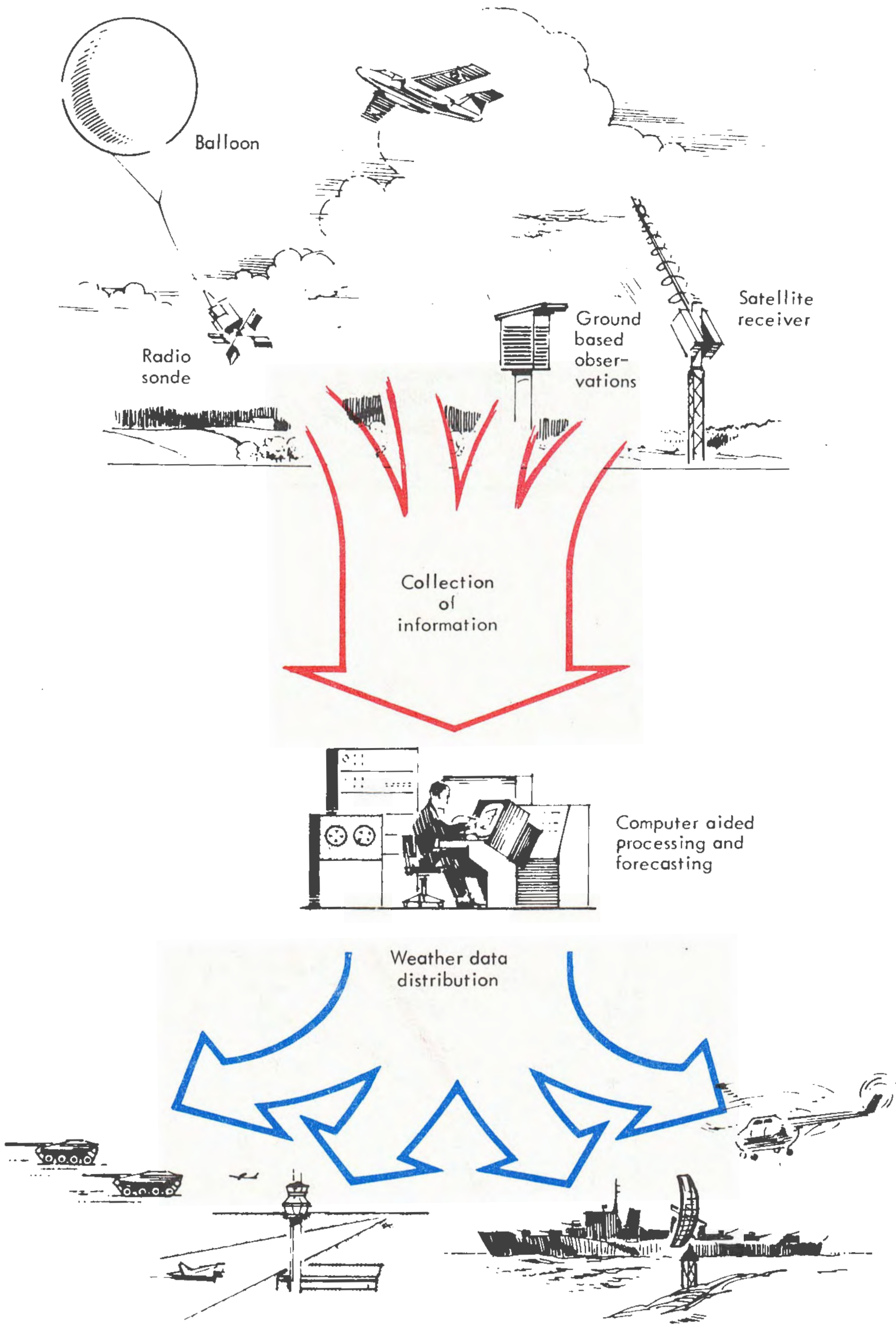


Figure 47. Weather service system

Integration

(See fig 48)

- Existing and New Equipment
- Interface Definition
- Gradual Build-up of Air Surveillance and Target Acquisition

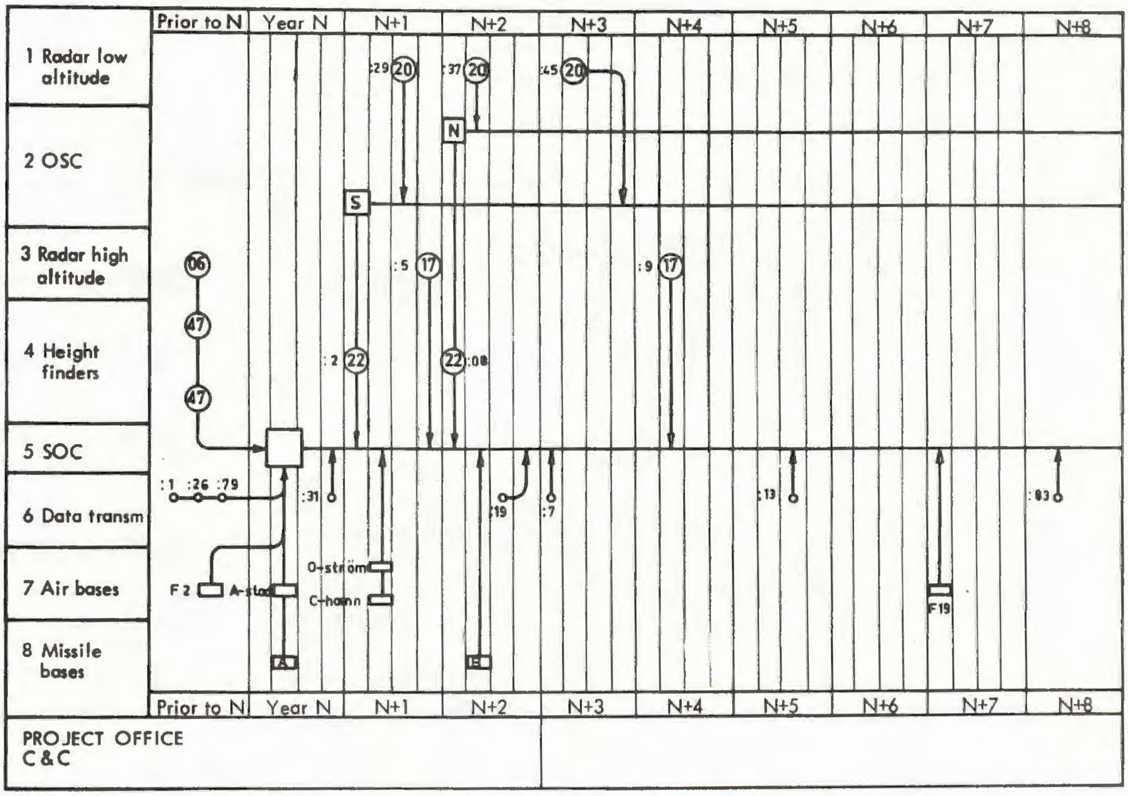


Figure 48. System build-up plan

5 Telecommunication

Information Flow in an Air Surveillance, Command and Control System

(See fig 49)

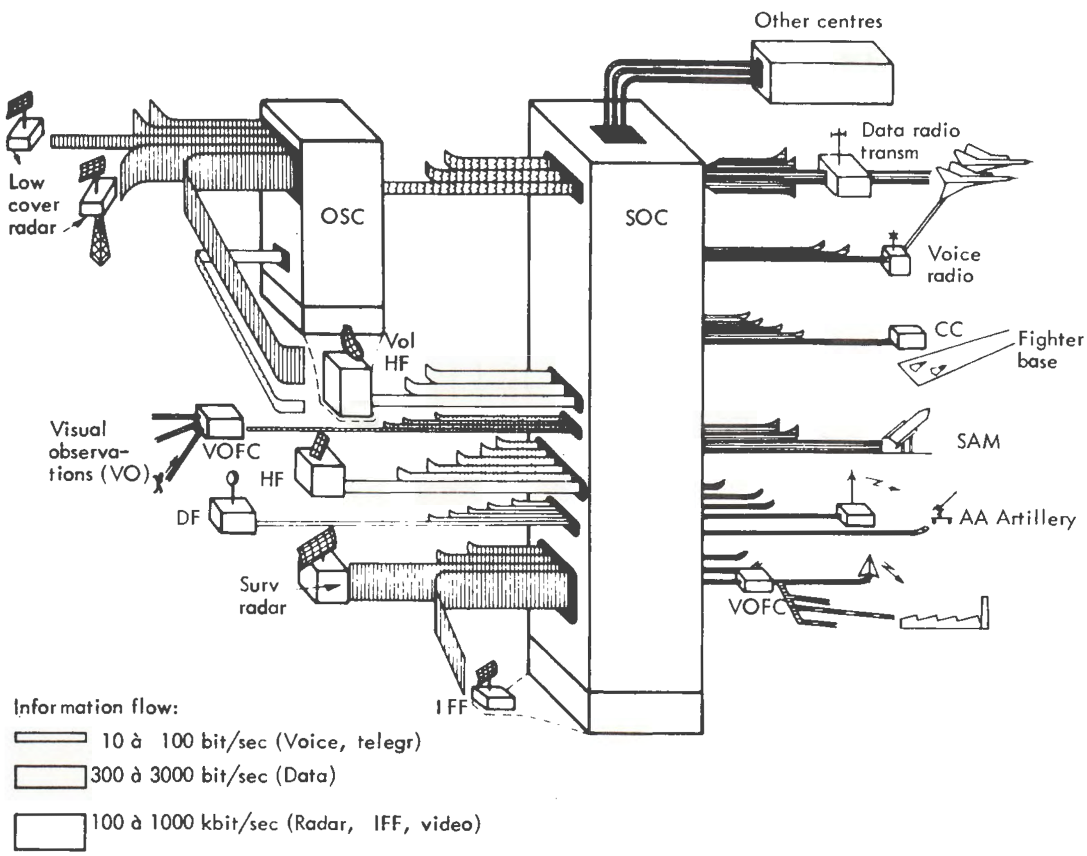


Figure 49. Air defence information flow

Switched Telecommunication Networks for Telephony, Telegraphy and Data

- Traffic Demands
  - Volume
  - Distribution
- Service Requirements
  - Priority
  - Security
  - Setting-up times
  - Congestion

- Switching Principles
  - Circuit switching
  - Message switching
  - Storing
  - Forwarding
- Network Structures (see fig 50)
  - Economy
  - Survivability
  - Reliability

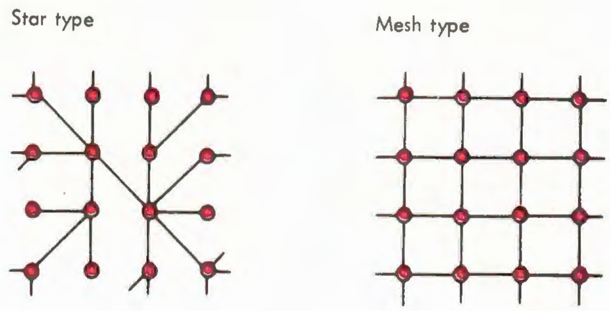


Figure 50. Network structures

- Routing Principles and Capacity Calculations (see figs 51, 52, 53)
- Transmission Quality and Signalling Systems
- Resistibility against Weapons (see fig 54)
- System and Equipment Specifications (see fig 55)

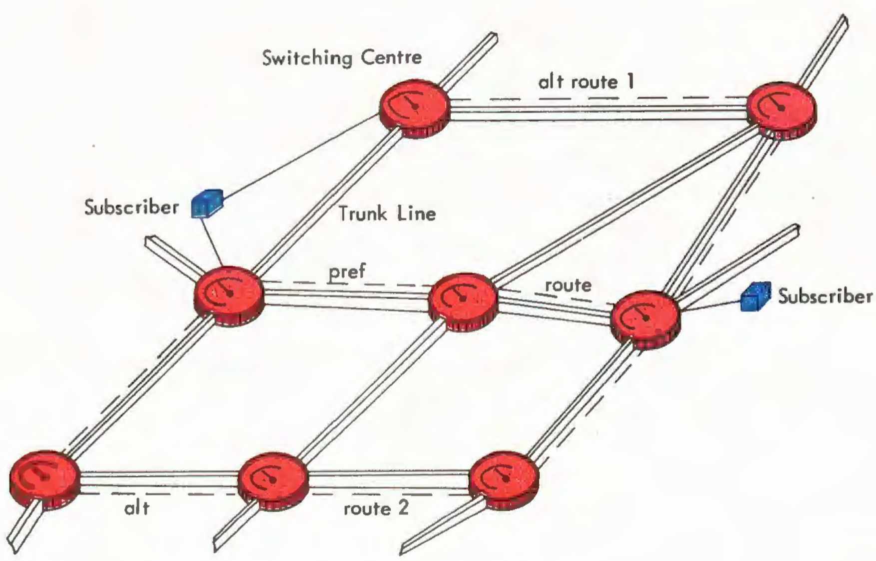


Figure 51. Alternative routing

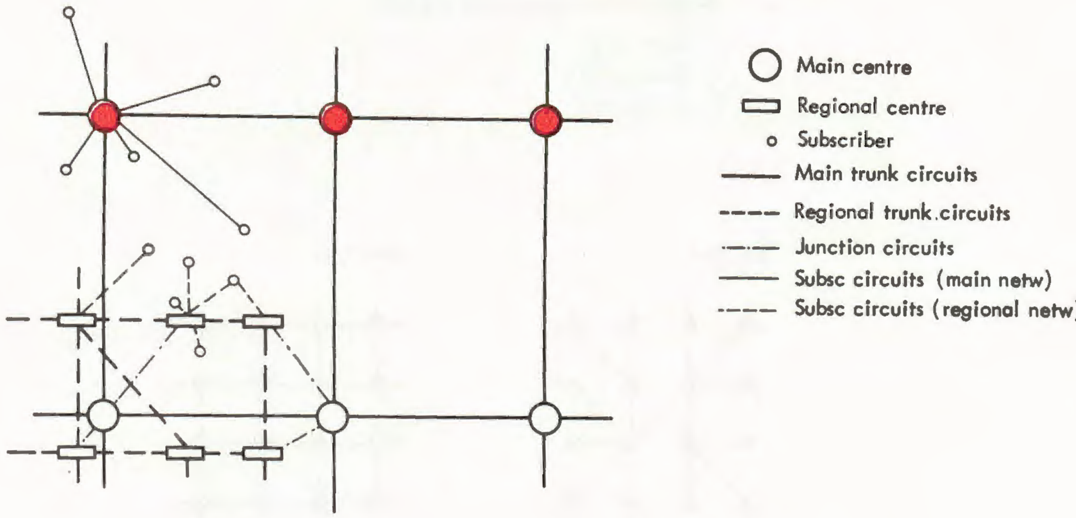


Figure 52. Main and regional networks

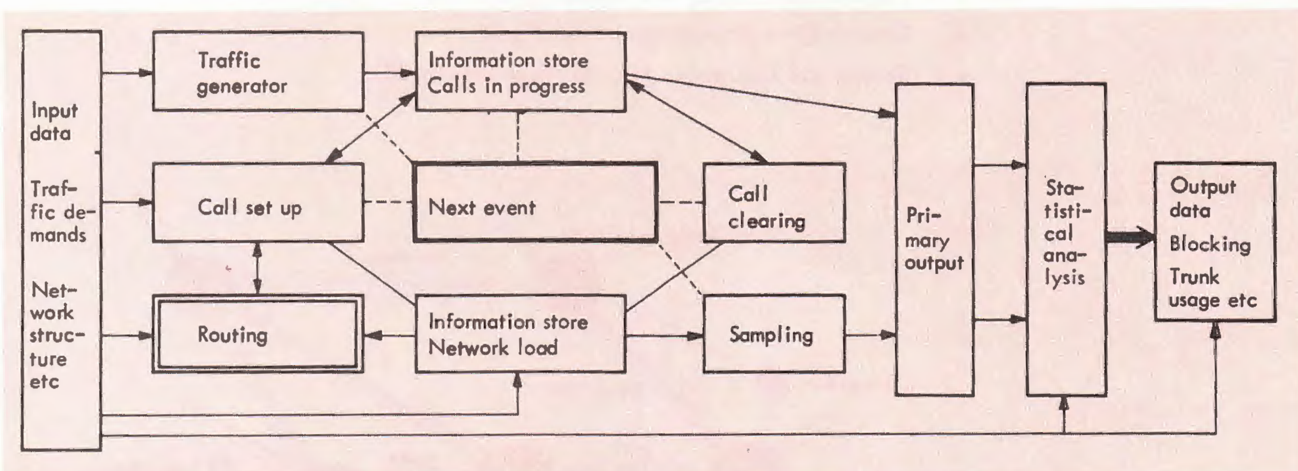
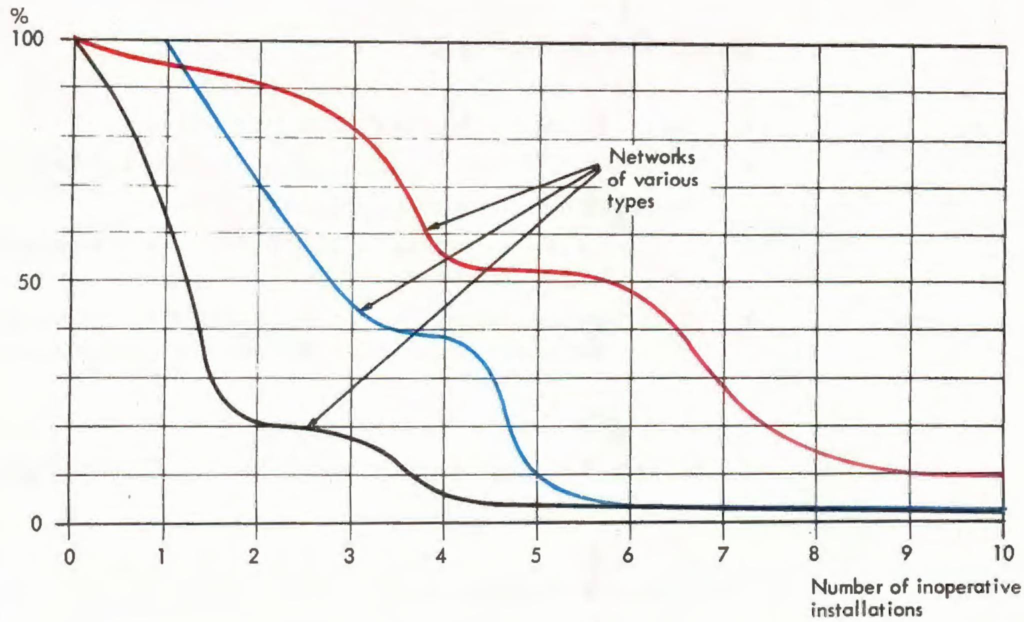


Figure 53. Simulation block diagram for studying routing principles and traffic engineering



Example of diagram showing network performance as percentage of actual to needed capacity versus the number of inoperative installations

Figure 54. Computer simulation of the resistibility of communication networks after damage to installations

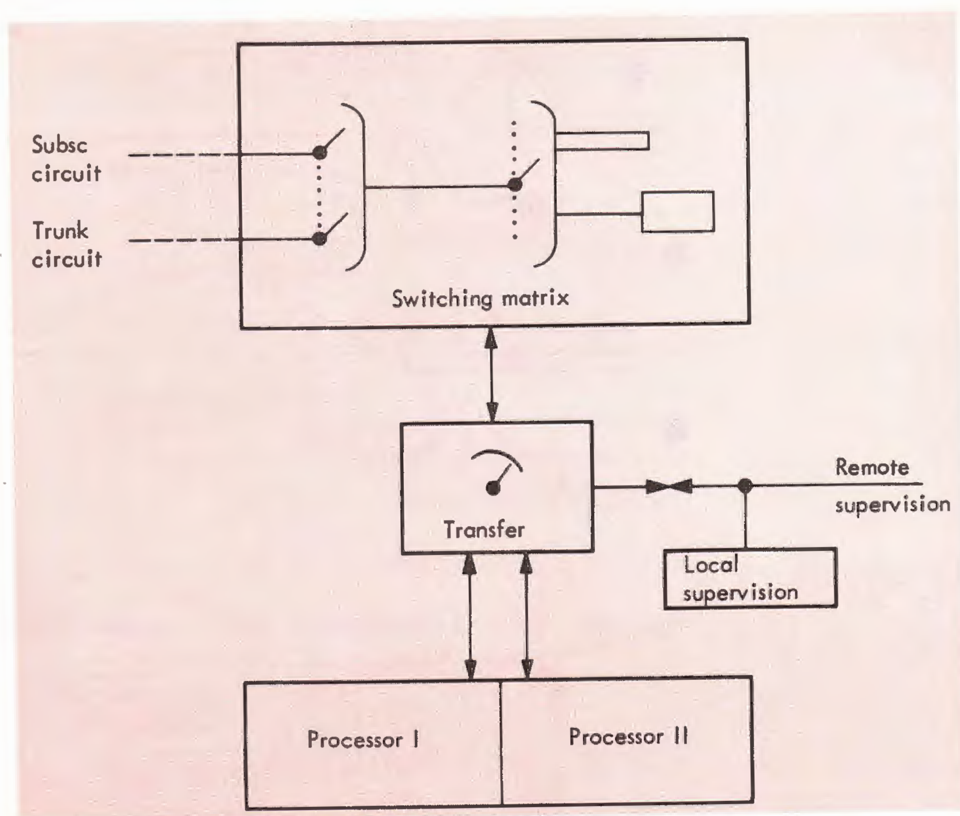


Figure 55. Stored program controlled telephone exchange

Data Communication

- System Design and Specification of Data Links
- Evaluation of the Performance of Data Channels and Modems
- Specification of Data Transmission Equipment
- Evaluation of Data Communication Performance in Existing Military and Civil Line Equipment
- System Design and Specification of a National Data Network - Especially Transmission, Automatic Switching, and Terminal Interface Problems

Ground-to-Air Voice and Data Communication

- Modulation
- Ground and Aircraft Aerials
- Remote Operation of Ground Installations
- System and Equipment Specification
- Computer Simulation and Jamming Resistance in Fighter-Guidance Communication (see figs 56 and 57)

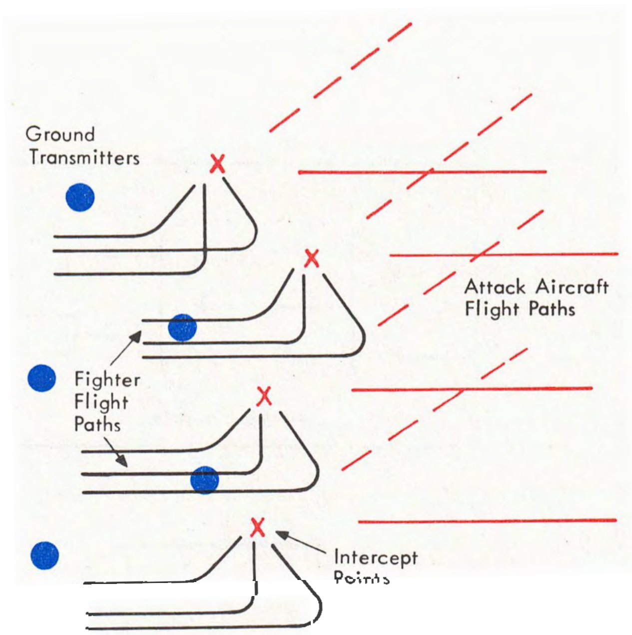


Figure 56. Ground transmitters, fighter and attack aircraft tracks with intercept points. Geometrical configuration

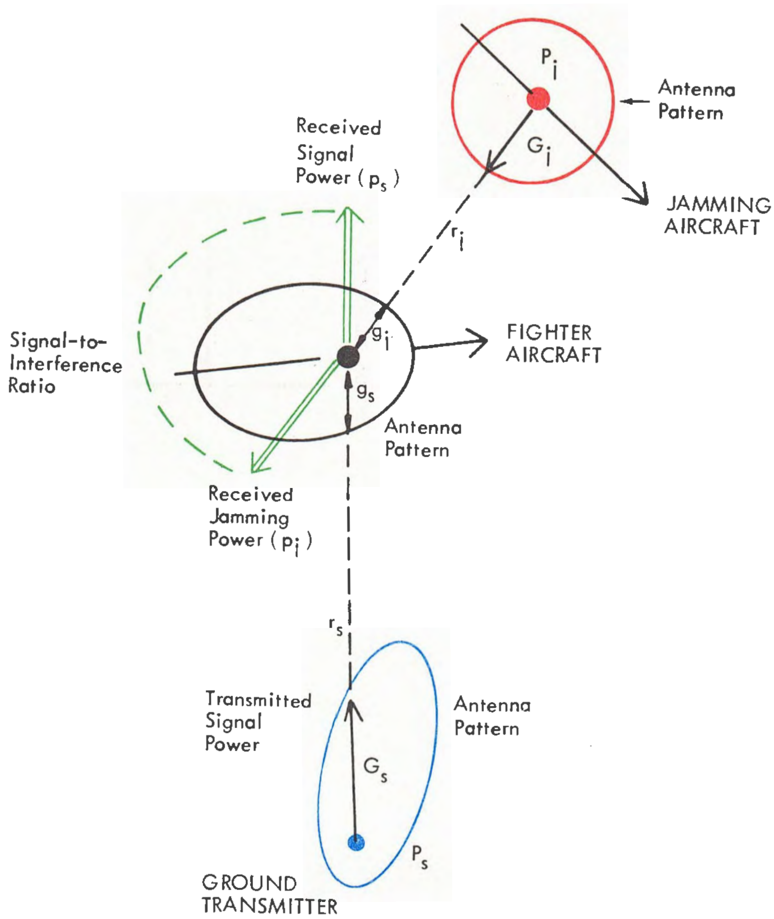


Figure 57. Signal and interference situation for intercept aircraft, jamming attack aircraft, and ground transmitter

Interference or EMC in Complex Installations

- Analysis of Interference Risks between Transmitters and Receivers - Electromagnetic Compatibility (EMC) Studies

  Background:

  - Crowded Spectrum
  - Unsatisfactory Frequency Allocation and Assignment
  - Geographical Concentration (operational and economical reasons)

  Aim:

  - To create a useful tool for identification, description and evaluation of interference situations in existing and planned communication installations

- Theoretical Models
- Simulation
- Evaluation
- Frequency Planning (see figs 58 and 59)
- Relocation of Equipment
- Equipment Modifications

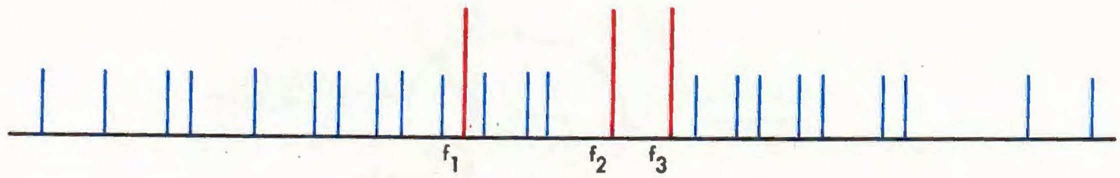


Figure 58. Generation of unwanted frequencies with three transmitters operating

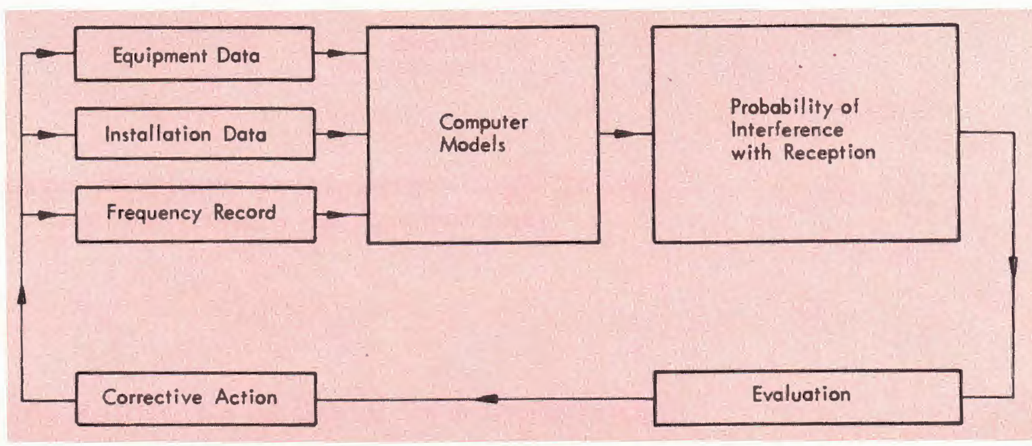


Figure 59. Simulation block diagram for computation of interference risks

6 Implementation

Planning of Sites, Buildings, and Equipment Installation

(See figs 60, 61, 62)

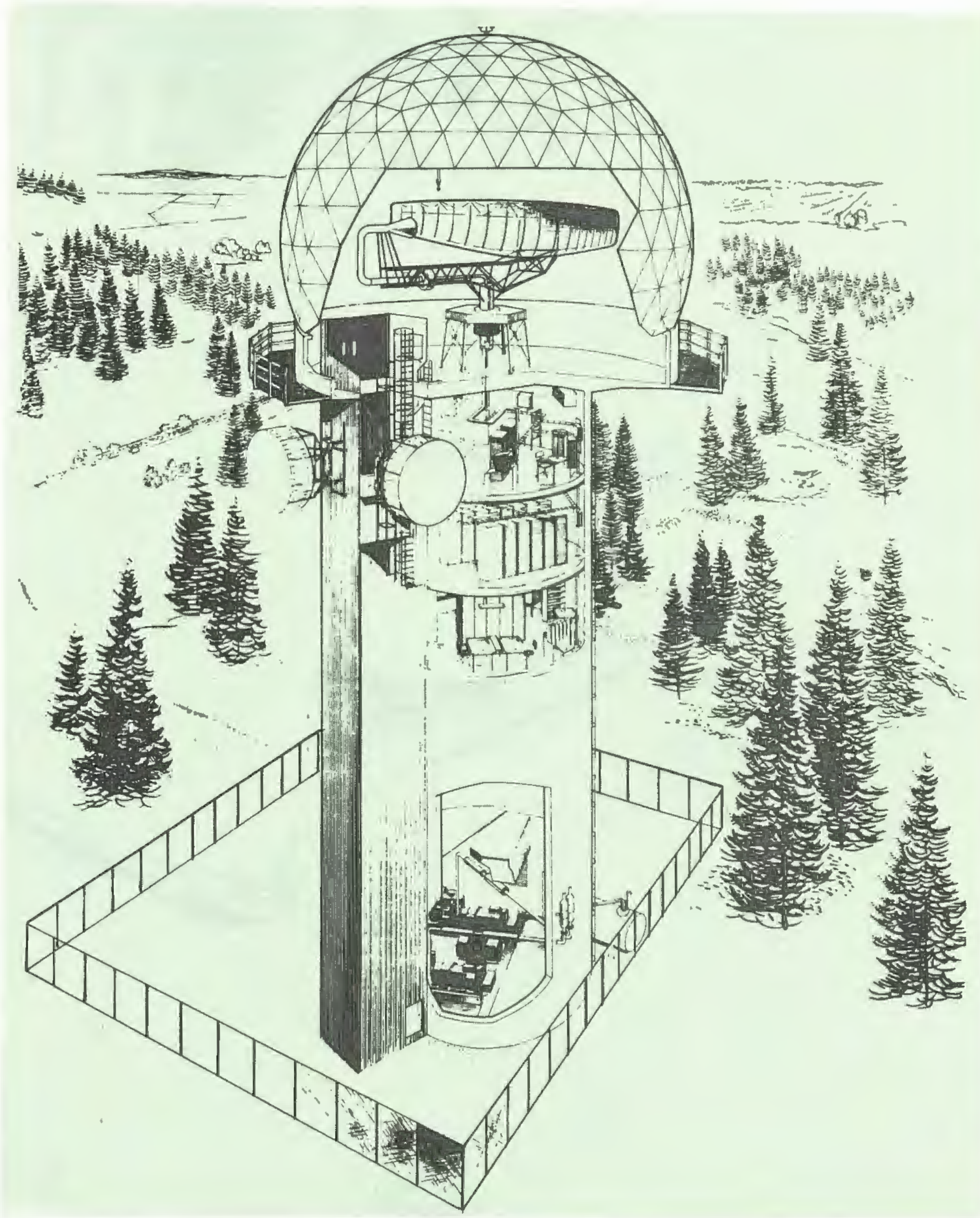


Figure 60. ATC radar station

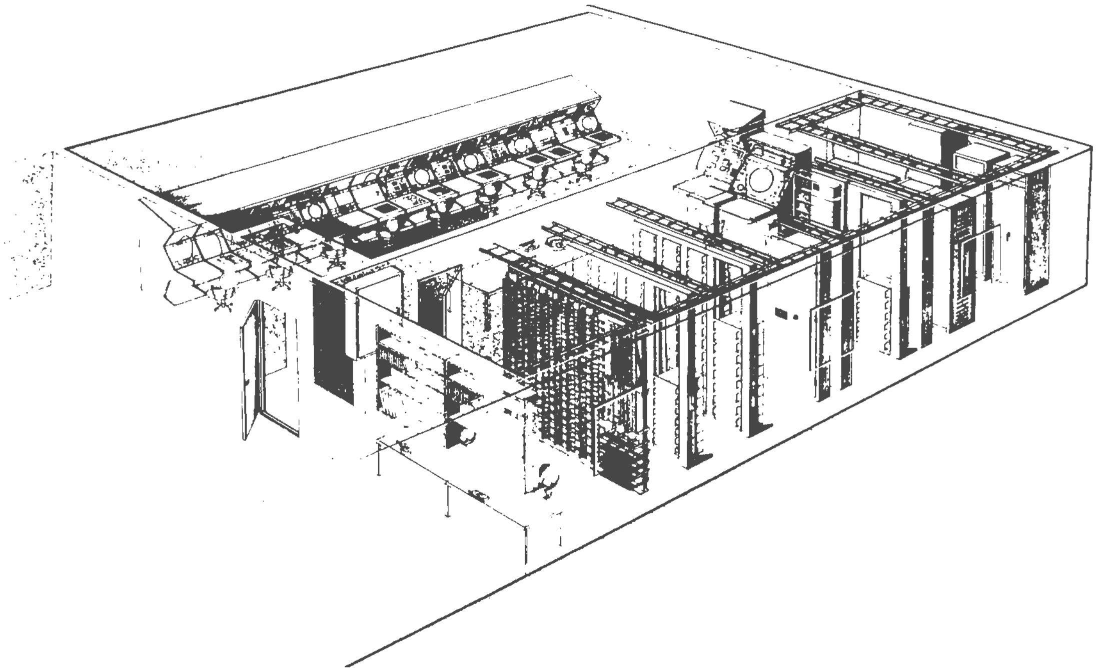


Figure 61. Operational subcentre

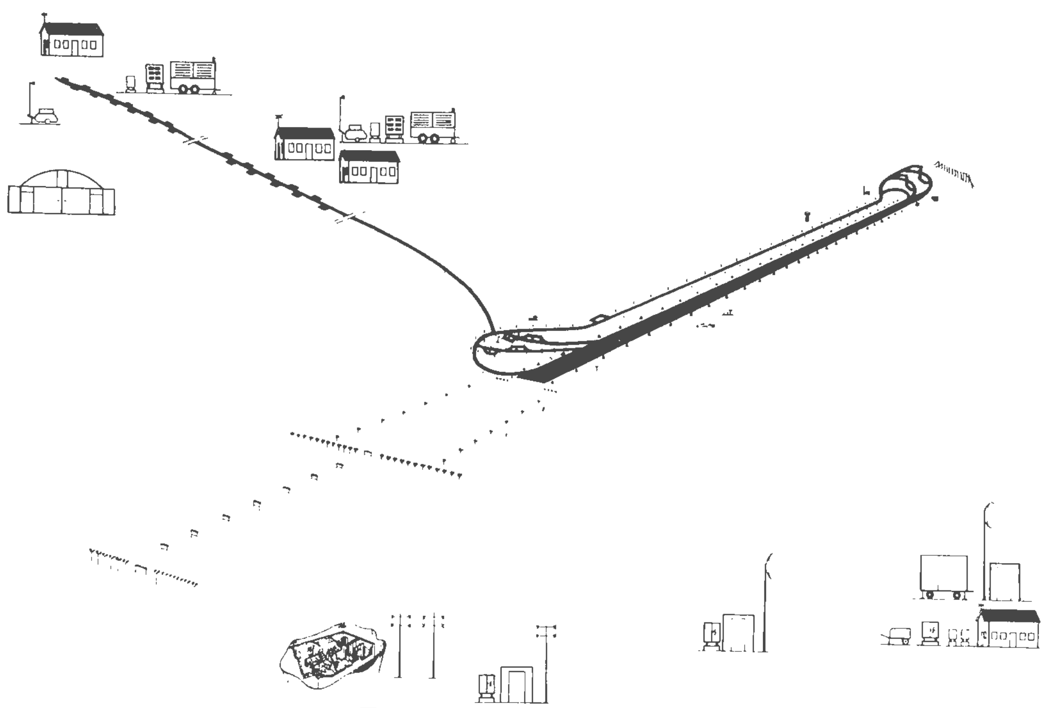


Figure 62. Air base electrical installations

Project Management

(See fig 63)

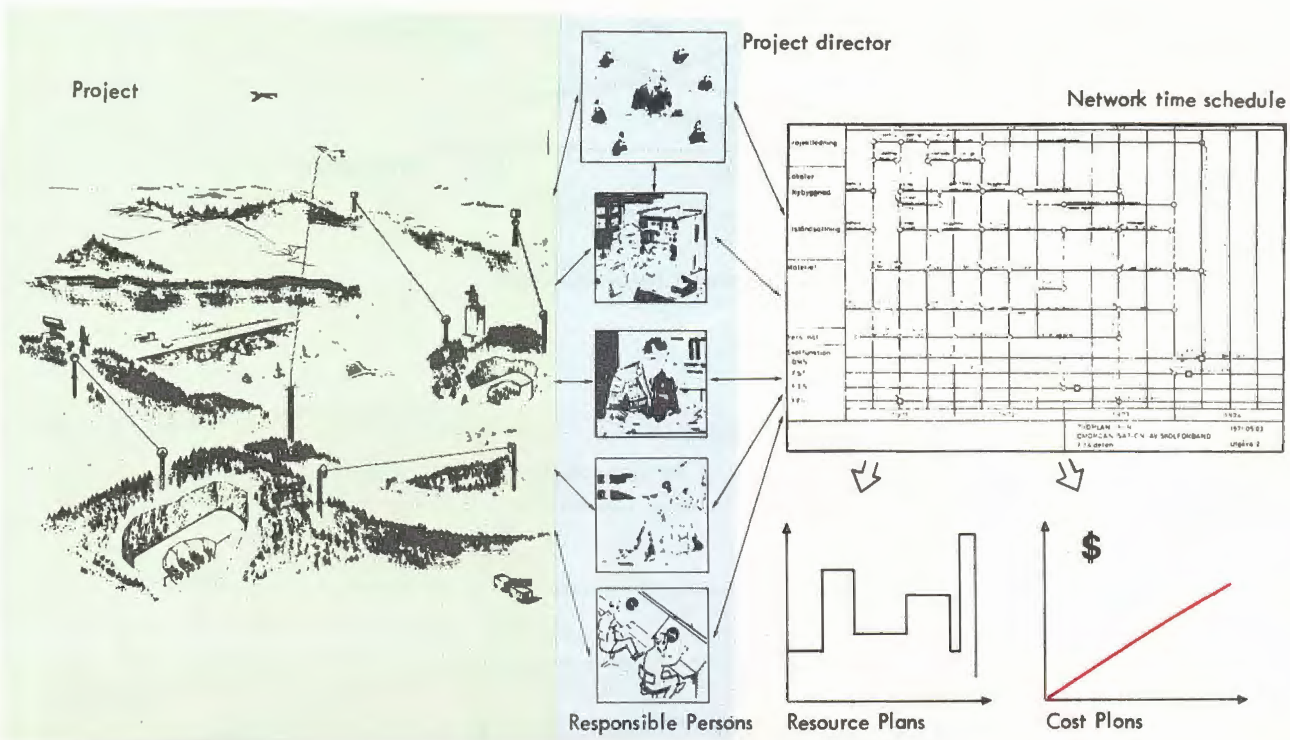


Figure 63. Time, cost, and resource planning

Maintenance Planning

(See figs 64, 65, 66)

Main steps in maintenance planning:

- Objectives
- Maintenance methods
- Preliminary requirements
- Preliminary maintenance quotations
- Coordination. Requirements
- Contractor's undertakings
- Quotations. Cost-effectiveness analysis
- Choice of contractor(s)
- Detailed maintenance preparation
- Need of resources. Evaluation
- Acquirement of resources
- Test in operation

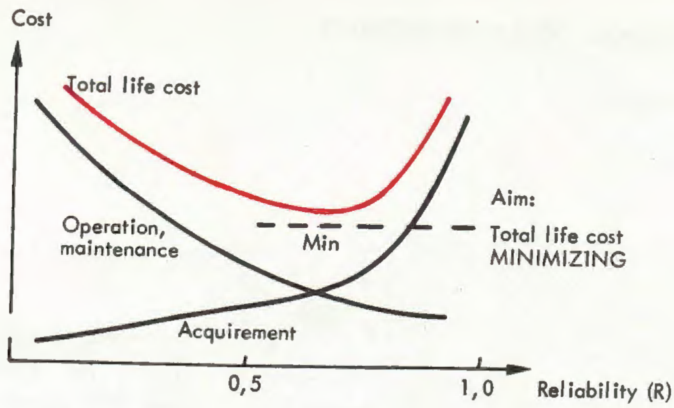


Figure 64. Minimizing total life cost

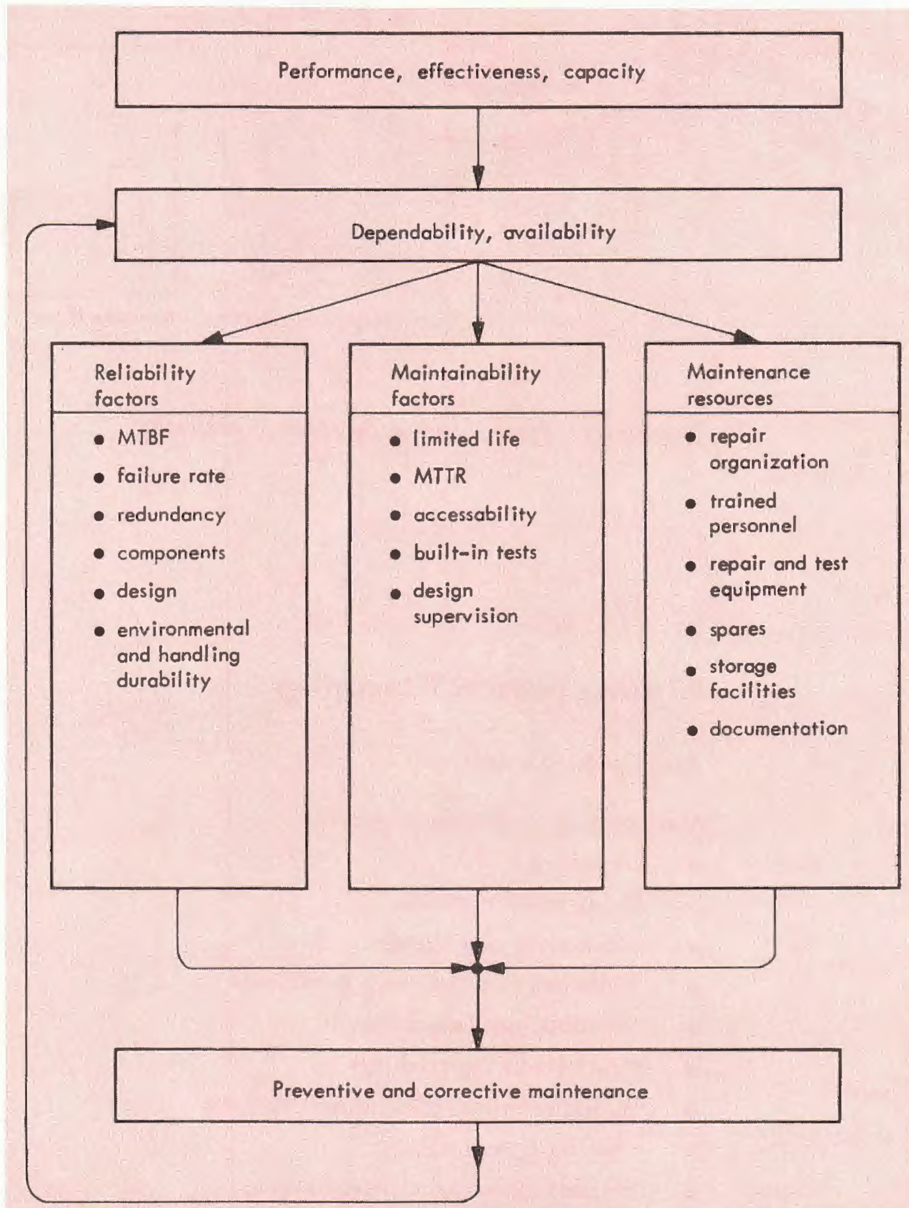


Figure 65. Diagram of maintenance and effectiveness factors

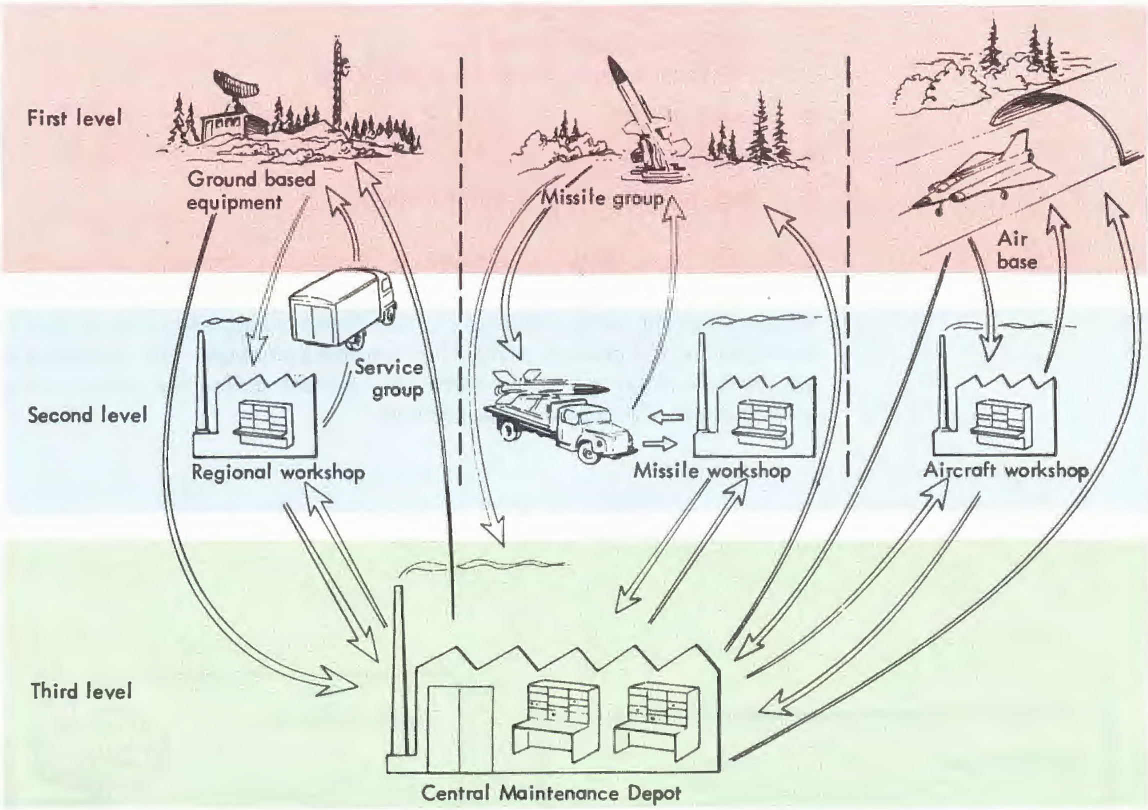


Figure 66. Maintenance levels, example

Testing and Evaluation

A command and control system for air defence is composed of many components and subsystems linked together by communication networks and operated by personnel belonging to different commands. The equipment and installations are furnished by different contractors and at different times. Finally the system components, such as radar stations, command centres, and communication equipment will be deployed at sites that are spread out over the whole country or a great part of it. It is therefore important to carefully plan and carry out extensive tests of different types (see figs 67 and 68). It is also necessary to evaluate the test results and to demonstrate the correct functioning of the system as a whole as well as its subsystems and parts (see fig 69). Some of the phases, activities, and points of consideration in a testing and evaluation program are:

- Contractor testing and/or customer testing
- Simulation and/or operational testing
- Equipment and subsystem testing
- Functional chain testing

- Overall system testing
- Various types of equipment and subsystem tests
  - Certification tests
  - Qualification tests
  - Preproduction tests
  - Lot acceptance tests
  - Individual acceptance tests
  - Critical weakness and reliability tests
- Test facilities
- Scheduling
- Data reduction and documentation

In the last phase of subsystem and system testing the using command in cooperation with the material administration or some other responsible procuring agency, will demonstrate the using command's (Air Force's) capabilities to operate the system according to the general goal set up for this command. The authority responsible for the evaluation will at the same time further define the effectiveness of the system in the operational environment.

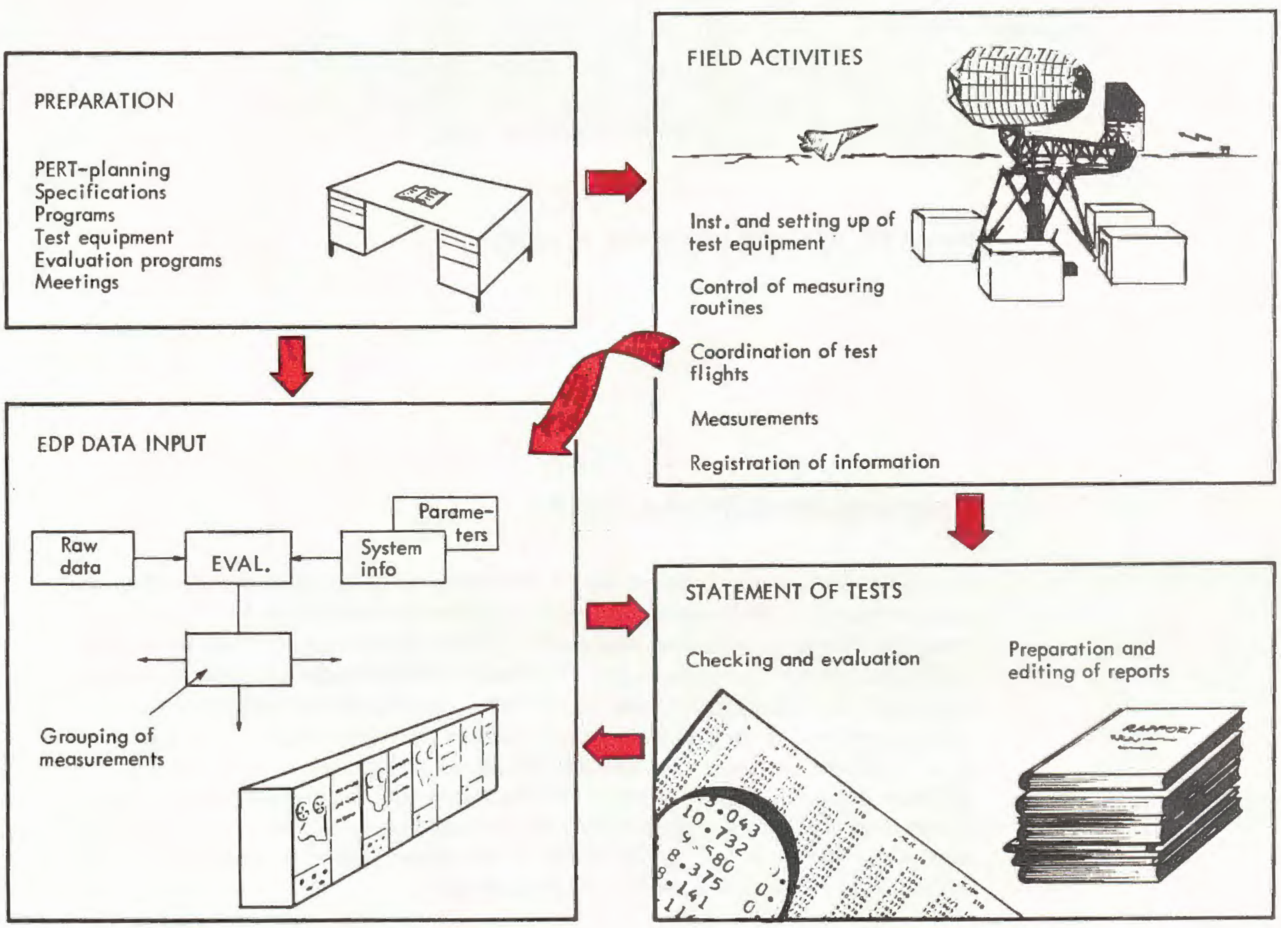


Figure 67. Testing and evaluation procedures

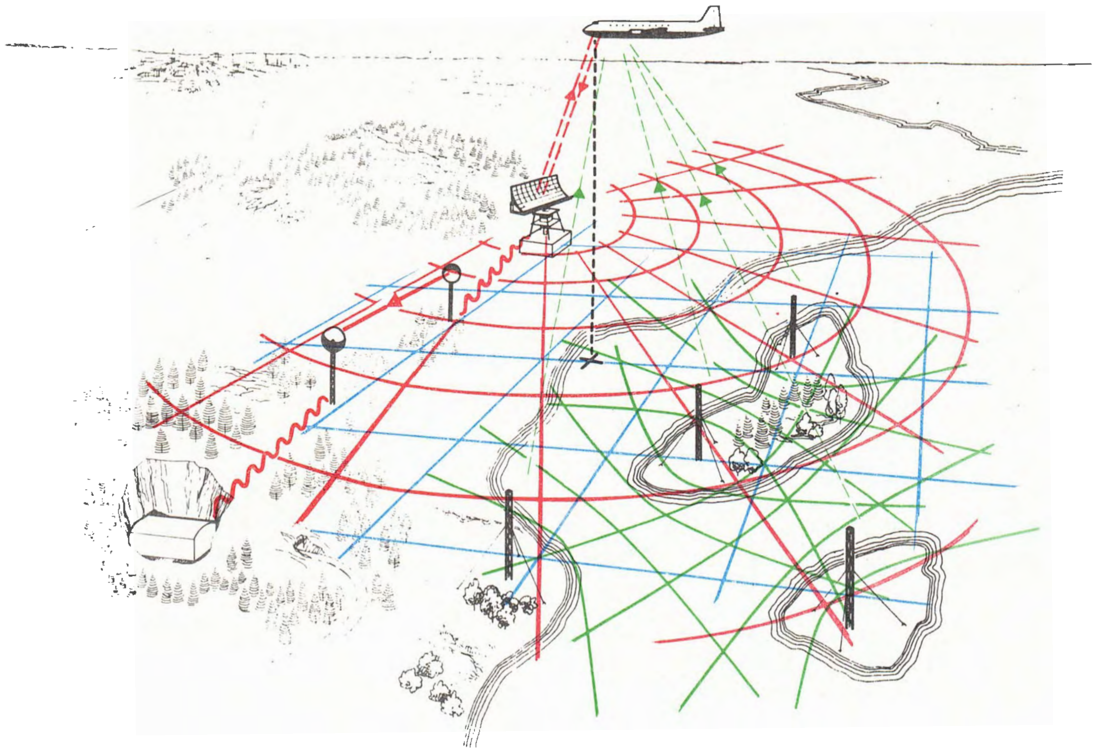


Figure 68. System testing. Radar position with reference to Decca chain

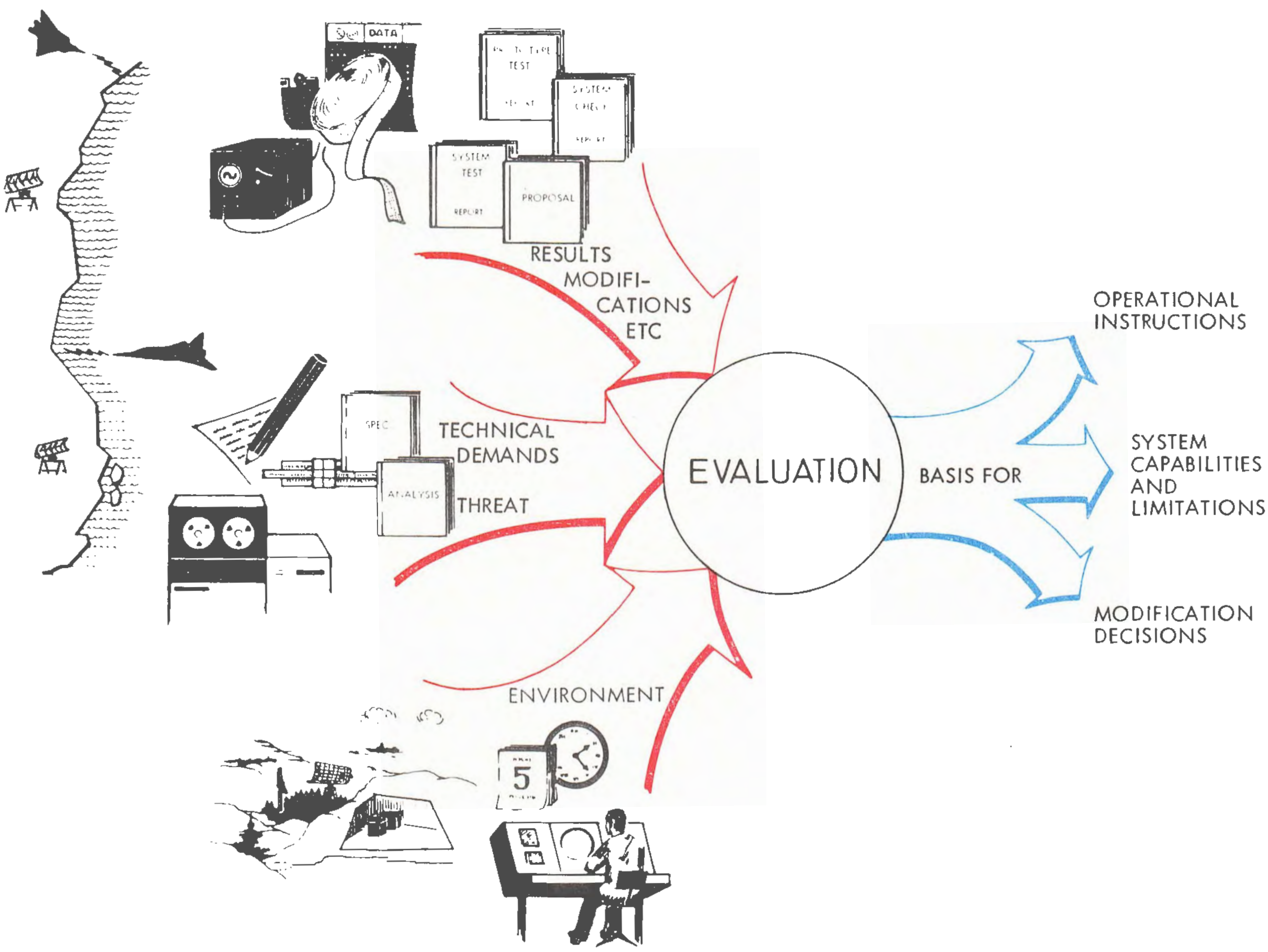


Figure 69. Principles of evaluation