Part IV
Principal Applications

MSCAN Fighter Radar (RDY Radar of the Mirage 2000)

19

Radar Applications and Roles

Chapter 2 gives an initial description of operational requirements, platforms, weapons, and systems functions. Before presenting the main specifications and technical descriptions of radar systems in Chapter 20, we list the principal aerospace applications in which radar plays a major role and discuss a number of them in this chapter.

19.1 Civil Applications

19.1.1 Space Systems

Satellite radars are used for

- observation and surveillance of the atmosphere
- observation and surveillance of the Earth's surface (land and sea), scatterometry, and altimetry
- meteorology
- satellite docking maneuvers, etc.

19.1.2 Air Transport Applications

Helicopter and aircraft radars are used for

- detection of rain or hail clouds
- detection of turbulence and wind shear
- air surveillance
- in-flight collision avoidance
- landing aids
- ground collision avoidance, etc.

19.1.3 Maritime Applications

Aircraft or helicopter radars are used for

- maritime surveillance, maritime search-and-rescue, anti-drug traffic operations

- pollution detection
- surveillance of coastlines and areas of economic interest, etc.

19.2 Military Applications

19.2.1 Space Systems

Satellite imaging radars are used for

- ground observation, detection, and target reconnaissance
- cartography, creation of 3-D Digital Elevation Models (DEM) of terrain
- strategic and tactical intelligence

19.2.2 Airborne Applications

Different categories of radar fitted to aircraft, helicopters, cruise missiles, or drones are used for

- air surveillance
- air superiority, interception and combat, policing the skies
- ground observation
- battlefield surveillance
- tactical support, ground attack, exclusion
- high- and very high-altitude penetration and bombing
- low- and very low-altitude penetration and bombing
- obstacle avoidance and landing aids

19.2.3 Maritime Applications

Airborne radars are used for

- maritime surveillance, vessel detection, and reconnaissance
- surface vessel attack
- submarine detection and attack
- coastline surveillance, tactical support, and ground attack
- air interception and combat, etc.

19.3 Examples of Applications

19.3.1 Ground Observation from Space

19.3.1.1 Operational Capabilities

One advantage of space-based radar is that it gives access to any part of the globe (depending on its orbit). It can be used to survey regions that, for various reasons, cannot be observed from an aircraft.

Its continuous presence in orbit ensures maximum coverage. The satellite is a permanent, repetitive, and systematic source of documentary intelligence. The ground segment must be sized accordingly.

Observation takes place in an incidence domain different to that of airborne radar and typically located between 15° and 80° (depending on operating modes). It minimizes the effects of projected shadows, makes it possible to observe land with very uneven relief, and, generally speaking, provides additional information.

If a small number of satellites is used, certain time performance is different to that of airborne systems. While real-time data transmission over a zone of interest is possible, the time needed to access the zone can be fairly long (several hours). Overfly time depends on orbit and cannot be changed at will. The data-refresh period is several hours.

19.3.1.2 Ultimate Aim of the Mission

The mission purpose is the expression of the operational requirements. Some examples are

- producing maps of industrial infrastructures and ports
- plotting maps
- detecting or recognizing vehicles
- detecting or recognizing aircraft on the ground
- detecting missile systems and defenses
- detecting activity, etc.

Operational requirements determine the characteristics of the radar and are the input data used to draw up the specifications. These specifications concern two main types of performance: image quality and time performance.

Chapter 14 describes the main parameters for image quality (resolution, linearity, radiometric resolution, contrast, signal-to-noise ratio, etc.). Table 19.1 gives some examples of performance over time.

Optimal image quality for a given mission cannot usually be determined using simple analytical relations. It requires an iterative operation similar to the following:

- definition of a reference radar based on preliminary theoretical analysis (transmitted power, antenna patterns, processing algorithms, etc.)
- use of simulation to produce test patterns corresponding to previously expressed operational requirements and well-defined image quality characteristics

TABLE 19.1. TYPICAL CHARACTERISTICS OF A GROUND OBSERVATION RADAR SYSTEM OPERATING IN SPACE

Time Performance	Average image take time (time between request and image take by the satellite)	Some 10 hours*
	Average age of information (time between image take and dissemination)	Some hours, real time possible
	Average revisit time (time between two successive takes of the same target)	Some 10 hours
	Overfly time	Imposed by orbit
Observation Conditions	Range of region observed	Some 100 km
	Sighting conditions	Imposed by orbit
Quantitative Performance	Coverage (dependent on operating time per orbit and on swath)	Some 10 000 km^2/h 24 h / 24 h
	Accessibility (dependent on orbit inclination)	For a polar orbit: Earth's surface (i.e., ≈ 5.10^{8} km^2 differed time)
	Swath width	5 to 500 km
Image Quality Performance	Incidence domain	15° to 80°
	Resolution	< 1 m to some 10 m
Aggression		Jammers, electromagnetic weapons
*Largely dependent on altitude and accessible incidence angle		

- psycho-visual analysis of test patterns using professional photo-analysts. This determines, for each situation, the different image quality parameters needed to meet each requirement. If necessary, the reference radar is modified to bring it into line with operational requirements.
- finally, sizing the radar to give an image quality capable of satisfying all operational requirements

19.3.2 Airborne Reconnaissance

With the advent of submeter resolution SAR sensors, SAR imagery has become a major source for military reconnaissance purposes. It is obvious that its all-weather/day-night capabilities make it invaluable for operational availability, especially in crisis periods when age of information is of crucial importance.

What has renewed the interest in such radars, however, is the ability of submetric modes to provide details about background and targets that were previously the unique privilege of optical sensors. In particular, at resolutions below 50 cm, the features of vehicles and planes begin to differ enough so that one is able to use SAR signature to recognize the class of a target (tank, fighter, truck, etc.) and sometimes to identify it (AMX-30 tank, Mirage F1 fighter, etc.).

Many articles on SAR automatic target recognition have been published in the past five years. The kind of performance one can expect from such technology is indicated in Novak (1997; 1999). To convince himself of the value of these SAR signatures the reader may also consult the Web site http://www.mbvlab.wpafb.af.mil, where various vehicles of different orientations at a resolution of 30 cm are freely available.

In fact, according to the various missions given to an SAR reconnaissance system, different modes have to be implemented. Table 19.2 provides some examples of different missions with the associated modes.

TABLE 19.2. EXAMPLE OF RECONNAISSANCE SAR MODES

<table>
<tr><th rowspan="2">Mission</th><th colspan="3">SAR</th><th colspan="3">MTI</th><th rowspan="2">Bandwidth (MHz)</th></tr>
<tr><th>Res. (m)</th><th>Swath (km)</th><th>type</th><th>Res (m)</th><th>Loc. (m)</th><th>Vmin (km/h)</th></tr>
<tr><td>Search of objectives / cartography</td><td>≈ 3</td><td>> 10</td><td>strip</td><td></td><td></td><td>NO</td><td>≈ 50</td></tr>
<tr><td>Search of objectives + activity assessment</td><td>≈ 3</td><td>10</td><td>strip</td><td>≈ 20</td><td>< 50</td><td>< 10</td><td>≈ 50</td></tr>
<tr><td>Ground- installation analysis</td><td>≈ 0.50</td><td>5</td><td>strip / spot</td><td colspan="3">NO</td><td>≈ 300</td></tr>
<tr><td>Target classification</td><td>≈ 0.30</td><td>> 2</td><td>spot</td><td colspan="3">NO</td><td>≈ 600</td></tr>
<tr><td>Target identification</td><td>≈ 0.15</td><td>> 1</td><td>spot</td><td colspan="3">NO</td><td>≈ 1 000</td></tr>
<tr><td>Surveillance / large-area cartography</td><td>≈ 20</td><td>> 30</td><td>scan</td><td>≈ 20</td><td>< 200</td><td>< 10</td><td>≈ 7.5</td></tr>
</table>

To illustrate the kind of clues that SAR images can bring to fulfill reconnaissance tasks, we provide an example of an operational scenario. To remain at an unclassified level, we shall stress background content and not military-target signature analysis.

The chosen scenario is the verification of the disused state of an airfield. For this purpose we have chosen the test site of Marigny (France), which was a former *NATO* airfield. Figure 19.1 provides a global view of the zone at a crude resolution. The different zones of interest are clearly indicated within the white box.

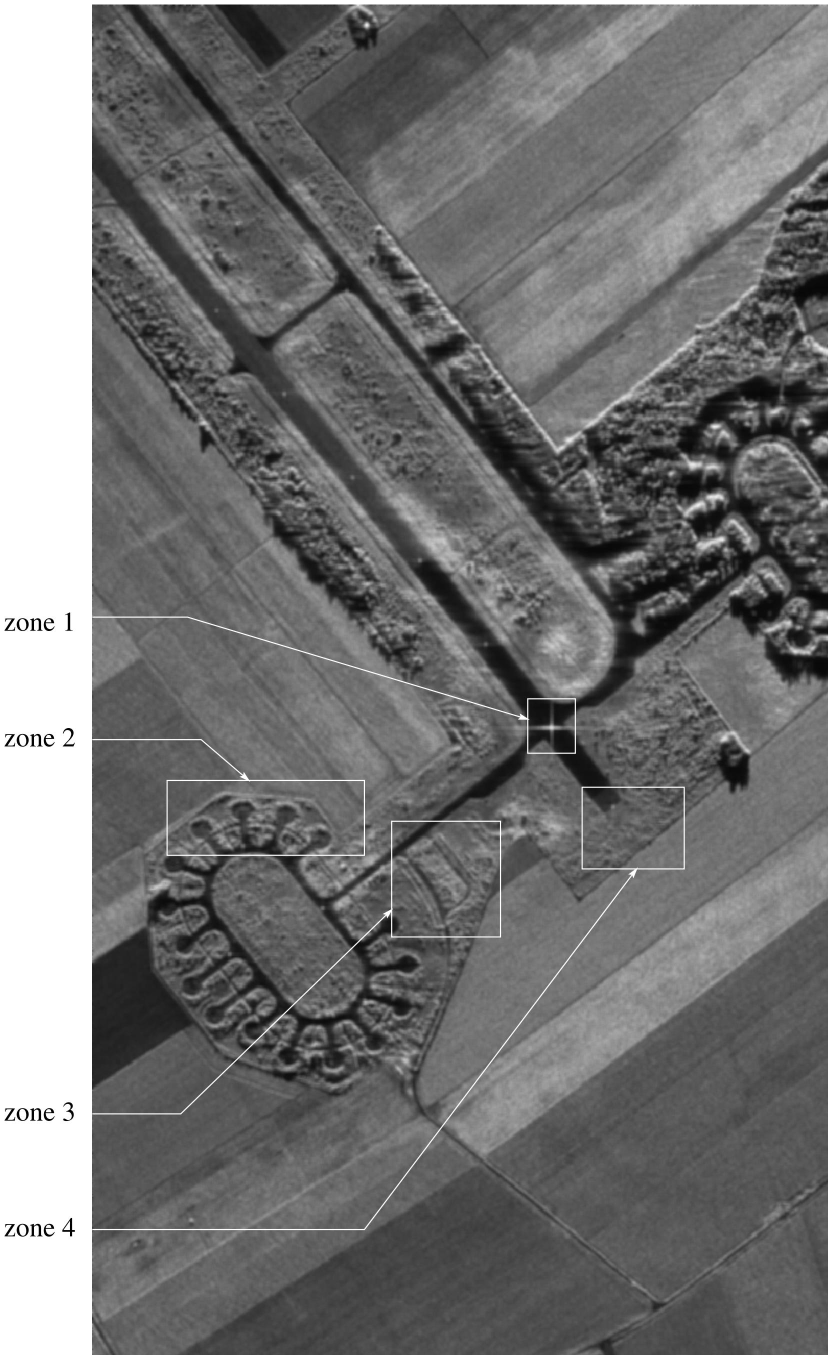

Figure 19.1 Global View of Marigny Airfield at Crude Resolution (Thales Document)

On the runway various trihedrals are placed for monitoring the SAR processing performance. Zone 1 corresponds to a large 5 000 m^2 trihedral. Seeing that all the images displayed are unweighted, one can see the range and azimuth side lobes associated with the 2-D sinc point-spread function.

We begin our investigation with Zone 2 displayed in Figure 19.2. This represents a part of the dispersal where the planes can park. One can clearly see that grass is growing between the patches of concrete. If we pay closer attention to the top left of the figure, we can hardly distinguish the communication paths that have begun to be occupied by the surrounding vegetation.

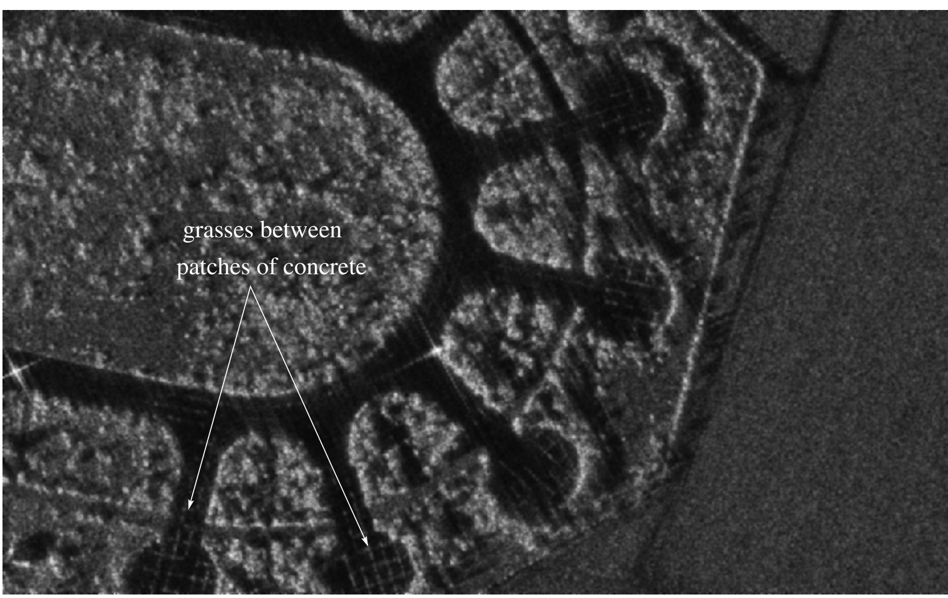

FIGURE 19.2 DISPERSAL AREA (THALES DOCUMENT)

Figure 19.3, associated with Zone 3, then shows a security area surrounded by its own fence. Now the three access gates are left open, which is another clue for us to state that this airfield is no longer in use.

Finally, Figure 19.4 shows the end of the crash runway and the airfield's external fence. One can see that shrubs are growing around the crash runway, which is incompatible with the security of the landing aircraft. The final sign that we point out is the presence of a discontinuity in the external fence.

Beyond the anecdotal aspect of this scenario, it is interesting to note the precision of the information one can get from submetric SAR imagery.

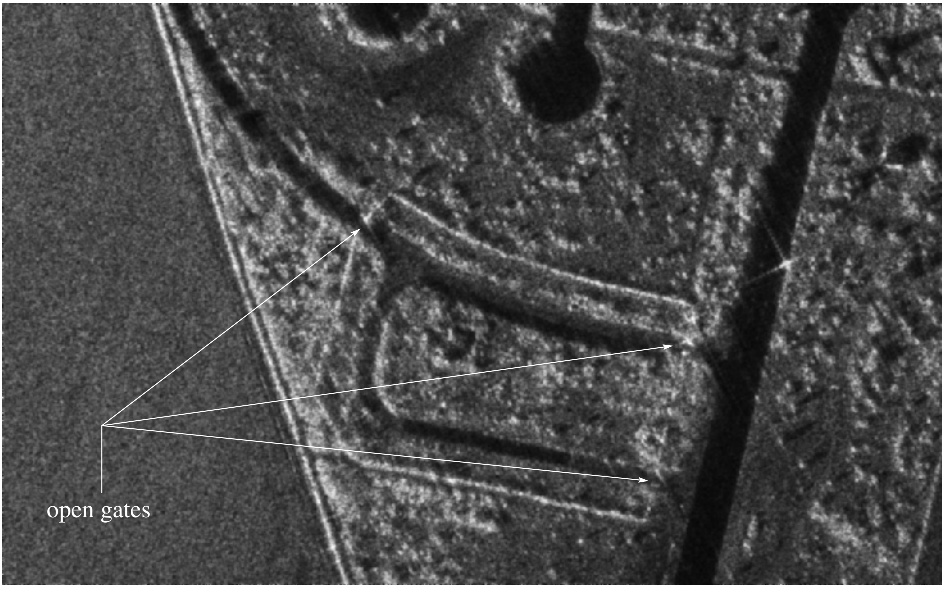

Figure 19.3 Security Area Protected by Its Own Fence (Thales Document)

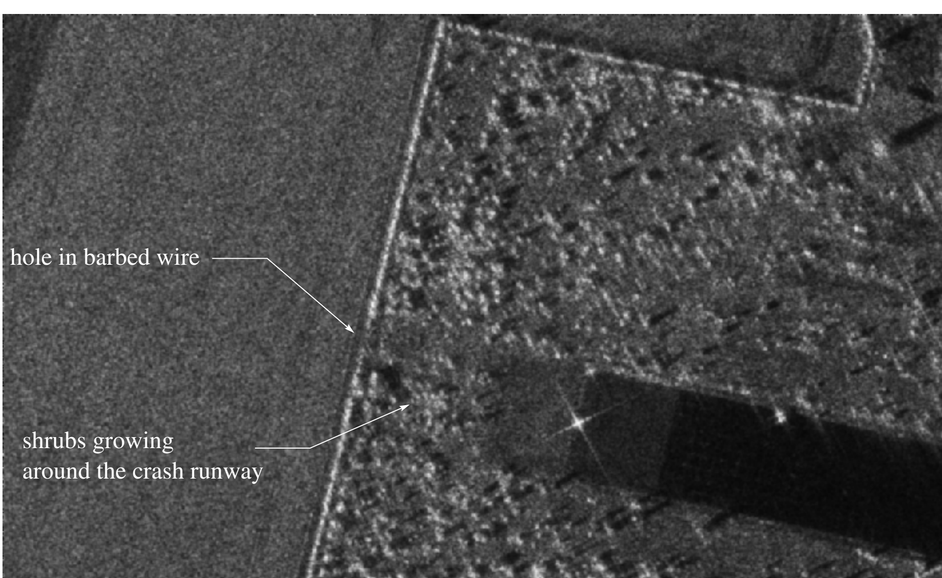

Figure 19.4 End of the Crash Runway and Part of the External Fence (Thales Document)

19.3.3 Air Surveillance

The purpose of air surveillance is to establish a target position over a territory or a theater of operations. It thus aims to detect, track, and identify all forms of aircraft (planes, helicopters, drones, and possibly missiles) flying over the zone observed and then to correlate tracks with information drawn from other sources (flight plans, other radar, sightings, etc.). If an aircraft is unknown or identified as an enemy aircraft, interception aircraft are alerted and sent in its direction. Air surveillance thus has a function similar to that of air traffic control. However, air traffic control is mainly concerned with navigation corridors and areas around airports, while air surveillance must cover all air zones, including targets flying at very low altitude with the aim of using land relief as a mask. This, added to the need to place the radar at high altitude to extend the radar horizon (curvature of the Earth), has led to the introduction of high-altitude airborne radar ($>$ 10 000 m) to complete the ground-based long-range radar network.

These systems, commonly known as Airborne Early Warning systems (AEW) have the following characteristics:

- *long range*: given the typically high speed of enemy aircraft, together with the time needed to identify them, alert a control center (which can be onboard the aircraft), prepare interception aircraft for take-off (e.g., two-minute warning), and the flight time needed to reach interception range and for interception itself, the system must have a range of several hundred kilometers ($>$ 300 km)
- *wide angular coverage*: the AEW has to cover several areas that can be spread over a wide angle in azimuth. Therefore, it requires an angular coverage of at least 150° on each side of the aircraft
- *very high tracking capabilities*: given the size of the area covered by the radar, several hundred aircraft can be present at one time
- *highly efficient ground-return rejection capabilities*: Chapter 7 showed how the need for ground return rejection is a major source of constraint for this type of application. The quality of spectral purity of the transmission-reception chain, the linear reception dynamic range, and the level of the side and far lobes of the antenna must be the highest possible (see Chapter 7).

The platform characteristics are

- *long endurance*: the need for continuous surveillance creates the problem of having a sufficient number of systems permanently operating in-flight to cover the zone in question
- *large payload*: apart from the fact that the platform must ensure an adequate power supply and be capable of carrying the required mass, installation of the radar antennas is a major problem. These must ensure the necessary coverage ($> 300°$ and $\approx 20\,000$ m altitude slices) regardless of obstruction by the airframe, wings, or engines

In certain contexts, the platform must be able to be flown from an aircraft carrier.

In addition to their detection function, these radar platforms can also act as command and control centers capable of management of the military air traffic, weapon systems allocation, and, in particular, handling the interception process itself by guiding the fighters.

Finally, an AEW system is a high-value target and must therefore ensure its own protection. Its large range and coverage domains mean it can detect air targets that pose a threat to its safety and control interception aircraft assigned to protect it. Moreover, it is usually fitted with self-protection equipment, such as threat detectors, chaff-and-flares dispensers, and towed decoys.

19.3.4 Maritime Surveillance

Maritime surveillance radar are used for the missions listed in Chapter 11.

19.3.4.1 Maritime Surveillance Missions

A maritime surveillance system usually comprises several devices, radar being one of the most important. The others are

- electronic warfare equipment—Electronic Support Equipment (ESM)
- active or passive acoustic equipment, launchable from the aircraft
- winched acoustic equipment when a helicopter is used as a platform
- forward-looking infrared (FLIR)
- cameras
- a Magnetic Anomaly Detector (MAD)
- a tactical computer
- operator workstations
- weapons (missiles, torpedoes, etc.)

The radar can be used continuously or intermittently, depending on the mission. The following examples, which do not seek to reproduce actual operations, aim to

- show different concepts of radar use
- show the complementary nature of the different items of equipment in the system

Search for Submarines Immersed at Periscopic Depth

The challenge is to detect the submarine while remaining undetected. This requires the combined action of the radar and the ESM. The plane flies at very low altitude (less than 1 000 feet) to minimize sea clutter. The radar completes one antenna revolution transmitting in panoramic mode every 5 to 10 minutes. This revolution is not repeated, as it would give enemy ESM the chance to confirm detection. Should an enemy radar be detected by the aircraft ESM, the radar is immediately switched over to sector scan mode in the direction of the signal. If target presence is confirmed, the maritime surveillance aircraft can head towards it and carry out its mission. If the detected target is a submarine periscope, the submarine will probably have dived before the plane arrives in the area. The chase thus continues using acoustic and magnetic equipment.

Surface Situation Initialization and Update

Discretion is not one of the main priorities for this type of mission. The radar operates in panoramic scan mode and tracks all detected targets using track-while-scan. If the radar is fitted with an ISAR mode, it can produce images of targets, thus building up its library. Generally speaking, the radar indicates worthwhile targets in the zone, as well as their speed and course. Maritime surveillance aircraft fly at medium altitudes (between 3 000 and 10 000 feet), compatible with the desired radar range and the constraints imposed by the other means of recognition, such as FLIR, photos, etc. If the system measures a temperature inversion while climbing (i.e., temperature increases instead of decreases after a given altitude), the aircraft should avoid flying above it in order to prevent signal extinction due to abnormal propagation of radar waves.

Surface Vessel Attack

In this type of mission, the aircraft must come close enough to the ship to get within the firing envelope of the air-to-surface missile. Of course, this must be achieved as discreetly as possible to avoid triggering the anti-aircraft response. To do so, the radar platform stops transmitting and flies at very low altitude (less than 100 ft.) to stay below the radio horizon of the ship's radar. Once within firing distance, the aircraft climbs to lock on to the target with its radar. The aircraft can then

- either use a *fire-and-forget* type missile, in which case it returns to low altitude and pulls away from the target as quickly as possible after firing
- or fire a radar-guided missile, in which case the aircraft must remain within radar visibility of the target until impact

19.3.4.2 The Radar Platform

A maritime surveillance radar system is relatively lightweight, between 100 and 150 kg for a modern radar. It can therefore be installed on a number of different aircraft. The three main types of platforms are

- turbo-prop aircraft (or even jet aircraft) weighing over 40 ton on take-off. These planes can be used for very long missions (up to 24 hours endurance in extreme situations) and have a wide radius of action (e.g., from France to the North Pole and back). They carry comprehensive weapon systems, with all the above mentioned equipment, and can store a lot of weaponry. They are designed to give optimum results when flying at very low altitude and very low speeds over the sea (very long wings). The system is operated by a crew of more than ten
- general aviation twin-engine aircraft weighing 10 to 15 ton on take-off. Usually designed for other missions, they can nevertheless provide a useful complement to a heavy aircraft flotilla. They can perform missions requiring less equipment or less endurance at a lower cost than heavy planes. They carry a crew of four to five
- helicopters: their advantage is their capacity to land on a vessel. They can therefore provide two types of protection:
    - against other ships, using their altitude to extend the ship's radar horizon
    - in anti-submarine combat, acting as remote ship equipment

  They also extend the vessel's weapon system by designating over the horizon targets for surface-to-surface missiles or by themselves carrying weapons. Their low speeds and limited radius of action means they are best suited to coastline or flotilla surveillance. The crew can be reduced to two or three only.

19.3.4.3 Installation

The best position for a maritime surveillance radar antenna is on an elevator located underneath the fuselage. The antenna can then be lowered during flight beneath the masks formed by the airframe. Vision is panoramic.

Installing an elevator, which means making a hole of approximately 1 m diameter in the airframe, is not always possible, particularly in pressurized planes. As a result, less advantageous locations, such as the aircraft or helicopter nose cone, must be used.

The radar units (transmitter, receiver, processing equipment, etc.) are installed in the cabin. The lack of major volume constraints in most situations has resulted in the development of standard unit formats. (Interception radars, on the other hand, are optimized to fit into the nose cone of a combat aircraft). Low power consumption (1 to 2 kW) is compatible with air-cooling systems.

19.3.4.4 Secondary Missions

A maritime surveillance radar also enables secondary missions, although the resulting performance is not as good as that of specialized radars.

For example, the long-range surface-target detection mode can be used to detect air targets, preferably in look-up mode. The low mean power of the radar and the presence of sea clutter limit range.

This mode can also be used to detect ground targets in desert zones or for reconnaissance over ground coastal areas. The presence of SAR/ISAR imaging can also prove advantageous for this type of mission.

Finally, a weather function (cloud and rain detection) is also generally available, using a main mode waveform combined with a specific processing method.

19.3.5 Battlefield Surveillance

In peace time or crisis, strategic intelligence services seek to acquire information concerning the potential enemy, e.g., infrastructure, concentration of forces, command posts, communications, etc. This information is obtained by various sensors such as visible or infrared cameras, SAR, and MTI radar. These sensors are placed on a variety of platforms such as planes, helicopters, and drones.

During conflict, the battlefield surveillance mission is to detect, locate, identify, and monitor changes in the enemy's resources: tanks and other vehicles, helicopters, motorized troops, air defense batteries, etc. It must enable target acquisition for the artillery or for tactical aviation forces. Information gathered by the different sensors is then transmitted to the ground, analyzed, and, in certain cases, correlated, etc. Results are then "merged" to facilitate decision making by command posts.

Radar modes adapted to the battlefield surveillance mission can be divided into two categories:

- MTI mode able to detect moving targets: vehicles, helicopters, and slow UAVs. The slower the platform speed, the greater the MTI effectiveness. Indeed, the best results are obtained when the platform is stationary. However, STAP technique, combined with long antenna, can compensate for aircraft velocity and give the required performance level to MTI radar on-board planes. It should be noted that in MTI mode, the detection domain is covered by the azimuth scan of the radar antenna and not, as with SAR, by platform displacement
- high-resolution SAR mode able to detect non-moving targets. The platform used must be able to achieve certain minimum speeds (see Chapters 14 and 15)

Ground surveillance radar systems on-board planes are now fitted with both types of modes. They are interleaved to provide simultaneously the moving targets map and radar images of the ground in strip-map and spotlight modes. Planes have the advantage of flying at high speed and high altitude (between 30 000 ft. and 50 000 ft.), allowing high performance SAR imaging and coverage of wide areas. The length of the antenna limits observation to both sides of the aircraft; this means that tracking of moving targets is not continuous during the turns of the radar platform.

Helicopters are specialized in MTI, covering 360° in azimuth. An advantage is continuous observation along the whole orbit trajectory, even during the turns. Thanks to the very low speed, observation axis are chosen to minimize the masks of terrain; the helicopter can be maintained continuously in view of a given area. Finally, it does not required an equipped airfield; it is operated from any type of terrain or Army base, where armored vehicles or other helicopters could be located.

Given that radar is an active and therefore non-discrete sensor, in order to reduce the vulnerability of its platform, it must be stationed well to the rear of combat zones, e.g., at 50 to 150 km stand-off range. In addition, the platform must be at a fairly high altitude (4 000 m to 15 000 m) to reduce shadowing by the terrain.

Note that information supplied by airborne radars can be frequently renewed under any weather conditions, which is vital for providing real-time information for maneuvering corps and tactical air units. The same is not true for space-based sensors; they are subject to the temporal and spatial constraints of satellite orbits.

Instantaneous Coverage

Figure 19.5 shows observation conditions with respect to the operational altitude of various platforms, where

- H is the platform altitude
- θ_D is the depression angle
- θ_{0E} is the elevation angle beamwidth
- R is the radar slant range
- R_S is the swathwidth
- $R = H \,.\, \text{cosec}\, \theta_D$, $R_S = R \,.\, \theta_{0E}\, \text{cosec}\, \theta_D$ (on ground level)

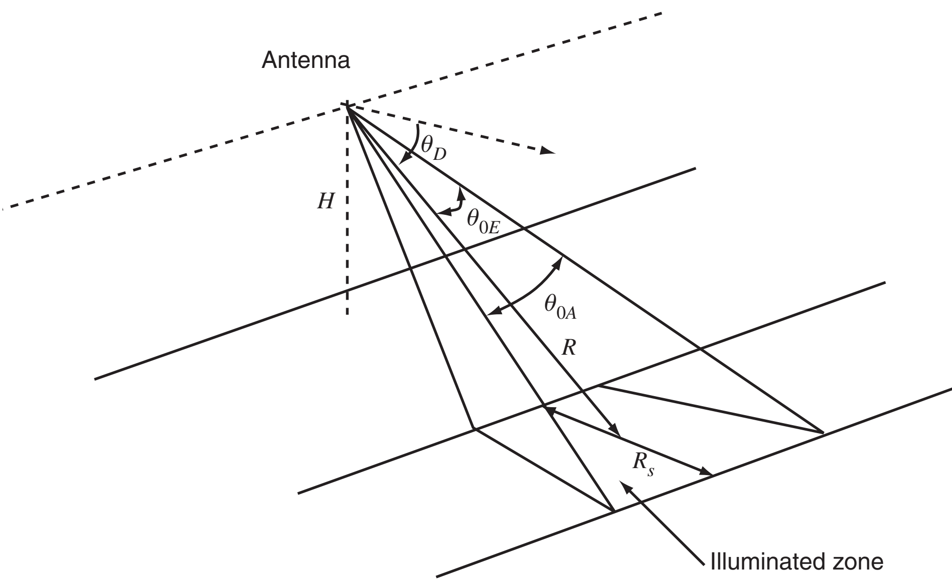

Figure 19.5 Radar Footprint on Ground

Take two examples:

- SAR is on-board a *plane*, where $H = 10$ km, $\theta_D = 8°$ and $\theta_{0E} = 10°$. This gives $R = 72$ km and $R_S = 90$ km

  Platform safety can be ensured. There is some shadowing and the data update rate is sufficient given that detection and reconnaissance concern mainly stationary or slow-moving targets
- MTI is on-board a *helicopter*, where $H = 3$ km, $\theta_D = 3°$ and $\theta_{0E} = 3°$. This gives $R = 58$ km and $R_S = 58$ km

  Platform safety can be ensured, the terrain and the infrastructure provide numerous masks, and, if safety is ensured, detection and positioning of moving targets can be almost continuous

19.3.6 Air Superiority, Interception, and Combat

Air superiority, interception, and combat are mainly air-to-air missions. There are others, some of which cover all or part of previously described missions. Their names and definitions vary according to the situation, and army and weapons system in question (coverage, general destruction, etc.). We shall not dwell on this subject, although the escort and airspace policing missions merit special mention.

The airspace policing mission, operational in peacetime, in all weather and after approach navigation, consists of visually identifying doubtful aircraft, both civil and military, entering or overflying territory.

The escort mission, which usually occurs at medium altitude, involves the protection of a friendly ground-attack airborne formation.

Using target designation supplied by ground-based or airborne equipment (AEW), the interception mission requires aircraft, either landed or in flight, to engage and destroy one or several planes that enter a friendly zone at any altitude. This mission requires a weapons system with highly effective components (platform: high climb rate, radar: long capability detection range, weapons: medium-range missiles with large differential height, etc.).

The air superiority mission aims to destroy all types of enemy aircraft. It is mainly performed at medium and low altitudes. It is an offensive mission that involves the location and engagement of an enemy aircraft in order to destroy it while in flight. It takes place over friendly territory or following penetration of enemy territory.

Combat, which can be the final phase of the two previously described missions, takes place at short range ($<$ 10 NM). It may begin face-to-face (front attack), but one of its aims is to take up position behind the enemy (tail attack) to reduce relative speed and cross speed and to ensure its own safety. Weapons used are very high-speed short-range passive (IR) or active (EM) missiles, or possibly a gun, which requires the attacking aircraft to come into line with the enemy aircraft. If the enemy aircraft is destroyed, the proximity of the attacking aircraft puts its safety at risk, and it must therefore be able to "pull out" rapidly. Both the platform and the missiles for this type of mission must be highly adaptive. The radar must be able to detect and track the target in a wide angular domain, with high cross speed and rotation velocities (see Figure 19.7).

In order to carry out these air-to-air missions, the radar must be placed inside the aircraft nose cone, where it is not masked. It is "protected" by a radome that is transparent to EM waves (in the radar bandwidth), and whose shape complies with the requirements of the airframe manufacturers and radar engineers.

The role of the radar in these missions is to

- search, either autonomously or using target designation, in given angular and range domains
- detect targets in all weather (with a very low false-alarm probability), regardless of platform and target altitude
- track one or several targets simultaneously
- identify the parameters of the tracked target: range, radial velocity, acceleration, velocity vector, etc.
- transmit these parameters to the weapon system so as to
    - establish the degree of threat posed by the targets
    - identify the target to be attacked first
    - select the most suitable available weapon
    - continuously compute the firing envelope of the chosen weapon
    - draw up a navigation function and provide orders to be followed by the pilot
    - trigger firing once the target is inside the firing envelope
    - determine the disengagement order
    - select the second target to be engaged, etc.

If the selected missile is semiactive, only one continuous tracking action can be engaged, as the missile homing head requires permanent target illumination. With missles with active seeker (radar), several targets can be simultaneously engaged (several missiles in simultaneous flight). This requires the use of a multitracking radar that supplies the missiles with the parameters of the targets for interception.

For some targets, at certain presentations, a radar in velocity search or continuous tracking mode can identify the target through spectral analysis of its RCS, this being modulated by its turbine blades (see Chapter 20).

Figure 19.6 shows an example of wide-range autonomous search (without target designation) using a radar fitted with a mechanical scanning antenna. The altitude interval covered, h, is proportional to the range and angular domain scanned in elevation.

A radar with a 50 NM range for targets of 5 m^2 RCS, fitted with a 60 cm diameter circular antenna whose beam at 3 dB is 3.5°, and scanning with four elevation lines (crossing over at 2 dB), will thus cover an angular elevation domain of 11.5° at 3 dB, or 0.2 radian. At 50 NM, this corresponds to an altitude segment, h, of 60 000 feet. This is far from covering all possible penetration altitudes, which can attain 100 000 feet. If

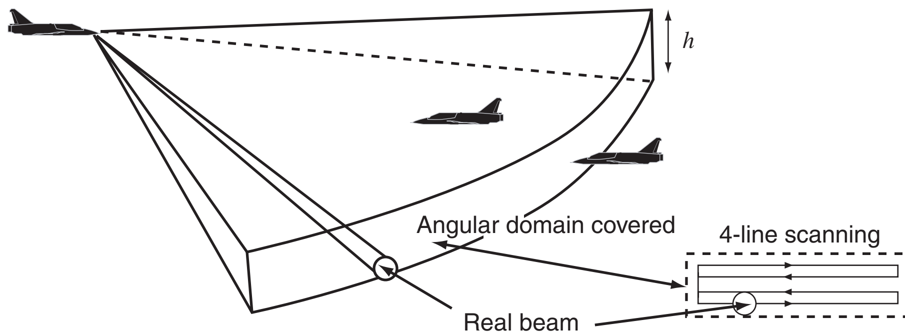

Figure 19.6 Autonomous Wide-range Search

the RCS of the target is less than $5m^2$, the detection range and altitude segment are reduced. This simple example shows the limits of mechanical scanning, and the advantages of target designation or of patrol flights with breakdown of the altitude segments to be monitored. It also illustrates the advantages of electronic scanning. Moreover, with antenna scanning of $\pm$ 60° in bearing at 100°/s, the total exploration time can be as long as 5.6 seconds (including the time taken to reverse the antenna scanning direction, which is approximately 0.2 s).

Figure 19.7 shows an example of search domains required for rapid acquisition of a hostile aircraft (in a close combat situation). The pilot selects these domains with regard to the conditions in which he can engage the enemy. They are suited to the use of a mechanical scanning antenna. In order to reduce reaction time, the three-axis tracking lock-on feature of the radar is automatic as soon as a target is detected. In a dogfight situation, the roll axis (if it is mechanical) is blocked as it has limited angular possibilities (e.g., $\pm$ 110°).

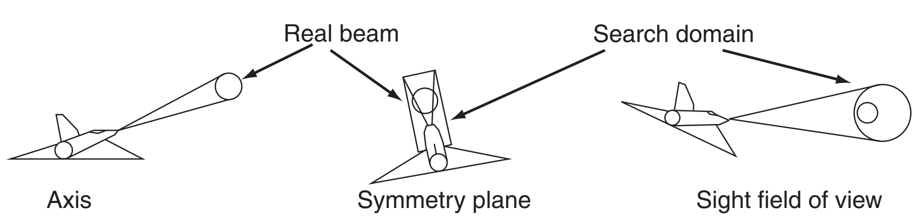

Figure 19.7 Search Domains in Close Combat

19.3.7 Tactical Support, Ground Attack, and Interdiction

Tactical support, ground attack, and interdiction are all air-to-ground missions. These offensive missions are generally performed by aircraft in formation at medium to low altitude (> 1 000 feet). Their aim is to destroy or neutralize ground targets such as bridges, infrastructures, airfield runways, tank formations, ground-to-air batteries, etc. These missions require

- detailed mission preparation (knowledge of the tactical situation)
- high-performance navigational resources
- air protection (escort)
- sophisticated countermeasures for the entire formation (powerful accompanying jammers)
- weaponry adapted to the targets, such as antiradar missiles, runway destruction bombs, rockets, laser-guided bombs, laser-guided air-to-ground missiles, etc.

In these missions, apart from the escort that is provided by air superiority aircraft (radar air-to-air function), the role of the radar is to

- perform ground mapping with monopulse sharpening of the real beam
- update the inertial control system with characteristic echoes if GPS is not available
- provide assistance for low-altitude navigation by means of "contour mapping" modes
- detect and lock on to contrasted fixed echoes in continuous tracking mode
- detect and track moving ground targets
- perform telemetry on an optically selected target (air-to-ground ranging)

A radar system uses only air-to-ground modes for these missions. However, in order to ensure self defense in close-combat situations using short-range missiles (IR, EM) or gun fire, the radar must have the air-to-air modes required for enemy acquisition and tracking; that is, the radar must be able to search along the axis, sight field of view, and symmetry plane and do continuous tracking. Each of the previously described air-to-air and air-to-ground modes can use low-PRF waves.

Should the tactical support aircraft be required to engage enemy helicopters, its on-board radar must be able to detect them either from the RCS of the airframe, or from the RCS of the main rotor blades. In the first case, moving ground-target detection and tracking modes are sufficient (except when hovering). In the second case, the use of a specific air-to-air mode adapted to the RCS characteristics of the blades is required. Such characteristics are

- a very brief appearance (between 50 and 400 μs)
- a wide spectrum (between 10 and 20 kHz at X-band)
- a stable repetition frequency (between 10 and 40 Hz, depending on the helicopter)

On the actual battlefield, tactical support can also be provided by helicopters flying in formation and armed with machine guns, guns, rockets, or air-to-ground missiles. However, the sensors used for fire control are optical or optronic and a radar can be used to ensure omnidirectional surveillance and target designation in air-to-air mode.

Figure 19.8 illustrates the "contour mapping" modes used at low altitude (500 to 2 000 feet). In this case, radar's role is to detect natural and man-made obstacles along the aircraft flight path and to determine their altitude so as either to enable the aircraft to overfly the obstacles with sufficient clearance to ensure its safety, or to avoid them. Although the mission is generally prepared in sufficient detail, some obstacles may not be listed. Similar, the plane may have to fly off-line outside the zone covered by mission preparation. Contour mapping provides a means of specifically displaying (e.g., in color) echoes located above and below the mapping areas. Three forms of contour mapping can be used:

- contour mapping (1) stabilized in the horizontal plane

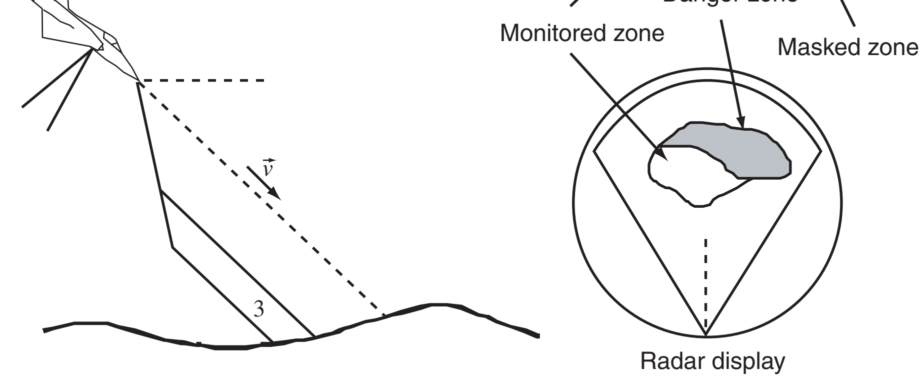

Figure 19.8 Contour Mapping Modes

- contour mapping with spatula (2) stabilized in the horizontal plane but whose action is reduced depending on range to avoid identifying high-altitude obstacles too early. Indeed, in enemy territory, safety is increased when the plane can fly at low altitude to take advantage of masks formed by land relief.
- contour mapping slaved to the aircraft velocity vector (3). This allows perfectly safe blind penetration, e.g., through clouds.

The pilot is free to choose the clearance altitude. He must navigate so that the detected ground is located between h_1 and h_2, thus optimizing safety with regard to land relief and enemy weapons. The pilot navigates in the vertical and horizontal planes; the radar simply supplies information. The altimeter, whose measurements arrive too late to be able to anticipate navigation, helps to increase safety over certain zones for which the radar supplies practically no information, such as a calm lake. Moreover, in situations of blind penetration, altimeter measurements are practically meaningless, unless correlated with a digital elevation model of terrain.

The contour mapping planes are horizontally stabilized with inertial navigation system data. The range domain covered must be at least 10 NM and the possible bearing domain must be at last $\pm\ 60°$. In elevation, two scanning lines covering 10 mR can be used for detection within an altitude segment of 6 000 feet at 10 NM. There is no detection below 3 NM, but previously detected echoes are stored and displayed as the plane advances. The map is thus complete.

19.3.8 Very Low-altitude Penetration

Low-altitude navigation ($>$ 500 ft.) cannot be used to penetrate far into enemy territory and still maintain required safety levels with regard to enemy fire power. However, in order to best take advantage of ground masks and to increase velocity, etc., the aircraft should fly as low as possible (between 200 and 300 ft.).

Three complementary actions can be taken:

- *terrain following*, which corresponds to navigation in the vertical plane
- *terrain avoidance*, which takes place in the horizontal and vertical planes
- *threat avoidance*, which involves navigating along a flight path in order to fly past enemy ground-to-air installations at sufficient range to ensure safety

If mission preparation were perfect—that is, if each element required for very low-altitude navigation were known (such as land relief, pylons, cables, ground-to-air batteries, including moving batteries, etc.)—and if navigation resources were also perfect (“digital file of terrain,” inertial navigation unit updated using GPS, etc.), the role of the radar would be reduced to a minimum, especially as it is not discrete.

However, because mission preparation is never perfect, and because the penetrating aircraft must ensure its own protection, the specialized radar with which it is fitted plays a major role. Not only must it detect all forms of land relief, it must also, and most importantly, detect pylons, their tops in particular. The radar’s contribution would be perfect if it were also able to detect cables strung between pylons. Finally, its performance must not be affected by rain clouds nor by rain itself. Unfortunately, this is far from being the case: a radar operating in X-band or Ku-band cannot detect cables, and a radar in W-band, although able to detect cables and pylons with sufficient resolution, is more sensitive to rain and less well-suited to ground detection over a large domain. A multipurpose system must therefore be fitted with two types of radar.

For terrain following, a mechanical antenna radar can be used. However, in order to perform the terrain avoidance mission under satisfactory conditions, an electronic scanning antenna is required because

- the angular domains to be explored are large, both in azimuth (± 60°) and in elevation (± 15°)
- a fine beam is required to obtain good resolution, particularly in elevation
- the detection-data refresh rate must be sufficient in each direction

Figure 19.9 gives an example of terrain avoidance with navigation in the vertical and horizontal planes.

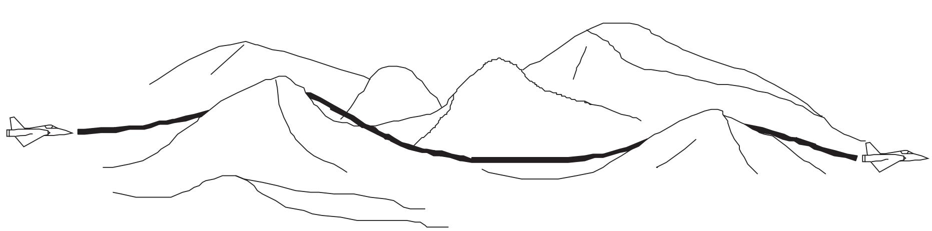

Figure 19.9 Terrain Avoidance

Threat avoidance is part of mission preparation, which determines the safest flight path prior to the mission. Other than in exceptional circumstances, the radar cannot identify enemy ground-to-air resources. However, the aircraft electronic counter-measures can detect, identify, and if necessary, jam enemy battery surveillance and tracking radar.

In terrain-following and especially terrain-avoidance missions, the crew must navigate under difficult conditions. However, from all the available data the weapon system can compute navigation functions used either for automatic piloting, or manual piloting should the pilot prefer to take control. In order to ensure maximum safety, clearance orders may be added to these navigation functions. These must be a trade-off between safety on the terrain being overflown, requesting a minimum altitude of flight, and enemy air defense efficiency, which increases with the flight altitude.