TITLE: Mission Planning Technology

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Erik Berglund
Swedish Defence Research Agency
172 90 Stockholm, Sweden
erik.berglund@foi.se

Summary

Some important aspects of mission planning are briefly outlined. More detailed discussions concern the missile's ability to avoid enemy air defences and to resist point defence.

Both the option of using low observables technology and the option of using terrain masking at low altitude are found to be viable techniques to avoid enemy air defences. It is argued that it is useful for the missile to employ countermeasures, such as manoeuvres, in the final kilometres.

The new threats to missiles posed by GPS jamming and anti-sensor lasers are briefly outlined.

A short discussion on the possibilities for mission planning opened up by the progress in information technology is included.

Introduction

Mission planning forms an important part of a successful strike with long range stand-off weapons. The most crucial aspects of the mission planning is, of course, to make sure that the missile finds its target and that it survives up until impacting the target.

The problem of penetrating enemy air defences is of concern for most sorts of aerial vehicles: manned aircraft, unmanned aerial vehicles (UAVs) and missiles. In particular manned aircraft and anti-ship missiles, have long faced the problem of penetrating advanced enemy air defences. Long range strike missiles are, in most scenarios, likely to face some enemy air defences.

Enemy air defences are often multi-tiered systems made up by interceptor aircraft, surface-to-air weapons, and electronic warfare.

The problem of defence penetration can basically be divided into:

- Destruction/suppression of the enemy air defences
- Avoiding enemy air defences
- Surviving enemy air defences

The following text will first focus on defence penetration by long range, stand-off strike missiles. Most of the discussion is, however, applicable also to other aerial vehicles. Then follows a discussion on a more network oriented approach to missile employment.

Suppression of Enemy Air Defences

Suppression and possibly destruction of enemy air defences plays an important role in air warfare. Long range strike missiles are likely to be used against the enemy air defences in conjunction with other components such as electronic warfare. Enemy air defences could also be suppressed by various means to facilitate an attack by strike missiles on other targets.

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Avoiding Air Defences

A common means of defence penetration is to attempt to avoid detection until it is too late for the defences to react in an effective manner. Avoiding, or delaying, detection can be accomplished by various means, e.g.:

- Low observables.
- High altitude, exploiting altitude limitations in threat sensors.
- Low altitude, exploiting terrain masking and propagation properties.

The predominant sensor used in air defence systems is the radar. Other sensors are infra red search and track (IRST) and radar warning receivers (RWR).

The detection range of a radar depends heavily on:

- Radar parameters (power, frequency, gain, noise levels etc)
- Antenna height
- Sea state (at sea)
- Terrain (on land)
- Atmospherical conditions
- Target altitude
- Target radar cross section (RCS)
- Electronic warfare environment

The radar equation in its simplest form gives the maximal range in free space as:

$$R_{\max} = \sqrt[4]{\frac{PG^2\lambda^2\sigma}{(4\pi)^3 S_{\min}}}$$

where
P is the power of the radar
G is the antenna gain of the radar
λ is the wavelength
σ is the target radar cross section (RCS)
$S_{\min}$ is minimal detectable returned signal

Low observables technology can be used to reduce the radar cross section of the strike missile. A combination of careful design of the geometrical shape of the missile and application of non-reflective materials can be used to reduce the RCS. The radar equation gives that a tenfold reduction of the RCS results in a reduction in radar range of 44%.

The predominant US concept of avoiding detection currently seems to be based on stealth technology and high altitude operations. This is a concept of operation that exploits the fact that most surveillance radar systems have been designed to detect normal targets up to reasonable altitudes, say 20,000 meters. As the detection range of the radar is reduced against stealthy targets, the altitude limits are also reduced. This makes it possible to fly above the ceiling of the radar as shown in figure 1.

Also against infra red sensors, the missile can employ low observables technology, e.g. reflective coatings to reflect the cold sky toward the threat sensor. IR low observables is much aided if the missile flies at a low altitude to exploit the background clutter.

An alternative solution to the problem of avoiding detection is to fly at low altitude to exploit propagation properties and terrain masking. As figures 2 and 3 show, low altitude has a great pay-off in reducing the detection range both in the anti-ship case and in the land attack case. At low altitude the detection range of enemy air defence sensors is already so highly limited by the physics of the environment, i.e. terrain masking and transmission properties, that there seems to be less pay-off for low observables. However, flying at extremely low altitude also has drawbacks, e.g. high fuel consumption and risk of crashing. Furthermore the footprint of the missile's seeker becomes small as the missile flies low. Flying low to exploit terrain masking consequently requires significant amounts of mission planning.

An important sensor for early warning of a missile attack, especially for ships, is the radar warning receiver (RWR). To remain undetected for as long as possible it is therefore vital that anti-ship missiles can stay silent for as long as possible. It is also useful for the missile to have a low probability of intercept (LPI) seeker.

Surviving Air Defences

The option to try to survive the enemy air defences is, of course, a last resort. However, an incoming strike missile is likely to face some point defence system defending a high value target, which would be difficult to completely avoid. Many of the concepts of aircraft survivability as treated by Ball (1985) also apply to missiles.

The threat systems can be either or both of soft kill systems and hard kill systems, e.g.:

- Jamming of GPS signals
- Jamming of radar seekers
- High Power Microwave (HPM) weapons
- Laser jamming of optical seekers
- Air defence guns
- Surface-to-air missiles
- Air-to-air missiles

As precision navigation systems partly based on the GPS system become more common and also more important in many systems, including precision strike weapons, it is obvious that GPS countermeasures become more interesting. An incoming strike missile would have to be designed to cope with GPS jamming. Much can be achieved by anti-jam features, such as directional antennas and signal processing. However, the most important part would be the use of an integrated navigation system based on inertial navigation and GPS. If the GPS receiver is jammed in the final part of the trajectory, the inertial system guides the weapon with adequate precision.

Other recent additions to the threat against aerial vehicles are directed energy weapons such as High Power Microwave (HPM) and anti-sensor laser. An HPM weapon is capable of jamming or even destroying unprotected electronics at fairly long distances. However, most missiles are protected against electromagnetic interference, which makes them a more difficult target for HPM weapons.

Anti-sensor lasers can use various concepts. At the lower end of the power spectrum the laser would operate in the same frequency range as the sensor and cause the sensor to lose track by generating strange patterns in the image (figure 4) or by completely blanking out the sensor. At higher ends of the power spectrum the laser could destroy the sensor or even the front end optics.

In order to survive the classical air defence systems, i.e. guns and surface to air missiles, the incoming strike missile could use:

- High speed to reduce the reaction time
- Saturation
- Low observables
- Electronic countermeasures
- Hardening
- Evasive manoeuvres

Saturation can be achieved by careful co-ordination between several attacking missiles or by using decoys. A possible development could well be for advanced strike missiles to carry their own decoys to be employed in the terminal phase.

Low observables could make it possible for the missile to exploit some design limitations in the weapons. However the pure physics of a close range encounter would not make it possible for the incoming missile to remain undetected.

Electronic countermeasures can be used to degrade the performance of the enemy air defences. Jamming can be provided by friendly manned aircraft or unmanned UAVs. A possible development could be to equip some strike missiles with onboard or off-board jammers.

To harden the missile enough for it to fully survive a hit, does not seem to be feasible. However, the missile could be designed to avoid unnecessary catastrophic events close to its target. For example the missile could be designed to stay on course even if the seeker is knocked out. Premature detonation or deflagration of the warhead should also be prevented, e.g. by the use of insensitive explosives.

Evasive manoeuvres can be used as a countermeasure against both anti-air missiles and anti-aircraft guns. Evasive manoeuvres against anti-air missiles are covered in the Guidance and Control chapter. Manoeuvres are especially effective against guns, due to the relatively long time of flight of the unguided projectiles.

Berglund (1998) shows that the effective range of anti-aircraft guns decreases very rapidly even for moderate target manoeuvres, figure 5. A simple rule of thumb for the effective range of a gun is developed as

$$R = \sqrt[3]{\frac{4fr^2v^4}{3ua^2 \ln \frac{1}{1-P_k}}}$$

where

R = effective range [m]
f = rate of fire [rounds/s]
r = lethal radius [m]
v = projectile velocity [m/s]
u = target velocity [m/s]
a = target lateral acceleration [m/s^2] ($a>0$)
P_k = required kill probability

Networking

Recent technological progress has made it possible to use information technology to integrate functions both within a weapon system and between systems much closer than previously possible. Buzzwords such as "network centric warfare" and "systems of systems" have been introduced to emphasise the importance of this development.

To integrate a long range strike missile in a network oriented system of system would in most cases require a communication link to and from the missile. That link could be an RF link, such as the satellite link in the upgraded versions of the Tomahawk cruise missile, or a fibre optic link, such as in the European Polyphem missile.

The communication link to the missile allows re-planning of the mission and updates of the target position. The link from the missile makes it possible to use the information from the missile sensors as inputs in the intelligence system. Information from the missile can also be used for bomb damage assessment.

Communication with the missile also makes it possible to use targeting data from off-board sensors to guide the missile. To be able to use the information from off-board sensors, the missile would need to have a high precision navigation system. Furthermore the targeting data must not only be accurate, it must also be updated often enough given the dynamics of the target.

The use of reliable off-board target data would more or less revolutionise some strike missions. First of all much cheaper missiles without advanced seekers could be employed. Furthermore in the anti-ship case, where the radar warning receivers usually provide the ships with the first warning, silent attacks would become possible.

The use of communication can also be extended to include communication between missiles in a salvo. This could facilitate features such as dynamic re-planning due to loss of one of the missiles or information from onboard or off-board sensors. Assignment of targets could also be co-ordinated between the missiles.

Mission Planning Tools

The planning of a strike mission employing long range missiles is a truly multidimensional problem. The objective of the strike is most often to achieve some more or less political result. To achieve the desired political objective it is often necessary to avoid collateral damage and, of course, to follow the stipulated rules of engagement.

When the target has been selected, the planning needs to consider the vulnerability of the target and select a suitable weapon to defeat it. Also the defences surrounding the target need to be analysed carefully.

Computer models are frequently used to select flight paths to the target area that give a low risk of detection by the enemy air defence system. Computer models can also be used to determine suitable routes in the target area, enabling the incoming strike missile to lock on to the target, while avoiding possible point defence systems.

This planning has normally taken place prior to launching the mission. However, the advances in information technology have now made dynamic re-planning during the mission possible. That re-planning can take place both in the command centre and onboard the missile itself.

Conclusion

Mission planning forms a crucial part of a strike with long range missiles. Important aspects are to make sure that the target area is reached and that the missile impacts the right target.

Both the concept of flying high and rely on low observables and the concept of flying low and rely on terrain masking make it likely that the missile can avoid detection by enemy air defences on the ingress to the target area. However, the option of terrain masking requires more detailed mission planning.

To avoid point air defence systems in the target area, it would be useful for the missile to employ evasive manoeuvres and other countermeasures during the last 5 to 10 km.

Strike missiles need to be hardened against GPS jamming, laser jamming aimed at optical seekers, and jamming aimed at any radar seekers.

The advances in information technology open new possibilities of dynamic re-planning during the mission and of collaboration between missiles.

References

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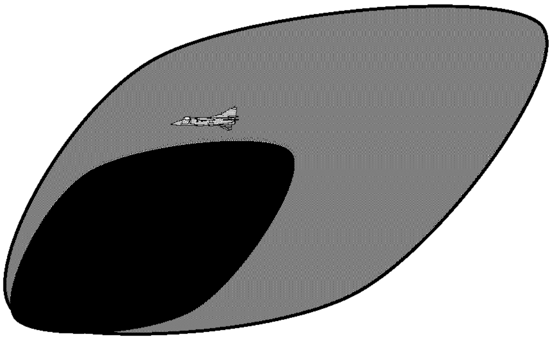

Figure 1. A stealthy aircraft or missile exploits the altitude limit of a surveillance radar, which has been reduced from its nominal value by the target's low RCS.

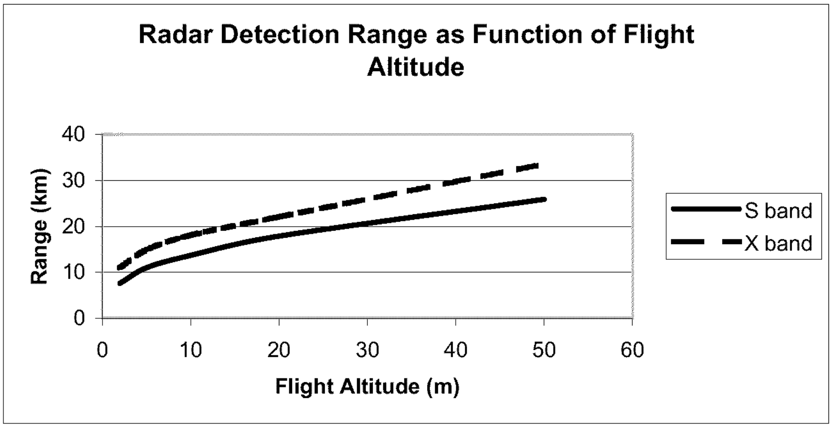

Figure 2. The detection range of a ship-borne radar against an anti-ship missile as function of missile altitude. The nominal range of the radar is 30 km and the antenna is at 10 meters elevation. It can be noted that the propagation properties in this case result in a range for the X band radar against the 50 meter altitude target that is greater than the nominal, free space range. (From Berglund, 1998)

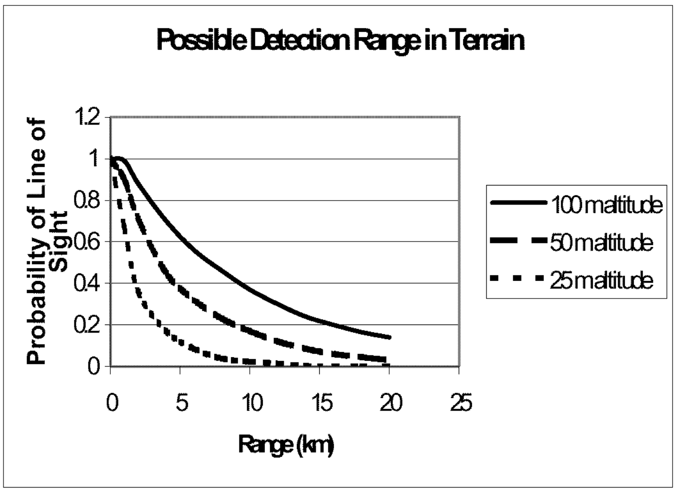

Figure 3. The probability of an air defence unit having line of sight to a target as function of range for different target altitudes in Mid-Swedish terrain. In this case the sensor is mounted on a 12 meter mast. (From Hansson and Berglund, 1999)

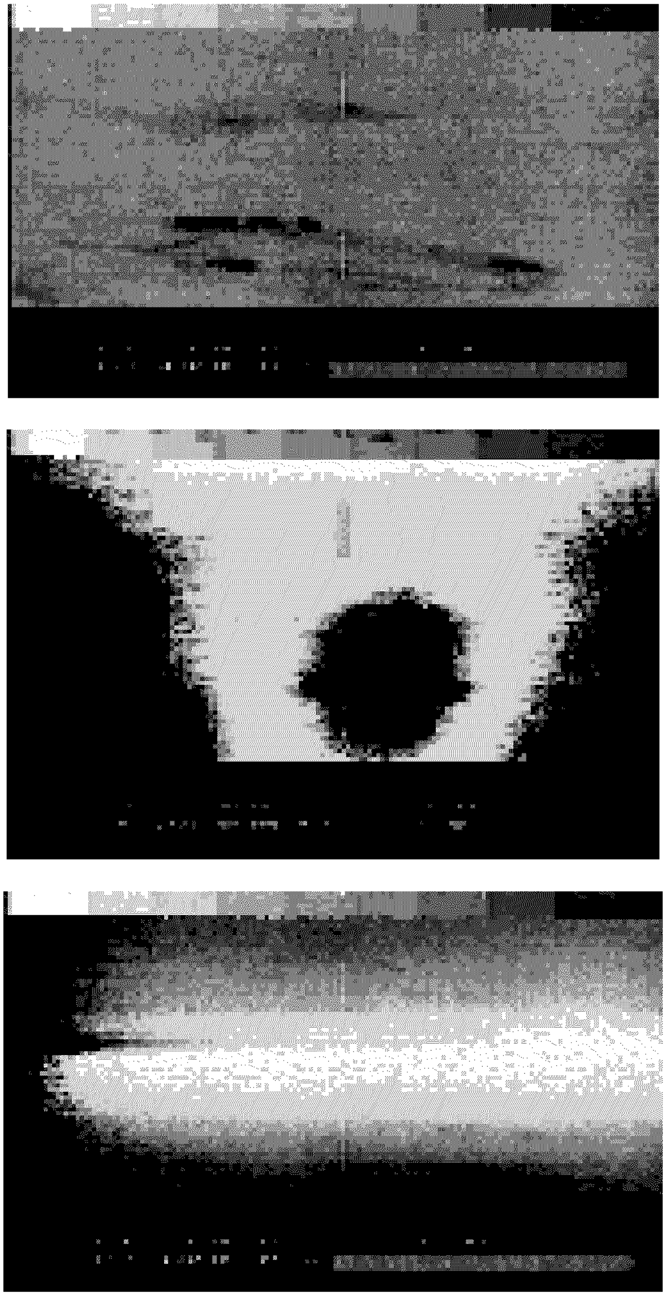

Figure 4. Examples of FLIR jamming. Top un-jammed image of target region with laser. Middle, jamming inside the field of view of the FLIR and bottom jamming outside the field of view. (Swedish Defence Research Agency)

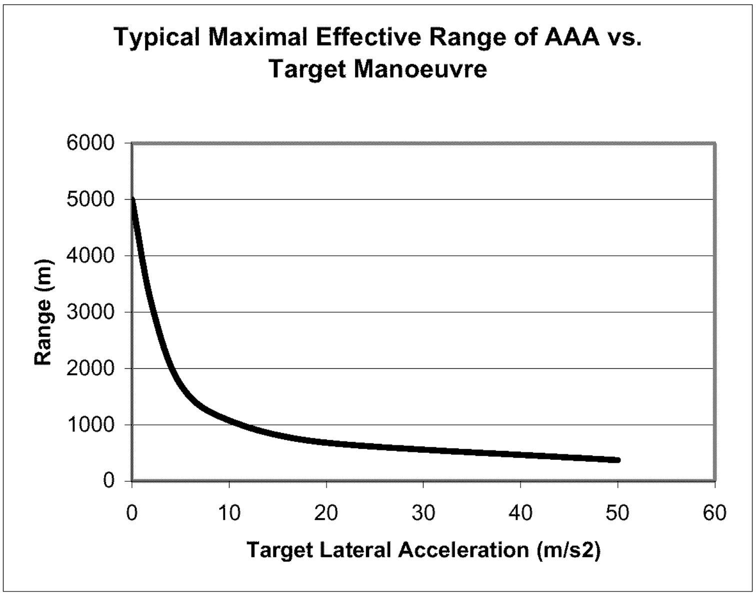

Figure 5. The effect of evasive manoeuvres on the range of a typical medium calibre anti-aircraft gun firing proximity fused ammunition at in incoming subsonic anti-ship missile.

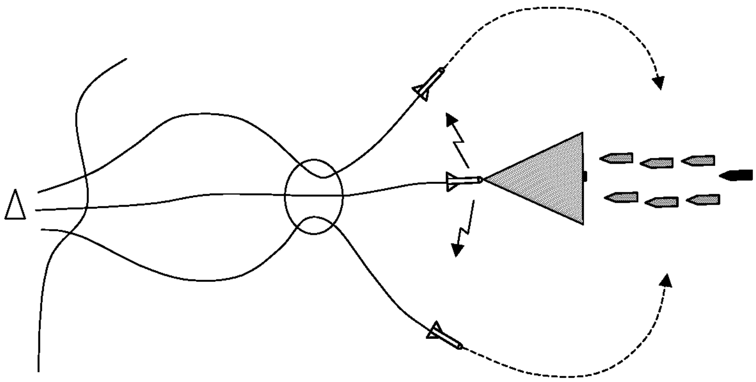

Figure 6. Communication between the anti-ship missiles in a salvo enables a tactic where only one missile activates its seeker while the others receive target data from the active missile and stay silent until the final approach. (From Alvå et.al., 2000)