This chapter presents our analysis of several critical survivability issues for the FTR. To achieve the benefits of vertical envelopment, the FTRs have to fly missions in the enemy’s second and third echelons with significant flexibility and without the need to delay flights because of survivability concerns. The survivability of the FTR under different levels of enemy air defenses is a critical issue for the vertical envelopment concept. The enemy’s ability to change his tactics, technology, and troops to minimize the impact of vertical envelopment must also be considered. To understand what survivability issues may be when the FTR is fielded, we conducted an assessment of current and projected future threats and countermeasures. We also investigated trends in the counter and countercountermeasure competition to better illuminate the challenges for FTR designers.

**FTR SURVIVABILITY AGAINST CURRENT RUSSIAN AIR DEFENSE SYSTEMS**

Figure 16 illustrates a lay-down of two-thirds of the air defense assets (ADA) that would be available today to a Russian army in an offensive operation. We assume one-third of the assets have been used or lost during an initial attack in which the Russian-equipped forces crossed the border and secured a 250 × 250-kilometer portion of territory (grid squares are 50 × 50 kilometers). We assume vertical envelopment implies the air insertion of the brigade combat team in the landing area shown in the figure. As a point of comparison, the density of anti-aircraft artillery (AAA) in Kosovo was ten times what is shown in Figure 16. Admittedly, the overall air defense in Kosovo was less sophisticated than the threat depicted in the figure.
Air Defense assets shown in Figure 16 include: the SA-12, a long-range (150-kilometer) radar-guided missile system comparable to Patriot; the SA-17, a medium-range (50-kilometer) radar-guided missile capable of engaging high-altitude targets (25 kilometers); the SA-15, a short-range (12-kilometer) radar-guided missile system mounted on an APC; the 2S6, which is similar to the SA-15 with an additional 30mm radar-guided AAA. The SA-18 is a third-generation, man-portable, IR seeker surface-to-air missile. Typically deployed in groups of two men, each with a launcher and two or more missiles (often referred to as a man portable air defense system, or MANPADS), the missile has a range of over 5 kilometers. The SA-13 is a second-generation IR SAM typically mounted on a tracked vehicle with a target-acquisition radar. The SA-13 missile is effective out to 5 kilometers. AAA for this application can be either optically or radar-guided and is effective against targets at ranges of 3 to 4 kilometers. Most of the missiles and AAA can hit aircraft flying as low as 10 meters above ground. Performance parameters are from Jane's Air

The laydown of ADA assets in Figure 16 allow us to test two levels of defense. Lower-quality units (truck-mounted infantry, for example) are along the coast and guard against vertical penetration from the water. In our simulations, we had Navy and Army helicopter pilots fly from point 1 to point 3 with various levels of situational awareness (SA), IRCM and RFCM, and suppression of enemy air defenses (SEAD). These units have considerably fewer air defense systems than the units along the forward line of troops (FLOT), which is to the east of the landing area (pilots flew the FTRs from point 2 to point 3). SA-15 coverage, for example, has several small gaps along the coast but none along the FLOT. There are no 2S6 or SA-13s deployed along the coast. In addition, there are far fewer SA-18 MANPADS along the coast than at the FLOT.

Figure 17 shows the results of RJARS\(^1\) (RAND’s Jamming Aircraft and Radar Simulation) runs aimed at modeling the coastal penetration of 42 FTRs flying in tactical trail formation (groups of 3 with 100-meter separation) to the landing area going through the defenses shown in Figure 16.

The figures show that whether the FTR has a large set of signatures (the radar, optical, and IR signatures are assumed to be twice as large as those of a current rotary-wing transport aircraft) or uses current helicopter stealth technology any attempt to fly the vehicles without SEAD or SA results in 100 percent loss of the aircraft. This occurs for penetration routes from cross-FLOT and from the ocean. Attrition levels drop to a still unacceptably high level if we assume suppression of all air defense radar sensors (high SEAD) and/or high SA (meaning the pilot has knowledge of the location of all RF emitters, radiating or not) similar to Operation Desert Storm. Even with the less demanding ocean flight penetration routes and usage of low-signature rotorcraft, the 15 percent sortie attrition rate is, for most missions, far from acceptable. We also note that because RJARS does not model the acoustic signature, the results would be even worse if acoustic anti-helicopter mines were deployed. In addition, passive

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\(^1\)The RJARS simulation model is described in Sollfrey (1991). RJARS has been updated as new threats were considered and model capabilities enhanced.
acoustic detection of the rotorcraft acquisition would enable AAA, RPGs, and IR SAMs to be cued to the rotorcraft without the help of search radars.

The results in Figure 17 indicate that in a high-threat environment, the FTR, even with dramatic success in research on signature suppression, will not be able to fly freely about the battlefield. There is a requirement for extensive SEAD and a set of operational protocols to improve survivability, but that will inevitably limit flexibility. For example, it may be necessary to fly around defenses or to fly only on penetration routes where the ground has been secured. However, SEAD is unlikely to destroy every machine gun, RPG, and IR SAM. The latter are highly mobile, small, and easy to hide in complex terrain. The current U.S. Air Force strategy of flying above these low-altitude air defense threats is clearly validated by our modeling effort. With tiltrotors, the Army could fly above these threats but will still
need to land, unlike the Air Force, in enemy-controlled areas. The maximum threat the aircraft can land in becomes the key issue if the fly-high tactic is used.

For the next two figures we reduce the level of defense to identify the minimum level of ADA the enemy needs to cause significant operational problems for the vertical envelopment concept. Other SEAD approaches using extensive onboard countermeasures are possible and will be discussed later in this chapter.

The results in Figure 17 led us to ask a different question: “What is the maximum level of defense that the FTR could fly through/land in without requiring significant operational support or modification?” Figure 18 shows a laydown typical of a Russian enemy infantry company given a mission to defend a key position against ground and air attacks. The company has six rocket-propelled grenades (RPGs), nine hand-held machine guns (HMG), and three tanks with a 125mm gun, each of which carries a single SA-18 hand-held IR SAM system (MANPADS). All the APCs have 30mm chain guns, which are modeled as anti-aircraft artillery. The vehicles all have thermal and opti-
tical sights. The company is distributed over a 3 × 5–kilometer area. Each weapon system is modeled as an independent ADA and given orders to fire at any aircraft within its lethality range.

Figure 19 shows the results of flying a group of 42 FTRs over the infantry company (path shown in Figure 18.) The results show unacceptably high attrition rates for the large-signature FTR, even in the case where the tanks and their associated MANPADS are removed. It is only in the case where signature reduction occurs, along with elimination of the MANPADS, that attrition rates reach the level where we can begin to contemplate use of the FTR without significant operational limitations or conditions. Aggressive use of IR countermeasures can help negate the IR SAM threat, but even a factor-of-five improvement over current IRCM still results in high sortie attrition rates. We also note that AAA effectiveness is dependent on vehicle size. If we model an FTR with current helicopter stealth technology and the physical size of two V-22s, its sortie attrition rate, for the no IR SAMs case, is the same as the base case.

![Figure 19—FTR May Be Vulnerable to Very Thin Defenses](image-url)
COUNTERMEASURES

Concerns about FTR survivability have been raised in several forums, and it is not uncommon for these concerns to be answered by expectations that technical advances in countermeasures may offset the threats. Figure 20, however, shows that an assumption of countermeasures effectively counteracting the MANPADS threat would require a reversal of the historical trend in this technology. Historically, the offensive threat has consistently stayed ahead of the defensive countermeasures.

IR SAMs were introduced in the late 1960s in Vietnam. The Soviet SA-7 and the U.S. Redeye were the first-generation IR SAMs. They used a low-performance uncooled IR detector and a spinning reticle to track and provide inputs to the missile guidance system. The target signal was an amplitude-modulated signal that was minimized when the target was centered on the spinning reticle. As the target maneuvered, the detector’s output signal increased with the amplitude proportional to the angle (off center) of the target relative to the missile. Flares could counter this type of seeker by generating a
signal brighter than the aircraft, causing the seeker to track the brighter object and ignore the actual aircraft signal.

The basic Stinger and SA-14s and 16s were developed to counter flares. Here the reticle is spun as well as a mirror in the missile receiver optics. Called FM conical scan, this approach gives an FM signal that is tracked. Since the signal is always present (not minimized like the spin reticle), the missile is flare-resistant. That is, it will not track a flare, though it may center on a point between the aircraft and the flare. The seeker’s narrow field of view causes it to center on either the aircraft or the flare as the missile approaches the aircraft. Two countermeasures to the FM conical scan missile were developed. The first is to pop a series of flares so that the seeker is confused by the time average center of the flares and aircraft (limited by the need for large numbers of flares. The second countermeasure is an IR jammer, consisting of a bright xenon lamp modulated at the seeker’s tracking frequency. This disrupts the phase-locked electronics in the missile’s receiver. This may be successful if the defense knows the modulation format of each IR SAM deployed in theater. It also requires the jammer signal to be roughly five times greater than the aircraft’s signal to “disrupt phase lock,” a problem with today’s transports’ high IR signature.

In any case, third-generation missiles were already deployed when IR jammers were deployed. Quasi-imaging sensors use a scan mirror and a detector array, or one detector and two scanning mirrors, to trace out a rosette pattern to generate the image. The rosette pattern used in later versions of Stinger does not revisit the exact same “pixel” each cycle, so jammers need a much higher jammer-to-target-signal ratio to guarantee that enough jamming signal gets through. The scanning system can, in theory, home in on the jamming source. With enough jamming signal you can saturate a block of angular space around the aircraft and hope the missile circular error probable (CEP) is enlarged accordingly. Directed IR countermeasures (DIRCM) can give the higher jammer-to-signal ratio needed, but this technology is still in engineering development. The programs have also been subject to funding cutbacks and cost overruns. The missiles have been in production since the late 1980s.

DIRCM and flares may not be very capable against real imaging missiles that are now in low-rate initial production. These use $128 \times 128$
IR and visible arrays. Jammers can make the problem worse, acting as a beacon. Flares are rejected due to track profile (objects that move away from the aircraft are ignored). Initial work with lasers to dazzle or saturate the imager will have some effect, but this may be countered by software changes in the missile’s tracking algorithm. Laser-based IR jammers have been demonstrated in the lab and field with brassboard units and may be operationally deployed in five years.

Already in development are two color imaging systems, as well as hyperspectral systems. In these the sensor looks at the object at several wavelengths from UV to IR. Helicopters have a unique spectral signature when compared to flares, IR jammers, etc. The best way to counter is to use a medium-power laser to burn up the sensor’s focal plane arrays. It will be a while before directed energy weapons (DEW) are on board transport helicopters.

We also note that no countermeasures exist for beamrider missiles such as the RBS 70, currently for sale on the world market.

We are not suggesting that the IR SAM problem is unsolvable. The technology to counter any IR missile can be developed. The key point is that historically it has been easier to modify offensive weapons than to develop new countermeasures. We should not assume that the enemy will let an IRCM system be effective against SAMs.

To generalize this point, we have observed a tendency in the FTR discussion for advocates to invoke various high-technology solutions to the survivability problem. As an example, one often-mentioned suggestion has been to install active defenses aboard the FTR using anti-aircraft (AA) gun technology. We contacted the two leading AA gun manufacturers, Oerlikon and Bofors. Oerlikon responded that “the feasibility to mount such a system on a helicopter for its own defence seems very low to us and, therefore, we have no interest in pursuing this.”

Bofors manufactures the AC-130 Spectre gunship’s main gun. The company was interested in the concept, but RAND was the first to

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2Telefax from Oerlikon, August 21, 2001.
inquire about this potential new application. We believe the development of “hard-kill” IR and RF SAM countermeasures is a critical element in the development of a survivable FTR or any aircraft that will fly in harm’s way.

The limited number of development activities for air defense countermeasures does not, however, support the vertical envelopment proponents’ claims for potential new ways of enhancing JTR survivability. We note that the current S&T plan has no active countermeasure component. It is risky to depend on other agencies to develop this critical technology.

Figure 21 illustrates that many key air defense assets are relatively inexpensive compared to the cost of transport aircraft. The chart shows a logarithmic plot of system costs and illustrates that low-altitude air defense systems are several orders of magnitude lower than transport costs. Long-range RF SAMs can have costs comparable to aircraft, but in the previous charts we illustrated cases where those SAMs are suppressed.
While it is reasonable to assume that the United States may be able to vastly outspend many Third World rivals, the cost ratios in the above chart indicate that the system cost imbalance may be so large that this may not be an important consideration. Costs for hand-held IR SAMs are as low as a few thousand dollars, and it is reasonable to assume that any rival will have a significant arsenal of these weapons. There are currently more than 500,000 IR SAMs deployed worldwide, most with current allies but some with former allies and/or current adversaries. IR SAMs can cost from around $10,000 for the older models to $100,000 for the current state-of-the-art missiles. The current (FY 2000) U.S. Army purchase price for a Stinger is around $50,000. Anti-helicopter mines will cost around $30,000 and represent another low-cost defense. If we invest in a large FTR fleet, it is reasonable to assume our adversaries would invest in anti-rotorcraft weaponry.

CHAPTER SUMMARY

We now summarize our survivability analysis. The FTR is a large, slow, and noisy (we have not modeled the acoustic signature) aircraft, and it is extremely vulnerable to a large number of low-cost, low-altitude threats such as guns, AAA, and MANPADS.

Technology improvements could allow the FTR to overcome many of the current SAM threats. We note, however, the history of IR and RF SAM countermeasures to lag a generation behind the missile seeker technology. If the FTR is to be survivable in the virtual envelopment concept, significant increases are needed in missile countermeasure development programs.

These arguments are not intended to exclude the potential of rotorcraft-facilitated vertical envelopment for the Objective Force. But they do imply that there will be significant operational constraints on the use of rotorcraft. Tiltrotors, with their ability to fly high above the low-cost, low-altitude threats, along with the Air Force’s ability to suppress medium/long-range RF SAMs, significantly enhance FTR mission survivability. Of course, the requirement to land remains. Another option may be to evade defenses, though it is always difficult to find out the location of small weapons like MANPADS. Other options may involve clearing paths on the ground or considering smaller armored insertions with only a few
FTRs. Finally, there is the option of using the FTR to fly around the edges of the battlefield and avoid penetration runs that would expose the vehicle to significant enemy fire. In any event, the notion of multiple FTRs freely flying around the battlefield cannot be considered unless there are new developments in ensuring survivability.