Who Goes There: Friend or Foe?

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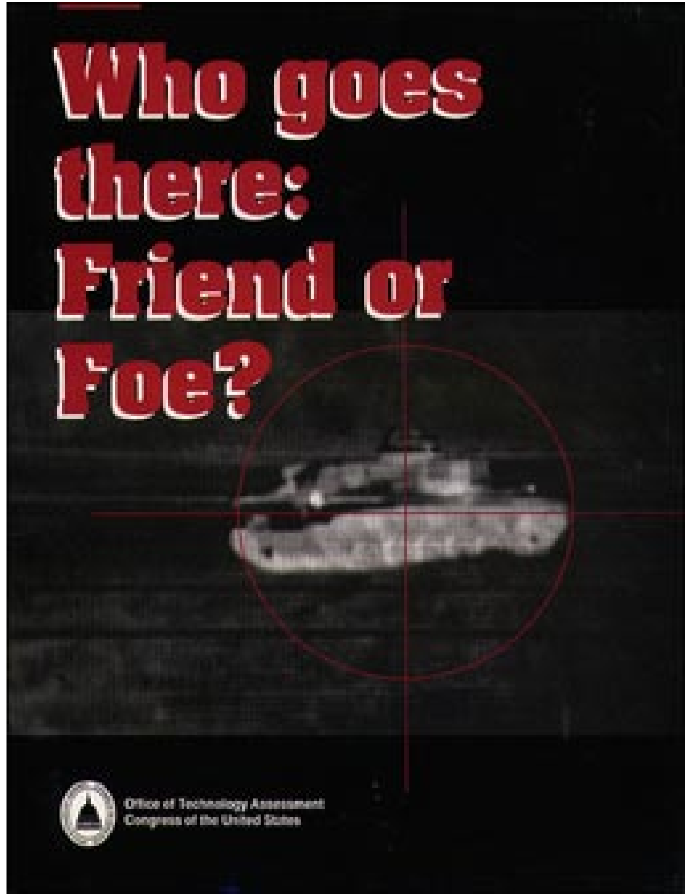

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Foreword

The recent Persian Gulf War focused attention on the problem of fratricide, or "friendly fire" casualties among combat units. Twenty-four percent of U.S. combat fatalities in that conflict were due to friendly fire. The House Armed Services Committee requested that OTA assess the technology and techniques available to reduce this tragic loss of life. Although friendly fire has often been dismissed in the military literature as an insignificant contributor to overall combat losses, in those few historical cases for which good data are available, estimated friendly fire losses have accounted for at least 10 percent of total losses. Friendly fire has been an important-and under-appreciated-source of combat deaths.

Combat is confusing, complex, and deadly. Friendly fire casualties can probably never be eliminated, but several measures can reduce them. Application of new and existing technology can make identification of friendly forces on the battlefield more reliable; improved communication can reduce confusion on the battlefield; and better training can help military personnel make crucial, rapid decisions under the extreme stress of combat.

Congress faces several decisions related to reducing friendly fire. These include:

- the choice of best technical approaches to pursue;
- the allocation of resources between systems that are devoted exclusively to reducing friendly fire and other systems—for example, better navigation and communication devices--that may reduce friendly fire in indirect and less visible ways;
- the best mix of near-term deployments and longer term research and development; and
- the need for cooperation and coordination among the military Services and with allies.

We wish to express our appreciation to individuals in the many government agencies and other organizations that provided information essential to the assessment and to the many reviewers who helped ensure its accuracy.

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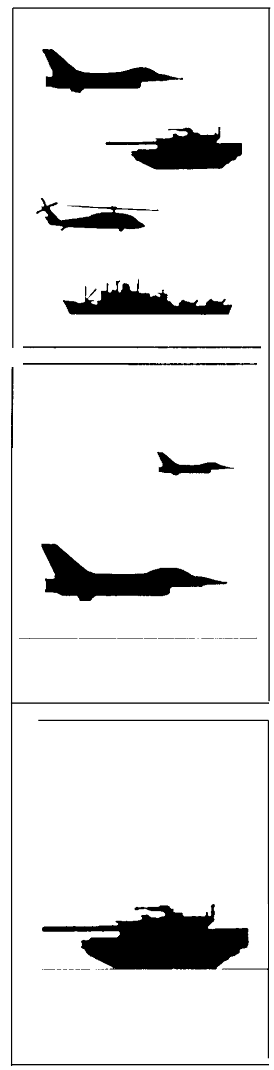
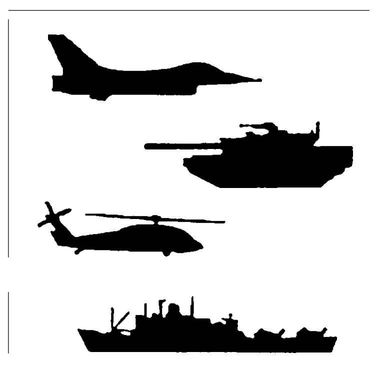


Introduction, Findings, Issues for Congress 1

America's recent combat in the Persian Gulf War brought new attention to an old problem: fratricide, or ‘‘fi-iendly fire, ’ that is, casualties from U.S. or allied weapons fired at U.S. or allied military personnel. Twenty-four percent of all U.S. combat fatalities in the war were caused by friendly fire. This figure seemed much higher than in previous wars and caused a sudden focus on avoiding fratricide in future wars.

The U.S. military and the American public are becoming increasingly sensitive to the human costs of military involvement, especially for contests of less than national survival. The United States has invested much in energy and equipment to keep casualties low. The high fraction of deaths in the Persian Gulf War due to fratricide was much higher than the nominal two percent rate frequently cited in the military literature. Broad-based data on fratricide rates are not available; but, a recent review of long-extant casualty surveys from World War II and the Vietnam War shows that fratricide estimates of 2 percent are unrealistic and 15 to 20 percent may be the norm, not the exception. Thus, one reason that fratricide seemed unusually high in the Persian Gulf War is that total U.S. casualties were low but another important reason is that past rates of fratricide have been systematically and substantially underestimated. If these rates are, indeed, typical, then reducing casualties from fratricide deserves the same kind of attention as reducing casualties from any other major source.



Beyond numbers of killed and wounded, fratricide has a compounding effect on combat effectiveness. Weapons aimed at friends are not aimed at the enemy. Friends killed by friends are not able to fight the enemy. Moreover, the psychological effects of friendly fire are always greater than from similar enemy fire. Combatants expect to be shot at by the enemy, but being shot at

Table 1-1—Detrimental Effects of Fratricide

- **Hesitation to conduct limited visibility operations**
- **Loss of confidence in unit's leadership**
- **Increase of leader self-doubt**
- **Hesitation to use supporting combat systems**
- **Oversupervision of units**
- **Loss of initiative**
- **Loss of aggressiveness during fire and maneuver**
- **Disrupted operations**
- **Needless loss of combat power**
- **General degradation of cohesion and morale**

SOURCE: Center for Army Lessons Learned.

by friends corrodes cooperation and morale; shooting at friends also destroys morale and can cause commanders to be overly cautious in combat. See table 1-1.

The Persian Gulf experience has concentrated the attention of the military Services on the problems of fratricide. Several new antifratricide programs were started within the Department of Defense, and existing programs have been accelerated, reoriented, or brought under new management control. New emphasis has been given to the fratricidal implications of other programs-such as those to improve communication-not explicitly or primarily intended to reduce fratricide. Doctrine and training are also being reexamined with a view to minimizing the risk of fratricide.

FINDINGS

Fratricide may be a significant source of casualties. Twenty-four percent of U.S. combat fatalities in the Persian Gulf War were caused by friendly fire. This seemed extraordinarily high compared to past conflicts. Several reasons have been presented for why the fraction should have been so large:

1. total U.S. losses were very low, thus the percentage of fratricides appeared abnormally high;
2. the war was so short that U.S. troops did not have a chance to gain much experience, reduce fratricide, and get the average down;
3. near-absolute dominance of the battlefield by the U.S. meant that only U.S. rounds were flying through the air and if a soldier got hit by anything, it was likely to be from a U.S. weapon; and
4. the unique characteristics of many U.S. weapons, for example, the depleted uranium in the M-1 tank round, made the fratricide that did occur undeniable.

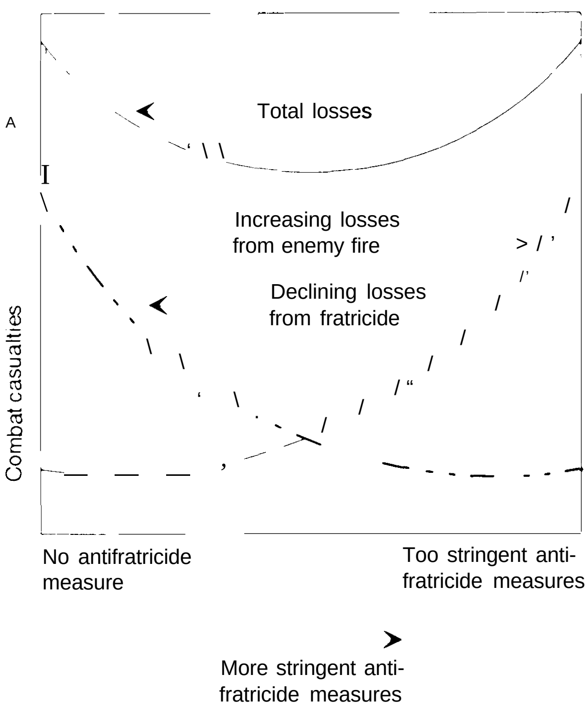
Some of these reasons will apply to a range of possible future military engagements. Whether or not fratricide in the Persian Gulf was particularly high compared to past wars, it may be representative of future conflicts.

The fourth point above deserves careful consideration. While military historians have frequently used two percent as a notional fratricide rate, the figure has been higher in all of those cases for which good data are available. A recent review of medical records from World War II, the Korean War, and the Vietnam War show fratricides to account for 12 percent and more of total casualties in those cases for which data are available. Perhaps the Persian Gulf War was not so unusual.

Reducing fratricide is desirable and feasible, but eliminating it is not. Although programs to reduce fratricide are certainly needed, setting a goal of eliminating fratricide is unrealistic and probably even counterproductive. Overly restrictive rules of engagement, for example, may so reduce combat effectiveness that casualties inflicted by the enemy increase more than friendly fire losses are reduced. See figure 1-1.

The new global military environment requires a reevaluation of antifratricide efforts. Any technical goals established during the days of the Cold War need to be reexamined. Past directions will not be completely reversed, but priorities among technical direction may change. For example, during the NATO-Warsaw Pact confrontation, which type of weapon was on which side was clear-cut. Today, noncooperative identification based on type of weapon or plat-

Figure I-I—Total Casualties and Antifratricide Measures



SOURCE: **Office of Technology Assessment, 1993.**

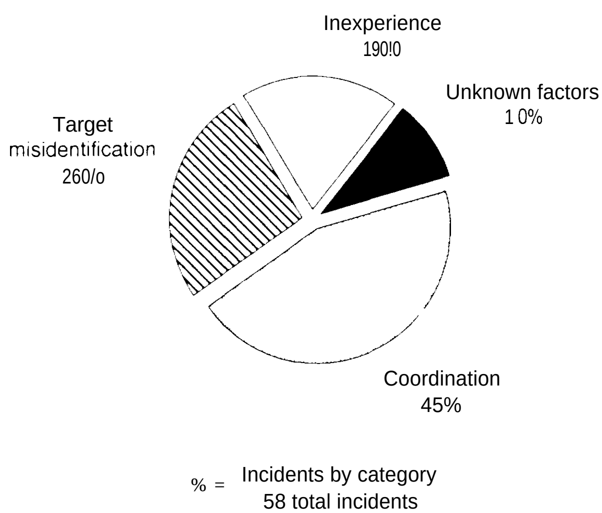
form will be more difficult in a world in which enemies and allies may own the same hardware. Also, future alliances, like that in the Persian Gulf, may be more ad hoc, making planning for and sharing of identification technology more difficult. On the other hand, some tasks should be easier to accomplish since few potential enemies will be as sophisticated as the former Soviet Union or possess the sheer numbers.

Fratricide results from multiple causes. Friendly fire is often thought of as due primarily, or exclusively, to misidentification. Investigation of particular cases usually reveals that the fratricide was in fact the last link in a chain of mistakes. That is, faulty navigation; poor communication, command, and planning; lack of fire discipline; and occasional malfunctioning equipment are responsible at least as often as misidentification. See figure 1-2.

With multiple links in a chain of causes, there are multiple solutions to the problem of fratricide by strengthening any of the links. For example, outfitting tanks with compasses will improve navigation, helping units to be where they are supposed to be and not to stray into fields of friendly fire. Improved radios allow the transmission of more of this navigation information. Improved displays within the tank would allow clearer representation of that information. And, of course, better sensors would allow better recognition of fiends seen through the sights of the gun. Each of these measures could reduce fratricide.

Some approaches to reducing fratricide have other benefits. For example, improved communication and navigation allow better command and control of combat units, more flexible tactics, and more efficient allocation of combat resources. All of this together could improve combat capability significantly while also reducing fratricide. An improved identification device will mostly reduce fratricide with much smaller side benefits. Thus, only the appropriate fractions of the costs of systems should be compared when considering their relative efficiency in reducing fratricide.

Figure 1-2—Causes of Fratricide: Direct Fire Fratricide in World War II, Korea, and Vietnam



SOURCE: U.S. Army

U.S. ARMY

Wreckage of a U.S. armored vehicle destroyed by friendly fire in the Persian Gulf War. The effectiveness of modern weapons makes identification mistakes deadly.

No single technical approach to target identification will be perfect. Identification techniques can be roughly divided between cooperative and noncooperative approaches. In general, cooperative techniques can provide positive identification of friends. Failure to respond to a cooperative identification query could be *assumed* to identify a putative target as an enemy, but in most circumstances, most shooters would be hesitant to use the lack of response as a justification to fire. Cooperative techniques could, however, categorize targets as either friends or unknowns and then noncooperative techniques could identify the foes among the unknowns.

The technology for avoiding fratricide of land surface targets lags behind the technology important **to avoiding** aircraft fratricide. Avoiding fratricide requires good navigation, communication, and identification. Yet multimillion-dollar U.S. tanks do not have compasses. Simple magnetic compasses will not work inside a 60-ton steel box and tanks are only now being fitted with radio-navigation equipment. Question-and-answer IFF systems, developed for aircraft a half century ago in World War II, are only now being developed for land combat vehicles. Programs to reduce ground combat fratricide will need special support for several years just to get up to where aircraft systems are today.

Coordination among the U.S. military Services and among U.S. allies is essential. Programs to develop technology to reduce fratricide must be coordinated among Services and allies from the beginning. The U.S. military emphasizes "combined arms" operations where the strengths of many different types of weapons are brought to bear simultaneously against an enemy. This approach presents many opportunities for friendly fire among aircraft, artillery, land vehicles, surface-to-air missiles, and so on. Fratricide reduction, as much as any other DoD effort, needs some central coordination, either from Office of the Secretary, the Joint Chiefs of Staff, or other special joint-Service organization. The Services realize the importance of coordination, and their ongoing multi-Service efforts should be encouraged and monitored.

Future conflicts are likely to be allied operations—as much for political as military reasons—and coordination of antifratricide technology development with allies must be maintained from the beginning. The utility in allied operations is one criterion by which prospective technology must be judged. For example, if technology being pursued for identification of friend and foe is so sensitive that it cannot be released to allies, especially ad hoc allies as we had in the Persian Gulf War, then the usefulness of the technology will be limited. This does not mean that these approaches are worthless, but the need for allied cooperation should be included as a program goal.

Nonmaterial changes will also reduce fratricide. Some cases of friendly fire in the Persian Gulf War could have been avoided by different pre-war training. For example, since the war the Army intentionally includes occasional stray friendly vehicles in training exercises and maneuvers to let soldiers practice ''don't shoot' situations. Simulators are an increasingly important part of training. In the past, these have not fully reproduced opportunities for fratricide; this lack is now being addressed.

The rules of engagement strongly affect the likelihood of fratricide. The Services train warriors and train them to be aggressive, But in many potential future conflicts, the conditions of the Persian Gulf War may recur: the U.S. was able to outrange, outsee, and outgun the enemy by a substantial margin. This capability could allow (but not demand) different rules of engagement. Many Persian Gulf fratricide occurred when a target was engaged quickly yet the shooter was in no imminent danger and could have been more deliberate. In situations where U.S. forces have clear weapons performance superiority, more conservative rules of engagement may reduce overall U.S. casualties. This is a very complex issue that is without a simple answer (e.g., if the United States had fought more slowly battle-by-battle, perhaps the overall envelopment of Iraqi forces would have failed), however, it at least deserves consideration.

ISSUES FOR CONGRESS

Allocation of Resources

Reducing fratricide will require new technology and equipment. That, in turn, requires funding, which then requires allocations within a finite defense budget. There is, as always, competition between efforts to reduce fratricide and other military needs. Having combat superiority helps to keep casualties down, so even if minimizing casualties is the goal, spending less on offensive weapons and more on avoiding fratricide is not automatically the answer. Two issues, however, suggest that the relative emphasis on fratricide prevention should increase: first, most military analysts interviewed by OTA for this assessment agree that antifratricide efforts, especially related to land combat, have not received sufficient attention in the recent past. Second, the experience of the Persian Gulf suggests that fratricide may be a relatively greater cause of casualties in future conflicts than has been appreciated in the past.

Each of the Services has IFF and antifratricide programs, and Congress will be asked to allocate resources among these. One of the findings of this report is that technology to help prevent fratricide of land surface targets is least developed and Congress may consider giving relatively greater weight for a few years to programs supporting these technologies.

Resources must also be allocated among various technical approaches to reducing fratricide. When comparing these costs, Congress may want to consider the potential multiple benefits of many approaches. Specifically, an IFF system will reduce fratricide by improving identification, but has only limited additional applications, while improvements in communication and navigation can reduce fratricide and have compounding benefits to overall combat effectiveness.

Short-Term v. Long-Term Goals

After the Persian Gulf friendly fire losses, the Services decided—with some prompting from Congress-that an accelerated antifratricide program was needed. The Army developed a plan for both “near-term” (less than 5 years) and “far-term" (7 or more years) solutions. The general technical approach for the near-term solution is fairly well determined to be a millimeter wave question-and-answer system. This has the advantage of being available to troops in the field within just a few years, although it is not the ideal long-term solution. The degree of pressure from Congress is part of the calculus by which the Services determine their allocation of effort between near- and long-term solutions. Congress may wish to make clear to the Army the extent of its urgency:

- should the Army get a less-than-ideal system in the field quickly so soldiers have something in the event of a new Persian Gulf-like conflict, or
- should the Army take a longer-term approach to get a better system while risking

that a conflict within *5 years* or so may result in too many friendly fire losses?

Cross-Service Coordination

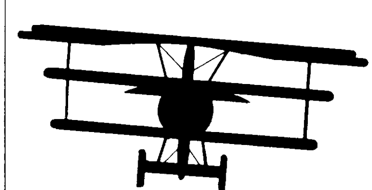
There is probably no better example of an effort where inter-Service coordination is needed than the development of antifratricide technology and equipment. The Services now have a General Officers Steering Committee that seems quite successful in assuring coordination among various Service antifratricide programs. Congress may want to pay special attention to Service coordination in future years to ensure that it is maintained at every level. Past experience is not uniformly encouraging.

One technical aspect of Service coordination is the compatibility of various IFF devices. Not every weapon can effectively fire at every other weapon; for example, fighter/interceptor aircraft and tanks cannot fire at each other. Is it really necessary that they be able to query each other's IFF devices? Yet fighters can fire at ground-attack aircraft and ground attack aircraft can fire at tanks. If they do not all have the same IFF systems, will ground-attack aircraft need two systems operating in parallel?

Historical Review of the Causes of Fratricide 2

On November 12, 1758, during the French and Indian War, Colonel George Washington of the British Army led a detachment of infantry to take a hill near Loyall Hannon (now Loyalhanna), Pennsylvania occupied by French soldiers and their Indian scouts. The French fled after a brief exchange of fire. But hearing the firing, a second detachment—under the command of Lt. Colonel George Mercer—approached the hill to assist. They arrived at dusk and the day was foggy, making visibility poor. Each side seems to have mistaken the other for French and an intense fire fight broke out, killing between 13 and 40.[1]

While the current high interest in combat fratricide is a direct result of U.S. experience in the Persian Gulf War, this tale shows clearly that fratricide is not a new problem. During the Persian Gulf War, incidents of fratricide received considerable press attention and caused international political friction.[2] There was bewilderment among the public and press about how fratricide could occur. After all, shouldn't it be *obvious* who are friends and who are foes? In addition, to some the losses from friendly fire seem less acceptable as an inevitable cost of war than are losses from enemy fire.[3]



[1] The Papers of George Washington, Colonial Series, vol. 6, W.W. Abbot, ed. (Charlottesville, VA: University Press of Virginia, 1988), pp. 120-123. A "detachment" could consist of between 200 and a thousand infantry.

[2] Just a sample of the popular press stories about friendly fire includes: Bruce van Voorst, "They Didn't Have to Die, " Time, Aug. 26, 1991, p. 20; Joshua Hammer, "Risking Friendly Fire, " *Newsweek,* Mar. 4, 1991, p. 33; David HackWorth, "Killed by Their Comrades, " Newsweek, Nov. 18, 1991, pp. 45-46; Glenn Frankel, "In Britain, Fallout from Friendly Fire, " *Washington Post,* May 18, 1992, p. D1; and David Morrison, "Foes Not the Only Threat in the Gulf War," *National Journal,* Feb. 9, 1991, pp. 335-336.

[3] Sensitive to the possibility of a different reaction to friendly fire losses, the Marine Corps readily admitted occurrences of friendly fire but was reluctant to identify precisely which deaths it caused. For example, a Marine Corps spokesman, Lt. Col. Ron Stokes, was reported as saying: "We don't want to start painting guys with a different brush-these guys were killed by the enemy and these guys by friendly fire. They were all killed in a combat action. If you start breaking it down, we're not certain that it benefits either the public or the families. See, ''Kitled by Friend or Foe, It's All the Same, " *The* New *York Times,* Feb. 14, 1991, p. B18.

The fratricide of the Persian Gulf War was unusual in some regards compared to that of past wars. Most striking was the apparently unprecedented high fraction of U.S. casualties resulting from fratricide; this was due in large part, of course, to the extremely low U.S. casualties inflicted by the enemy.

In addition, the *types* of fratricide were different from other large mechanized land battles, such as those of World War II. In World War II, the most deadly reported individual incidents of fratricide were the result of bombing of friendly troops by friendly aircraft. Surface-to-surface fratricide resulted most often from indirect-fire weapons, that is, artillery fired at a target that the crews could not see. The Persian Gulf War had an unusually high fraction of fratricides from direct-fire weapons—for example, tanks-shooting mistakenly at other land targets, which they could see but misidentified.

This chapter, a historical review of fratricide, shows how serious a problem fratricide has been in past wars and reveals patterns in the occurrence of fratricide in past wars that might suggest lessons for the future.

There are difficulties with a historical approach. The movements of armies are usually well recorded, but the record of particular actions by front line soldiers that might lead to fratricide is spottier and less reliable. Thus, many casualties due to fratricide are never realized to be such, and many that are recognized as fratricide are probably never recorded as such. Within the military historical record, the record of fratricide is particularly suspect because fratricide is a mistake and a full airing can be embarrassing or traumatic and can end careers.

Recording of fratricide has not been uniform. Casualty report forms, for example, have not included fratricide as a cause. Thus, fratricides during the Vietnam War were cataloged under either ''accidental self-destruction" or "misadventure.

Colonel Washington's unfortunate "misadventure" illustrates these problems well. After the Loyalhanna incident, Washington was criticized by some of his officers for losing his customary aplomb under fire, for which he was justly famous. What responsibility he felt after the action we can never know, but he made no mention of the circumstance of his casualties in the next day's reports to his superior officers. In fact, he never mentioned the event in any of his writings until almost 30 years later when, in marginal comments on a draft of his own biography, he related a version in which Colonel Mercer clearly fires the first shot.

The historical record does provide lessons. Many of the cases of fratricide include human errors, not just technical or tactical specifics. Because people change more slowly than machines, history probably provides some useful lessons for today.

Very few works are devoted specifically to fratricide. One particular case of fratricide is probably the most famous because a popular book was written about it, *Friendly Fire,* by C.D.B. Bryan (also serialized in the New *Yorker* and the subject of a television series);[4] this work deals primarily with a victim's family and its dealings with the U.S. Government. Lt. Colonel Charles Schrader's paper, *Amicicide,* contains far and away the largest collection of historical ancedotes of fratricide of any single source and it is cited widely in this chapter.[5] OTA also contracted for two papers on fratricide and they are used freely in this chapter.[6]

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[4] Courtlandt Dixon Barnes Bryan, *Friendly Fire (New York,* NY: Putnam, 1976).

[5] Charles Schrader, *Amicicide: The Problem of Friendly Fire in Modern War (Fort* Leavenworth, KS: U.S. Army Command and General Staff College, 1982).

[6] Richard R. Muller, "Fratricide and Aerial Warfare: An Historical Overview" and John C. Lonnquest and W. Blair Hayworth, Jr., ''OTA Fratricide Study."

This chapter is organized not by chronology but rather by the lessons important to finding technical and procedural solutions to the problem of fratricide. This approach is necessarily somewhat arbitrary since fratricide almost always results from a complex and confused chain of mistakes, making strict categorization impossible. (A gunner may aim toward a friendly target because he is disoriented but certainly will not pull the trigger unless he *also* fails to identify the target properly. Is the fratricide then due to his disorientation or his failure in identification?)

The chapter concentrates on, but does not restrict itself to, American experience. This should not, of course, imply that the U.S. military has a particularly serious problem with fratricide; even a quick glance at military history shows that every army that has fired a shot has had to take into consideration hitting one of their own, or else quickly learn hard lessons. Following the historical anecdotes are some data from the National Training Center—an instrumented, automated facility for combat manuevers--and finally a synopsis of the Persian Gulf incidents.

TYPES OF FRATRICIDE

There are no universally accepted definitions of friendly fire' or ''fratricide. The broadest—and older-definitions include any case in which anyone is hurt by a weapon from his own side other than his own. Thus, if an artillery round is faulty and falls short on friendly forces, that is friendly free; but if it is faulty and blows up in the breech and kills the artilleryman pulling the lanyard, that is an accident. More recently, the military has adopted definitions that exclude pure accidents and grossly malfunctioning equipment. The narrowest definition would include only *willful,* but mistaken, attacks on friendly forces. The current Army Training and Doctrine Command (TRADOC) definition is: ''The act of firing on friendly personnel or equipment, believing that you are engaging the enemy. '

This report uses a definition that excludes *purely* mechanical malfunctions but includes all other cases of friendly personnel receiving fire from weapons operated by other friendly personnel. Perhaps surprisingly, the material difference between the definitions is not great since few fratricide result *solely* from equipment failure.

■ Fratricides Due to Accidents

Malfunctions always occur, of course, and when dealing with weapons, they can be deadly. For example, in 1968, an F-4 flying to support troops engaged near Ban Me Thout, Vietnam, dropped a napalm canister on a church, killing 13 civilians. The cause was determined to be simply a faulty bomb rack.[8]

More often, however, malfunctions are just part of a chain of errors, sometimes compounded by human actions. For example, in World War 11, the lead bomber of a group would determine the target and all others in the group would release upon seeing the leader's release. During the attack on the Abbey of Monte Cassino in March 1944, a bomb rack malfunction resulted in the premature release by a lead bomber, which resulted in its and others' bombs being dropped on friendly positions. Similarly, on July 24 of that year, during the preparation for the breakout toward St. Lo, when the bomb rack on one lead bomber prematurely released, the other 15 bombers in the group immediately released their loads; unfortu-

[7]Briefing entitled, ''TRADOC Fratricide Study" (undated but received 1992). Note that, in practice, the Army does not always stick with this very strict definition, For example, some of the incidents from the Persian Gulf would have to be called "accidents" if using this narrow definition,

[8]Schrader, op. cit., footnote 5, p. 55.

nately they landed on the U.S. 30th Infantry Division, killing 25 and wounding 131.[9]

Ever since World War I, cases of rear gunners damaging their own aircraft have been common and continue to the present. Helicopter gunships are equipped with traverse-limiting rods that prevent the side-door machine-guns from swinging so far to either side that rounds could hit the helicopter. When such a rod broke on one helicopter during the Vietnam War, the gunner in the heat of battle tracked a target so far forward that he fired into the cockpit and wounded the pilot.

Even when weapons operate properly, unfortunate circumstances can cause what, in the broadest sense at least, might be classed as fratricide rather than accident. In the early morning hours of 5 November 1942 during the second Battle of Guadalcanal, the destroyer *Walke* was hit by Japanese naval guns and torpedoes. With the burning destroyer clearly sinking just a few minutes after being hit, the battleship *Washington* passed close by and launched life rafts for the *Walke's crew.* However, when the destroyer went down soon after, the depth charges on its hull exploded—just as they were designed to when reaching a certain depth-killing many of the crew in the water above.[10]

Some accidents due to human error could be avoided by different equipment design. A U.S. bomber in World War H bombed an air base of the U.S. Ninth Tactical Air Force after the bomber was hit accidentally by a packet of chaff; the surprise caused the bombardier to hit mistakenly the bomb release switch.[11] During the Vietnam War, an F-100 attacking a North Vietnamese Army Headquarters instead dropped bombs over a kilometer short on U.S. troops when the pilot hit the bomb release while trying to adjust the aircraft's trim button.[12]

Fratricide Due to Command and Control Failures

Failure of command and control is a far more common cause of fratricide than simple failure of equipment. Command and control includes telling units where to be, having units know where they are, and keeping units properly informed of the locations of neighbors.

The nighttime Battle of Cape Esperance began late on the night of October 11, 1942, with the destroyer *Duncan* breaking away from her group and charging off in total darkness toward a formidable Japanese fleet. The *Duncan* closed on a Japanese cruiser and opened fire. The crews of the American cruisers, seeing gun flashes very near known Japanese cruisers, assumed that the flashes came from a Japanese ship and attacked with eight inch guns. The flashes stopped almost immediately. Very likely the target had been the hapless *Duncan,* which was in flames, unable to free, and sinking within ten minutes of leaving its group. (Misidentification had been her downfall but it might also have saved her from further attack. During the Japanese retreat, the Japanese apparently *also* assumed that the ship within their midst was Japanese and did not attack, although heavy cruisers passing very close by could have disintegrated the little destroyer with a single salvo.[13])

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9 Robert H. George, ''The Battle of France," in *The Army Air Forces in World War II, Volume Three, Europe: Argument to V-E Day, January 1944 to May 1945,* Wesley Frank Craven and James Lea Cate, eds. (Washington, DC: U.S. Government Printing Office, 1983), pp. 228-277.

10 This repeated a similar tragedy of a week earlier when the destroyer *Laffey* sank and her depth charges killed several of those few crew members that were able to abandon ship. C.W. Kilpatrick, *The Naval Night Battles in the Solomons* (Pompano Beach, FL: Exposition Press of Florida, 1987), pp. 91, 118, and 121.

11 Army Air Forces, op. cit., footnote 9, p. 230.

12 Schrader, op. cit., footnote 5, p. 58.

13 Kilpatrick, op. cit., footnote 10, pp. 52-64.

The occasional misplaced shot is bad enough, but worse fratricide can occur when two friendly units start exchanging fire. One unit fires by mistake and the other unit-assuming fire to be a positive identification of enemy—returns fire. On August 8, 1944 during the fighting on Guam, two battalions of the 77th Infantry Division got into a prolonged fire fight. The exchange might have started as each side fried off several mortar rounds to calibrate the weapons' emplacement positions before settling down for the night. Rounds from each side fell near the other; both assumed that it was Japanese fire and thus returned fire with small arms and more mortars. This firing, of course, made it obvious to each unit that the other was enemy and then the accompanying tanks got involved. A real firefight was under way. Finally, their mistake became apparent, in part when each battalion called up the same artillery battalion to request that artillery fire be directed at the other.

A similar exchange became one of the worst cases of fratricide in the Vietnam War. One artillery unit aimed its guns correctly but used the wrong powder charge so the rounds went too far and landed on another U.S. artillery position. The second position responded with deadly accurate counterbattery fire. This duel went on for over 20 minutes and resulted in 90 casualties, all from friendly fire.[14]

Command and control procedures can prevent fratricide when identification is difficult. From the time that aircraft were first used for ground support in World War I, airmen knew that identification of ground units would be difficult. General William ''Billy' Mitchell said, "Our pilots had to fly right down and almost shake hands with the infantry on the ground to find out where they were. '[15] To avoid fratricide, both of infantry and pilots, World War I military com-

B-17s of Eighth Army Air Force bombing Berlin in 1944. One plane strays beneath another and has its tail clipped by falling bombs. Even perfect identification of friends will not eliminate all fratricide.

14 Schrader, op. cit., footnote 5, p. 21.

15 Richard Hallion *Strike From the Sky: The History of Battlefield Air Attack, 1911-1945* (Washington, DC: Smithsonian Institution Press, 1989), p. 39.

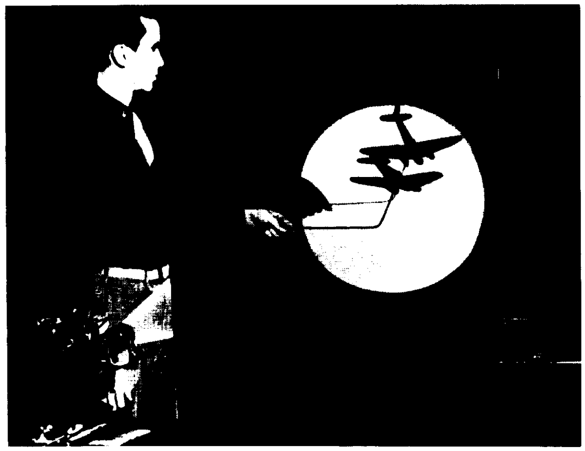
manders divided up combat areas into ''no-fwe" zones and "free-fire" zones.[16]

At the outbreak of World War II, the Germans had the best developed system for air-ground coordination. They began with a World War I system of colored panels to mark infantry positions. This worked well in the attacks on Poland until Polish defenses broke and the German army began a war of maneuver. The German 10th Panzer Division then reported 'constant" attacks by friendly airplanes.[17] The same story was repeated on the Western front, the Germans introduced a system of safety lines *(Sicherheitslinie)* to avoid attacks on their own troops,[18] which worked well at first but, again, once a war of maneuver began deep in French territory, fratricidal attacks increased sharply.

Clearly, in both cases above the change was not in the ability to identify; German pilots did not suddenly forget how to identify tanks that they could have identified the day before. Rather, identification had been difficult all along and operational command and control procedures, developed to serve *in lieu* of identification, broke down when the character of the fighting changed.

Recognizing the importance of rapid maneuver, and the strain it placed on any operational measures to avoid fratricide, the Germans worked diligently to develop better ground-to-air signaling and training programs to increase pilots' identification skills.

The single most famous case of fratricide illustrates the extreme difficulty of coordinating a complex attack by hundreds of elements, even along a stationary front. The carpet bombing in



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World War II classroom instruction in aircraft identification using resin models.

preparation for the Normandy breakout near St. Lo was filled with problems, with those precipitated by mechanical failure of a bomb rack cited above being just the beginning.

German defenses around the Allied armies in Normandy were tenacious but spread thin. Allied commanders decided that a single, concentrated blow would breach the defenses, allowing Allied armor to pour through the gap. The plan to puncture the defenses was called Operation COBRA. The first phase of the breakout was to be a carpet bombing of German positions. The attack was to start with 380 medium bombers hitting specific targets, followed by over 1,500 heavy bombers, B-17s and B-24s, dropping over 3,300 tons of bombs, with over 500 fighter-bombers and dive-bombers attacking anything that survived. For three hours, the sky would be filled with airplanes.[19]

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16 Maurer Maurer, ed., *The United States Air Service in World War I, Vol. II* (Washington, DC: Office of Air Force History, 1978), p. 373.

17 Williamson Murray, "The Luftwaffe Experience, 193941, '' in B.F. Cooling, cd., *Case Studies in the History of Close Air Support* (Washington DC: Office of Air Force History, 1990), pp. 85-86.

18 Genkdo. XIX. Armeekorps. Ia, Anlagenheft Z. KTB Nr 2, ''Zusamrnenarbeit mit der Luftwaffe, ' National Archives and Records Administration Washington (NARA) T3 14/615/372-393.

19 These numbers come from Craven and Cate, op. cit., footnote 9, p. 232. Most of the narrative is taken from Martin' Blumenson, *Breakout and Pursuit* (Washington, DC: Department of the Army, Office of the Chief of Military History, 1961), pp. 228-239. Part of the problem with a historical review of fratricide can be seen by a comparison of these two "official" histories, one by the Air Force, the other by the Army. The Army was on the receiving end and their history relates much of the controversy between the air and ground commands, while the Air Force history states somewhat matter-of-factly that ''Technically viewed, the bombing was good. " (p. 233)

The attack was delayed a week by weather, Then the July 24, 1944 attack was partially underway when it, too, was called off because of low visibility. (But not before the inauspicious short bombing described above.) Finally, the main attack took place on July 25.

General Omar Bradley thought that the benefit of the bombing would be greatest if the infantry attack could follow immediately after. He wanted ground forces as close as 800 yards even though the air commanders warned that 3,000 yards was the closest safe distance. They compromised at 1,450 yards.

Bradley and other ground commanders had insisted that the bombers approach parallel to the front, so that any ''short' bombing would result in bombing the wrong Germans, not in bombing the wrong side. The air commanders argued that this made their machines too vulnerable to antiaircraft fire. Bradley seems to have believed that he had agreement when he left the last planning meeting. Years later he insisted that "the Air Force brass simply lied" about the direction of the attack.[20]

With so many aircraft, mistakes were inevitable, Visibility was poor. Heavies were to bomb from 15,000 feet but a layer of clouds forced many down to 12,000 feet, which in turn forced groups to reassemble in crowded skies and bombardiers to recalculate bombing solutions in flight. Allied positions were marked with smoke, which was hard to see in the haze and essentially useless once the bombing started, since the bomb explosions raised mountains of dust that mixed with the smoke.

Human error was the cause of most of the short bombings. Mistakes were disastrous when committed by the lead plane of a group because command and control procedures called for the lead plane to sight the target and all other planes to release when the leader did. One lead plane had a broken bomb sight and released visually. Another bombardier thought he was on target but was orienting on the wrong landmarks.

Succeeding flights of bombers would almost never be able to see their targets because of the dust raised by first salvos. Therefore, their attempts to bomb targets were really the bombing of dust clouds, under which they hoped the bombs would find targets on their own.

Unfortunately, in this case, wind blew the dust toward U.S. positions and every wave of bombers struck a little closer. The war correspondent Ernie Pyle wrote later:

> As we watched there crept into our consciousness a realization that windows of exploding bombs were easing back towards us, flight by flight, instead of gradually easing forward, as the plan called for. Then we were horrified by the suspicion that these machines, high in the sky and completely detached from us, were aiming their bombs at the smokeline on the ground, and a gentle breeze was drifting the smokeline back over us! An indescribable kind of panic comes over you at such times. We stood tensed in muscle

NATIONAL ARCHIVES

Soldiers of the U.S. 30th Infantry Division dig out after being bombed near St. Lo by the U.S. Eighth Army Air Force.

20 Hallion, op. cit., footnote 15, p. 211.

and frozen in intellect, watching each flight approach and pass over us, feeling trapped and completely helpless.[21]

A company commander wrote,

> The dive bombers came in beautifully and dropped their bombs right where they belonged. Then the first group of heavies dropped them in the draw several hundred yards in front of us. . . The next wave came in closer, the next still closer. The dust cloud was drifting back toward us. Then they came right on top of us. We put on all the orange smoke we had but I don't think it did any good, they could not have seen it through the dust. ..22

The results of the misplaced bombing were deadly. Added to the casualties of the abortive attack on the 24th, the short bombings on July 25 caused official casualties of 490 wounded and 111 dead.[23] In addition, the 30th Infantry Division alone reported over 160 casualties due to "combat fatigue, " that is, soldiers simply stunned by the experience but not necessarily showing any bodily damage.

Among the dead was Lieutenant General Leslie McNair, Commanding General of the Army Ground Forces, pro tern commander of the 1st U.S. Army Group, and a strong supporter of air-ground combined operations. He had come to the forward area on the 25th specifically to help morale after the short bombings of the 24th.[24] He was killed instantly and could be identified only by his West Point ring.[25]

The bombings at St. Lo caused resentment between air and ground commanders. The commander of the 30th Infantry Division said, 'Theres no excuse, simply no excuse at all. I wish I could show some of those air boys, decorated with everything a man can be decorated with, some of our casualty clearing stations."[26] General Dwight D. Eisenhower reportedly swore never to use heavy bombers in combat support again, but their usefulness was too apparent and the ban did not last.

On the positive side, Operation COBRA also motivated important U.S. improvements in command and control of bomber groups and in procedures for marking of friendly lines on the ground. During Operation QUEEN, the Allied attempt to breach the Roer River, a carpet bombing preparation like that for Operation COBRA was to open the way for the infantry. This time giant fluorescent cloth panels marked the positions of friendly troops and tethered balloons flew parallel to the front line. U.S. troops also marked their positions by using their *90* millimeter antiaircraft cannon to fire red smoke shells straight up, and the bombing went well.[27]

Repeating the earlier German experience, however, the Allies found that these command and control procedures-depending on careful marking—broke down as soon as a war of maneuver began.

In operations near Cherbourg, a single British division, the 51st Highland, on a single day, August 18, *1944,* reported 40 separate attacks by friendly aircraft (more than occurred during the entire Persian Gulf War).[28]

On August 7, 1944 during OperationTOTALIZE—a franticly paced and fluid attempt to cut off a

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21 Cited in, Max Hastings, over/oral: *D-Day, June 6, 1944* (New York, NY: Simon and Schuster, 1984), p. 254.

22 Blumenson, op. cit., footnote 19, P. 237.

23 Ibid., p. 236.

24 Robert L. Hewitt, *Work Horse of the Western Front: The Story of the 30th Infantry Division* (Washington, DC: Infantry Journal Press, 1946), p. 37.

25 Russell Weigley, *Eisenhower's Lieutenants* (Bloomington, IN: Indiana University press, 1981), p. 170.

26 Hastings, op. cit., footnote 21, p. 255.

27 Kent Roberts Greenfield, "Army Ground Forces and Air-Ground Battle Team, " Study No. 35 (Historical Section: Army Ground Forces, 1948), p. 89.

28 Hasting, op. cit., footnote 21, p. 303.

huge German force fleeing through Falaise--U.S. heavy bombers bombed short, causing 300 casualties among British, Canadian, and Polish ground forces.

A week later, British bombers attacked U.S. Army forces. The primary culprit was a failure of inter-allied coordination. U.S. Army units used yellow smoke to mark their positions while the Royal Air Force used yellow smoke to mark its targets. A historian records one witness saying, "... the more the troops burnt yellow flares to show their position the more the errant aircraft bombed them."[29]

Sometimes failures of communication have forced gunners to fire on forces knowing full well that they are friendly. By the very strictest definition--that is, willful but *mistaken* attacks on friendly forces—this would not be friendly fire. The German general Guderian recounts how, during the blitzkrieg into France, Luftwaffe airplanes attacked his units. The ground units knew that the airplanes were German but were forced to return fire in simple self-defense. One pilot bailed out when flak hit his plane and Guderian himself was waiting for him on the ground.[30]

General Omar Bradley recalls that a flight of American A-36s attacked his armored column in Sicily. The tankers properly identified the aircraft as friendly and lit off yellow smoke flares, the markers for ''friendly' armor, but the attacks continued so the tanks returned fire and downed one of the planes, When the pilot parachuted to earth, the tank commander said, ''Why you silly sonuvabitch, didn't you see our yellow recognition signals?" To which the pilot replied, "Oh. . . is that what it was? '[31]

On August 15, during the breakout from Normandy, one American fighter pilot had the bad luck to mistakenly strafe the headquarters of the XIX Tactical Air Command near Laval. Antiaircraft gunners knew full well that the plane was American but again for self-defense were forced to return fire. Flak brought him down.[32]

Fratricide Due to Fire Discipline Failures

At the lowest level, ''command and control' devolves into something as straightforward as "fire discipline.' Indeed, where command and control concerns the actions of units, fire discipline concerns the actions of the individual shooter.

The following case illustrates a string of mistakes, fire discipline being just one: In the fighting in France, a group of eight tanks set out in low visibility in late afternoon of July 9, 1944. They were under strong pressure from superiors to make a symbolic advance by the end of the day. At a critical road junction, the group commander turned right instead of left, bringing them upon Company C of the 823 Tank Destroyer Battalion, later to hold a U.S. record for most German vehicles killed.

Based on the tactical situation, the company expected no U.S. tanks to be on that road and the tanks were approaching from the direction of German lines; thus the company reasonably assumed that they were German. The first tank took a direct hit from a 76 millimeter antitank cannon and was destroyed. The others continued to advance and opened fire. At 400 yards, the defenders recognized the tanks as American. One very brave sergeant stood up and waved wildly to get the tanks to stop firing but they kept on. The defenders stopped firing, took cover, and hoped for the best. One of the passing tanks shot at an uncamouflaged halftrack at a range of 15 yards, wounding a driver.[33] This incident shows that

29 John Terraine, *A Time for Courage: The RAF in the European War, 1939-1945* (New York, NY: Macmillan, 1985), p. 661.

30 Heinz Guderian, *Panzer Leader* (New York, NY: Dutton, 1952), p. 113.

31 Hallion, op. cit., footnote 15, p. 178.

32 Craven and Cate, op. cit., footnote 9, vol. III, p. 255.

33 Schrader, op. cit., footnote 5, p. 82.

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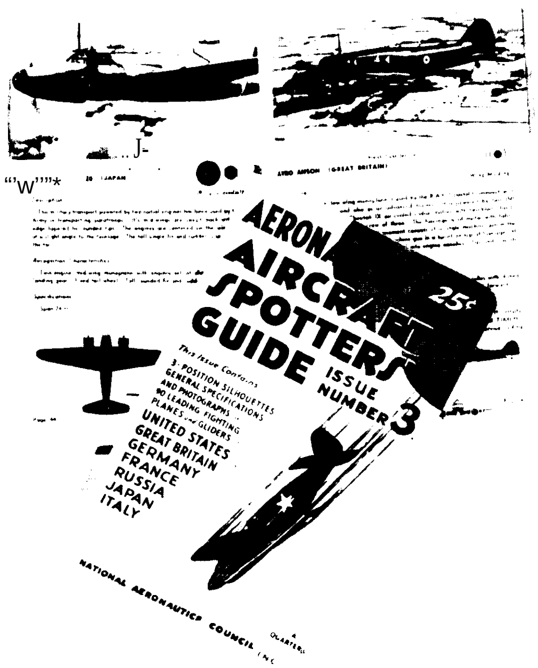

Aircraft Spotters' Guides distributed to troops in the field during World War II. The most basic identification system is comprised of the human eye and the human brain, but these require training to be effective.

fratricide occurs because of compounded errors; in this case, starting with poor navigation, poor communication, and faulty identification, and ending with lack of fire discipline, since inability to identify can hardly justify firing at a halftrack at 15 yards.

Lack of fire discipline was the major contributor to the worst antiaircraft fratricide in World War II. On July 11, 1943, the beachhead on Sicily was to be reinforced with a drop of 2,000 paratroops. The troops left Tunisia in 144 C-47 transports. The fleets and ground forces had been alerted to the drop. The flight went well until, when crossing over the coast at a very visible but vulnerable altitude of 1,000 feet, the transports were fired on by a lone machine-gunner. The beachhead forces had been attacked just hours earlier by German bombers and, once the firing started, discipline collapsed; everyone on the ground was 'throwing everything they had at us' as one airborne company commander later put it. A destroyer even fired on transports that had ditched at sea. The results were a disaster. Of the 144 transports, 23 were shot down and 37 damaged. One hundred forty one paratroops and air crewmen were killed. Many of the transports that survived did so by scattering; thus, of the original force of 2,000, only 500 or so could be effectively organized on the ground in the drop zone.[34]

Just two days later, the British suffered a similar incident in their zone of Sicily. Nineteen hundred paratroops were to capture the Primosole bridge, but more than half the transports were hit by either ship- or ground-based antiaircraft fire. Three hundred men did reach and capture the bridge.[35]

Fratricide Due to Navigation Failures

Closely related to command and control are the problems of navigation. During World War II Pacific fighting and in Vietnam, many artillery fratricides resulted from forward observers correctly calling in fire *relative to their putative positions,* but not knowing their own locations precisely.[36] This seems characteristic of jungle fighting, when forces could go long periods without knowing just where they were. The Marine Corp still refers to "The Battle of the Tenaru River' (on Guam), which actually took place on the Ilu River, but because the maps were so poor and the vegetation so thick, the men on the ground did not know that at the time.[37]

34 Carlo D'Este, *Bitter Victory: The Battle for Siciliy, July-August 1943* (New York, NY: William Collins, 1988), pp. 307-308.

35 Albert Garland and Howard Smyth, *Sicily and the Surrender of Italy* (Washington, DC: US. Army, Office of the Chief of Military History, 1965), p. 218.

36 Schrader, op. cit., footnote 5, p. 23.

37 Adrian Stewart, *Guadalcanal: World War II's Fiercest Naval Campaign* (@redo% England: William Kimber, 1985), p. 50.

Navigation, not identification, clearly was the problem when Navy dive-bombers were called in to attack Japanese defenders on the tiny island of Tanambogo. The planes bombed *the wrong island,* adjacent Gavutu, killing three Marines and wounding nine others.

Navigational blunder was responsible for mistaken aerial bombing of civilians in World War II. One of the earliest incidents was a German error. On May 10, 1940, 20 Heinkel 111s set off to bomb Dijon. One Luftwaffe lieutenant got separated from the group due to bad weather. When a city suddenly appeared below, he took it to be Dijon and bombed it but it turned out to be the German town of Freiburg. (Instantly, the Ministry of Propaganda announced that Allied aircraft had initiated a deliberate policy of 'terror bombing, ' with the innocent citizens of Freiburg as the frost victims.)38 In general, however, these sorts of gross navigational error rarely caused fratricide in World War II.

Fratricide Due to Identification Failures

Finally, many fratricide are due to straightforward misidentification. The first aircraft used in combat in World War I did not even display national insignia. When German ground fire brought down a Zeppelin on August 23, 1913, the Germans painted Iron Crosses on all their aircraft. The British adopted markings too, but quickly learned that gunners confused the Iron Cross and the Union Jack insignia so they switched to red, white, and blue roundels similar to those used by the French at the time.

Oftentimes an observer sees what he is looking for, not what he is looking at. The "scientific method' calls for first forming a hypothesis and then searching for evidence that it might be wrong. Psychological tests show that people recognize things in the opposite way, by forming

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A World War II classroom for training sailors in the identification of naval ships and airplanes.

a hypothesis and then searching for additional evidence that it is correct.

On May 15, 1941, a formation of Fairey Swordfish took off from the British carrier *Ark Royal* as part of the epic search for the German battleship, *Bismarck,* They soon spotted a large warship and launched torpedoes against it. But it was the cruiser *HMS Sheffield,* a ship that did not look anything at all like the *Bismarck.* A historian wrote, "Expecting to see the *Bismarck, Bismarck is* what they saw. ' Fortunately, skillful evasion by the *Sheffield* ensured that the torpedoes missed, One Swordfish pilot radioed, ''Sorry for the kipper. ' '[39]

Seeing what one expects to see accounts for a particularly dangerous opportunity for fratricide: patrols returning to friendly lines. Since scouts and patrols are coming from the direction of the enemy, getting past friendly, but nervous, guards and lookouts can be tricky. Thomas ''Stonewall' Jackson went ahead of his own troops to reconnoiter Union lines during the Battle of Chancellorsville. Just as Jackson was returning to confederate lines, forward units of General Joseph Hooker's Union infantry reached the North Carolina troops near Jackson. Some shots were fired and the hastily dug-in Confederates were greatly

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38 Wolfgang Dierich, *Kampfgeschwander "Edelweiss": The History of a German Bomber Unit* (London, England: Ian Allen, 1975), p. 26.

39 Ludovic Kennedy, *Pursuit:* The Chase *and Sinking of the Battleship Bismarck (New* York, NY: Pinnancle, 1975), pp. 154-155.

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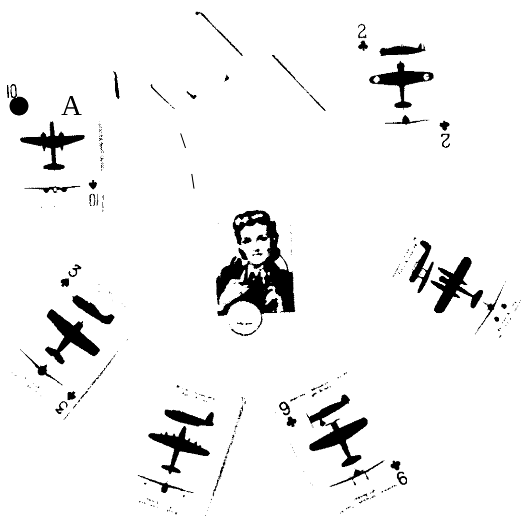


World War 11 troops were given free packs of Airplane Spotter Playing Cards. Maintaining good identification skills requires constant practice,

excited by anticipation of the oncoming assault. Hearing the firing, Jackson hurried back toward his own lines but under the nervous conditions a forward Confederate picket—seeing riders approach from the direction of known enemy forces—shot and mortally wounded the general.[40] Some admirers of Jackson argue that his death changed the course of the war, which, if true, would make it the fratricide of greatest consequence uncovered during this research.

Misidentification due to similarities between weapons are more understandable. Many friendly fire losses during the Battle of Britain were attributed to the similarity of the Supermarine Spitfire Mark I and the Messerschmitt Me-109E fighters. Also, the Bristol Blenheim twin-engine fighter resembled the German Junkers Ju88 medium bomber. The latter similarity lead to the destruction of three Blenheims. One section of Canadian Hurricanes, thinking that the planes below them were Junkers, attacked but pulled away at the last second when the leader realized his mistake. The next section still went in for the attack, in part because they mistook the yellow and red Very recognition flares for tracer fire from machine-guns. One Blenheim blew up in the air and the other two crash-landed.[41]

During World War II, considerable effort and attention went to improving identification of aircraft. As one response, the British developed electronic IFF devices. A touring "air circus" was also organized so ground forces could practice identifying real aircraft overhead, not resin models in a classroom.

TACTICAL CONSTRAINTS DUE TO FEAR OF FRATRICIDE

At times in the past, fratricide has been accepted as a costly necessity of combat. For example, World War I tactics made some fratricide almost inevitable. Trench defenses could be captured if the defending machine guns were suppressed by artillery fire while the attackers approached the trench works; thus, the attackers wanted the artillery to pound defensive positions up to the last second. In this situation, attackers were willing to have friendly artillery fall very close because they believed that the losses due to fratricide would probably be less than those from enemy machine-gunners.[42] A World War II battalion commander said, "We must teach our soldiers to remember that when they follow the artillery barrages and air strikes closely, they

40 G.F.R. Henderson, *Stonewall Jackson and the American Civil War* (New York, NY: Da Capo, 1988), p. 678.

41 Richard Collier, *Eagle Day* (New York, NY: Avon, 1969), p. 140.

42 For example, from Ian V. Hogg, *Barrage: the Guns in Action* (New York, NY: Ballentine Books, 1970), p. 21, "The French, with their greater elan and still-unconquered spirit of attack at all costs, were known to observe that unless the infantry suffered 10 percent casualties from their own artillery, they weren't following the barrage close enough!" or". . the 'creeper' [rolling barrage] covered the ground progressively in front of and behind the objectives. All the infantry had to do was to stay close to it even if the occasional short round sprayed them with shrapnel." from Shelford Bidwell and Dominick Graham, *Fire Power: British Army Weapons and Theories of War, 1909-1945* (London, England: Allen and Unwin, 1982), p. 111.

eventually suffer fewer casualties even though an occasional short may fall on them. ' '[43]

Yet no commander can afford to be indifferent to fratricide and avoiding it can limit tactical options. For example, the need to insure safety of infantry operating with artillery severely hampered the flexibility of the massive British battle plans for the great World War I attack at the Somme.

Fratricide has a greater cost than the direct combat loss of the forces hit. Fear of fratricide can so inhibit a commander's actions that combat efficiency is much reduced. The Center for Army Lessons Learned (CALL) reports several consequences of fratricide incidents that reduce combat effectiveness.[44] These are listed in Table 2-1.

In addition, friendly fire does not need to kill to have a *suppressive* effect. In some instances, for example in World War II battles on the islands of Biak and Luzon, groups of infantry as large as battalions spent whole afternoons pinned down by friendly fire of various sorts, seriously disrupting coordination of attacks.

Nighttime World War 11 naval battles are filled with cases of tactical confusion in general and fratricide in particular. During the Battle of Cape Esperance, control broke down from the start with the charge of the destroyer *Duncan,* described above. The situation became so confused so quickly that the American group commander, Admiral Scott, ordered ''Cease firing, our ships! Scott further ordered that ships flash their recognition light (colored lights up either side of the bridge).[45]

The Americans' problems with sorting out the situation benefited the Japanese enormously. Firing was halted for four minutes. This may not seem like much until considering that the heavy cruiser *Salt Lake City* had fired 80 eight inch rounds in the first two minutes of the battle and the light cruisers were averaging an incredible 150 rounds a minute each—so four minutes was a long time. Furthermore, the signal lights revealed the ships' locations to the Japanese.

Table 2-l—Detrimental Effects of Fratricide

- **Hesitation to conduct limited visibility operations**
- **Loss of confidence in unit's leadership**
- **Increase of leader self-doubt**
- **Hesitation to use supporting combat systems**
- **Oversupervision of units**
- **Loss of initiative**
- **Loss of aggressiveness during fire and maneuver**
- **Disrupted operations**
- **Needless loss of combat power**
- **General degradation of cohesion and morale**

SOURCE: Center for Army Lessons Learned.

Finally, the lights *identified the* U.S. ships for the Japanese. Ironically, their commander, Admiral Goto, had thought that he was under mistaken attack from another Japanese force and had been hesitant to return fire, but the distinctive recognition lights showed the force to be American. Within an eight minute period shortly after midnight, Scott ordered recognition lights to be flashed three more times. The group was never completely under control and both sides withdrew without a clear decision.

During the Battle of Savo Island in the early morning hours of August 9, 1942, the crew of the heavy cruiser *Vincennes* believed that she was coming under friendly fire so she hoisted a huge American flag up the mast. The Japanese assumed that this must mean that she was the flagship and therefore concentrated their fire on her. Two minutes later, Japanese cruisers took the U.S. destroyer, *Ralph Talbot,* under fire. Her skipper,

43 Schrader, op. cit., footnote 5, p. 17. Also from footnote 53 of chapter one of Schrader: ''An experienced infantry officer who served as a battalion S-3 in Vietnam related to the author that it was his common practice (and that of others) to accept up to 5 percent friendly casualties from friendly artillery in the assault before lifting or shifting fires. The rationale, of course, is that it is preferable to suffer 5 percent casualties from one's own fire plus 5 percent from the enemy than to permit the enemy, through lack of adequate suppression, to inflict 15 percent casualties on the attacking force. '

44 Center for Army Lessons Learned, *Fratricide Risk Assessment for Company Leadership,* CALL Handbook No. 92-3 (Fort Leavenworth, KS: Center for Army Lessons Learned, March 1992), p. 4.

45 Unless otherwise cited the following naval accounts arc from Kilpatrick, op. cit., footnote 10.

Lt. Commander Callaham, also believed that he was being fired on by friends so he turned on his recognition lights. This action was so unexpected that the Japanese were momentarily flummoxed, worrying that perhaps they were firing on another Japanese ship. The Japanese cruisers were forced to use search lights to illuminate the *Talbot.* She took several hits but escaped into a squall.

Nearby, on August 21, again in the early morning darkness, the U.S. destroyer *Blue* and the Japanese destroyer *Kawakaze* detected one another at almost the same time. The American ship was equipped with radar, which the Japanese had deployed on only a very few ships-and those units were primitive. For night fighting, the Japanese relied instead on specially trained lookouts equipped with oversized, night-use binoculars. During clear weather, the Japanese visual method was as good as U.S. radar. In this particular case it was better. For whereas the *Blue* detected a blob on a radar screen, the *Kawakaze* detected and *identified* target. Thus, as the *Blue* was creeping forward to get a better view, the *Kawakaze* was launching 21-inch diameter *"Long* Lance" torpedoes that ripped the stern off the American destroyer. She was later scuttled.[46]

During the closing moments of the Battle of Empress Augusta Bay, the cruiser *Montpelier* received direct orders to fire at a target at specified coordinates. In the pre-dawn darkness, the *Montpelier's* commander was uncertain of the target and intentionally directed that the first salvo should miss. He then listened in on the TBS (Talk-Between-Ships) radio for two minutes and, failing to hear any complaints, commenced firing to hit. This time, the incoming rounds quickly got the attention of the target, which turned out to be the American destroyer *Spence.* Radio calls for a cease fire were heeded before any damage was done but, clearly, the lack of identification required a tactical solution that would have given some advantage to an enemy, either a chance to evade further fire or return fire.

Caution induced by fear of fratricide can be exploited by an enemy. During World War II, artillery fire began the preparation for an attack by the 3rd Infantry Division against the town of Osheim on January 23, 1945. The leading battalion reported that shells were landing on their position and the barrage was halted. More range was added and the barrage resumed but rounds still fell on the lead battalion. Finally, the Americans discovered that the fire was coming from nearby German tanks that held their fire until the barrage started, specifically to fool the Americans into believing they were receiving friendly fire and so trick them into calling a halt to the barrage. (Incidently, the 3rd Division later adopted rules that called for finishing planned barrages regardless of reports from forward units, which may have contributed to later fratricides.)[47]

The Japanese also used the technique of synchronizing the artillery fire with their enemy artillery, although perhaps for different reasons. On Guam and elsewhere in the Pacific theater, Japanese artillery and mortar crews would wait until U.S. artillery was firing before firing their own guns, thus increasing the difficulty of locating them by their sound. In addition, of course, U.S. troops noticed that when U.S. artillery fired, they often received incoming rounds, causing them to believe it was friendly fire.

THE PREVALENCE OF FRATRICIDE

Any conclusions about the general prevalence of fratricide developed from a collection of anecdotes must be regarded with healthy skepticism. Several sources use a figure of two percent of casualties that have been due to fratricide in

46 Stewart, op. cit., footnote 37, p. 50.

47 Schrader, op. cit., footnote 5, p. 9.

20th century wars. In fact, the two percent figure seems to have become almost a rule of thumb.[48]

One of the great difficulties is knowing who fired which shot. Only rarely is reliable evidence available, but it is sobering to discover that when evidence is there, it often reveals fratricide that participants at the time were unaware of. Two cases from the same campaign provide interesting examples. The reader has doubtless noticed that many examples used here come from the Solomons naval campaign. This is not surprising when one considers that many of the major battles there took place at night, resulting in poor coordination and frequent misidentification. But the same conditions that made mistakes likely made it unlikely that they would be detected.

In one case, however, U.S. friendly fire left a clear fingerprint. U.S. warships carried a limited supply of ''dye-loaded" shells, with each ship carrying a different color. The added dye allowed two ships shooting at the same target to distinguish the splashes of rounds hitting the water and thus independently adjust their fire. When the light cruiser *Atlanta's crew examin*ed battle damage after nighttime engagements off the coast of Guadalcanal, they discovered nineteen hits from eight inch shells loaded with green dye, the color of the heavy U.S. cruiser *San Fransisco.*

The depleted-uranium rounds used by U.S. tanks during the Persian Gulf War left a similar telltale and again, fratricide rates turned out to be higher than previously suspected. That combat is discussed further in the last section of this chapter.

Perhaps the best estimate of overall rates of fratricide come not from traditional military histories and action reports but from the medical records. The U.S. military has long kept records of the causes of casualties. Unfortunately, the normal reports lack enough detail to determine conclusively that a casualty was caused by friendly free. Moreover, without a detailed accounting of *all* casualties in a given time or place, we cannot know the numerator and denominator needed to calculate the *fraction* of casualties caused by friendly fire.

In a few cases, starting in World War II, however, detailed casualty surveys have been carried out that allow a reliable estimate of the frequency of friendly fire losses in those cases. The frost was conducted by Dr. James Hopkins, who maintained detailed records of cause of wound for every casualty in his batallion. He served for part of the war on New Georgia Island-near Guadalcanal--and part in Burma. He examined the wounded and conducted interviews after actions. Hopkins was able to determine that 16 percent of those killed and 19 percent of those wounded were the victims of friendly fire by his broad definition, which includes accidents in the use of weapons.[49] By TRADOC's current, narrower definition, as applied by Dr. David Sa'adah of the Department of the Army, Surgeon General's Office, the figures would be 13 percent and 14 percent.[50]

Two other comprehensive surveys examined all of the casualties from two divisions in Bougainvillea, in the South Pacific, in 1944. Almost a hundred of the killed were more carefully examined by autopsy to determine cause of death.[51] These surveys reveal that 24 percent of

48 See Schrader, op. cit., footnote 5, p. 105; Trevor Duprey, *Attrition:* Forecasting *Battle Casualties and Equipment Losses in Modern War* (Fairfax, VA: Hero Books, 1990), p. 3; and Dwight Dickson and Elrin Hundley, "Avoiding Not So Friendly Fire," *Military Review,* July 1992, p. 57.

49 James Hopkins, ''Casualty Survey-New Georgia and Burma Campaigns,'' in James C. Beyer, cd., *Wound Ballistics* (Washington DC: Office of the Surgeon General, Department of the Army, 1962), pp. 237-280 from the series, *Medical Department, United States Army in World War II,* Colonel John Lada, Editor in Chief.

50 See Colonel David M. Sa'adah, Office of the Surgeon General, Headquarters, Department of the Army, "Friendly Fire: Will We Get It Right This Time?' p. *7.*

51 Ashley W. Oughterson et. al., ''Study of Wound Ballistics—Bougainville Campaign, " in Beyer, ed. op. cit., footnote 49, pp. 281-436.

the deaths were due to fratricide, using the narrower current TRADOC definition.[52]

In Vietnam, only the United States and its allies had certain types of weapons, for example, air-delivered ordnance of any sort-especially napalm, certain types of artillery, and so on. Thus, by examining the wounds of casualties and determining g the type of weapon that caused them, one can estimate the fraction that are caused by friendly weapons. Using this approach, some unpublished reports cited in the press estimate that perhaps 15 to 20 percent of the casualties in Vietnam were fratricides.[53]

The U.S. Army also conducted careful casualty surveys during the Vietnam War that were compiled in the Wound Data and Munitions Effectiveness, or "WDMET" study. The data were collected between 1967 and 1969 from elements of one cavalry and three infantry divisions. An absolute figure for fratricide is not available from the WDMET survey. However, the data include the type of weapon causing the injury, and in four cases the type is very specific and was almost certainly in the hands of U.S.-or at least allied-troops: the M16 rifle, the M79 grenade launcher, artillery (excluding mortars), and Claymore mines. These four weapon types alone accounted for 11 percent of all U.S. casualties, including 10 percent of the fatalities.[54] The summary of the data compiled by Colonel Sa'adah is shown in table 2-2.

These casualty surveys cover only limited cases for which data are available, but again it is worthwhile to note that in every case where data are available, the fratricide rate is significantly higher than the two percent that frequently appears in print as the nominal fratricide rate.[55]

Despite the hit-and-miss of using historical anecdotes, the types of fratricide do show some patterns. As might be guessed, indirect fire weapons or long-range weapons (in past wars, artillery and bombers) have been more likely to be responsible for friendly fire. Also, the damage done by these weapons is disproportionately great because mistakes involving single-shot weapons, like tank guns, kill one friend at a time, while artillery barrages and bomber attacks can devastate whole units. The Persian Gulf war did not have any artillery fratricide. This may be good luck or reflect an important change brought about by better communication and navigation.

Perhaps surprisingly, there seems to be no strong correlation between type of action and likelihood of fratricide; it is just as likely during offense or defense. Fratricide between neighboring units appear to become more likely the greater their separation in the chains of command. Whenever units operate near one another and have poor communication, poor navigation, or are poorly controlled, fratricides can occur.

Fratricide of almost any type are more likely during periods of limited visibility when identification is harder. However, although better identification is frequently presented as *the* solution to friendly free, Schrader classified only about a quarter of the cases in his review as due *primarily* to misidentification. The majority of fratricide were more properly explained by failures of command and control or fire discipline. See figure 2-1.

52 Sa'adah, Op. cit., footnote 50, p. 8.

53 David Morrison, "Foes Not the Only Threat in the Gulf War," *National Journal*, Feb. 9, 1991, p. 335, citing the work of Colonel David HackWorth.

54 Sa'adah, op. cit., footnote 50, p. 10.

55 During the course of this assessment, the author has had several opportunities to collect personal accounts from military personnel that served in Vietnam. This is admittedly a totally unscientific sampling but the clear concensus is that a 2 percent fratricide rate is a serious underestimate. See also app. A in Colonel Sa'adah's paper, "The 2 Percent Nonsense."

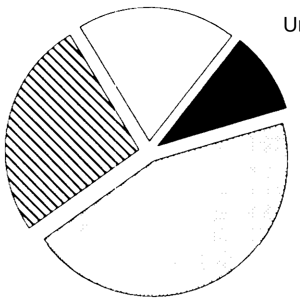
Table 2-2—Friendly Fire Data in Combat Casualty Surveys—World War II Through Operation Desert Storm

Survey location/name forces in survey	Line	No. of cases in survey	No. of cases KIA + DOW	No. of cases WIA	KIA + DOW by friendly fire No.	KIA + DOW by friendly fire %	WIA by friendly fire No.	WIA by friendly fire %	Prevalence: survey definition	Prevalence: TRADOC definition
New Georgia and Burma/Hopkins	l a	370	102	268	16	16	50	19	17.970	
Jungle perimeter defense	lb	353	99	254	13	13	36	14		14%
July 18-Aug. 5, 1943,										
Spearhead across Burma,										
Feb. 15-June 8, 1944										
Bougainvillea Beachhead perimeter	2a	1,788	395	1,393	63	16	156	11	12.3%	
defense	2b	1,778	392	1,386	60	15	149	11		12%
Feb. 15-Apr. 21, 1944										
Bougainvillea autopsy	3a	99	99	0	30	30	0	0	Not computed	
Mar. 22-Apr. 21, 1944, 25% of all	3b	91	91	0	22	24	0	o		24%
KIA + DOW within Bougainvillea survey										
Vietnam WDMET	4a	5,993	1,279	4,714	NC	NC	NC	NC	"almost	
Components of 5 Army divisions	4b	5,993	NC	KIA+DOW=WIA=667					certainly more	11%
June '67-June '69, preferably in									than 10%"	
offensive engagements										
Vietnam WDMET autopsy	5a	500	500	0	NC	NC	o	o	Not reported	
July '67-Nov. '68, 500 consecutive	5b	500	500	0	51	10	0	o		10940
autopsies within VN WDMET										
All U.S. Forces, Jan. 17-Dee. 15, 1991	6a	613	146	467	35	24	72	15		17%
Operation Desert Storm	6b	613	146	467	35	NC	72	NC	Not reported	

Within each survey, Line a displays the data as presented in the original study. Line b standardizes this same data to the current TRADOC definition of "fratricide."

KEY: DOW = died of wounds; KIA = killed in action; WIA = wounded in action; NC= not calculated.

Figure 2-1—Causes of Fratricide: Direct Fire Fratricide in World War II, Korea, and Vietnam



SOURCE: U.S. Army

THE NATIONAL TRAINING CENTER

Data collected from the National Training Center (NTC) at Fort Irwin, California are important enough to warrant special notice. The Army maintains training centers where visiting units can engage in mock combat with "OPFORS' or "opposing forces." The NTC is of particular interest because it has been equipped with a sophisticated laser direct-fire engagement system called the Multiple Integrated Laser Engagement System, or MILES. The NTC is also equipped with location and engagement recording systems.

Guns on tanks, infantry fighting vehicles, even personal rifles, are equipped with lasers. When the gun 'fires' a blank round, the laser also fries. Each of the major weapons and each of the personnel have detectors that sense when a laser "hit" occurs.

The laser pulses are coded in such a way that the detectors know the type of weapon that freed. Thus, if a tank detects that it has been shot by a rifle, nothing happens; but if a rifleman's sensor detects that he has been shot by a tank, his sensor registers a' 'kill.' A kill is signified by activating a flashing light. Each shot and each hit activates a small radio pulse indicating type of shooter and target, which is picked up by antennas spaced around the training center. These data are recorded along with their time, and data are analyzed by computer after each exercise to explain to the participants various mistakes that were made.

The Army emphasizes that its training centers are for *training*, not experimenting or data collecting, so the system has not been set up with fratricide data collection in mind. It nevertheless provides invaluable insight into the causes of fratricide. Some questions arise about the relevance of the data since these are not real battles so perhaps the participants do not behave the way they would in actual combat. Nevertheless, the data are enormously rich compared to information about real battles, so if one believes the simulation valid, the data are proportionately useful. One can then try to examine hits caused by friendly fire and hope to learn something of the circumstances.

Much of the following is taken from a brief RAND study that evaluated data from 83 battalion-sized battles.[56] See figure 2-2. Considering the causes of the fratricides observed, the study states:

> Of the 18 cases of fratricide, one-half could have been prevented had the shooting vehicle been aware of the location of a sister organizational unit, for the destroyed vehicle was located in a friendly formation with no enemy nearby. Another third of the cases could have been prevented if the shooter had knowledge of the location of individual isolated friendly vehicles, a more difficult requirement. One-sixth of the cases involved the killing of a friendly vehicle while close to opposing force (OPFOR) elements.

56 Martin Goldsmith, *Applying* the National Training *Center Experience-Incidence of Ground-to-Ground Fratricide*, RAND Note N-2438-A (Santa Monica, CA: The Arroyo Center, RAND Corporation February 1986).

> In this class, only an Identification Friend or Foe (IFF) device could provide the information necessary to positively avoid fratricide.[57]

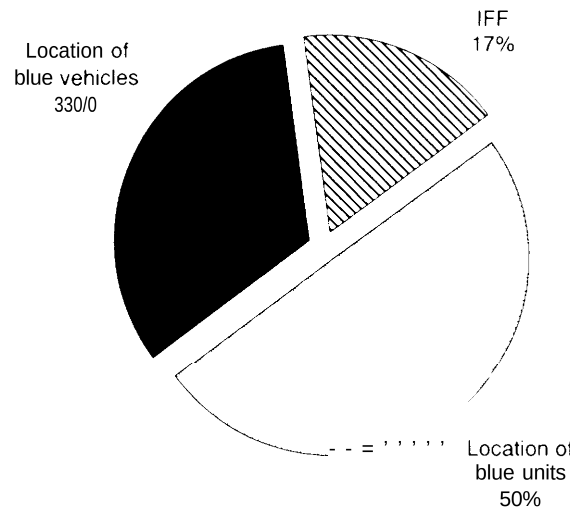
The data indicate that at least 1 percent of the "blue" vehicles killed were killed by friendly *direct* fire. This figure is much less than in the Persian Gulf War. Two possible biases may explain the difference. The NTC data may underestimate some fratricide. For example, if the lasers cannot penetrate through dust, then no kill is recorded even though a tank round would have scored a hit in actual battle. This effect works to reduce hits from enemy attacks as well as fratricidal attacks, but since fratricide is more likely to occur in dustier conditions, it might be under-recorded to some degree. In addition, the OPFOR train all year long on the same ground and are excellent troops (according to their own evaluation, not just good but the best). Thus, total blue "casualties" are usually high in the simulated combat, unlike the Persian Gulf experience, and the resultant ratio of friendly fire casualties to total blue casualties unusually low.

Artillery cannot be simulated with MILES but other means are available, The data available indicate that 3.6 percent of artillery fire missions resulted in some fratricide. This result appears worse when one considers that only about a third of the artillery missions hit anything at all, friend or enemy. Thus, *of those artillery fires that hit anything,* about one-tenth hit friendly forces. Experience at the NTC also suggests that fratricide resulting from artillery-delivered mines and unexploded submunitions may be almost as serious a concern as other artillery fratricides, although the MILES data do not now allow a quantification of this effect.

Some fratricides were clearly caused by misidentification but more were due to disorientation. (This result depends on the terrain; preliminary unpublished data from a similar test facility in Hohenfels, Germany suggests that disorientation is not as important there as misidentification. However, the German test range is much smaller and some nearby hills apparently provide easy orientation landmarks.) Several fratricides at the NTC occurred when no enemy forces were nearby and, moreover, the commanders knew that enemy were unlikely to be near.[58] These cases could be cured by better fire discipline. Mistakes due to true misidentification were most common in melees and poor visibility.

The data collected at the NTC is now being exploited for fratricide ''lessons-learned.' Most of this work is now coordinated through CALL, or the Center for Army Lessons Learned, part of the U.S. Army Combined Arms Command at Fort

Figure 2-2—Types of Information Needed to Avoid Fratricide: Direct Fire Fratricide at the National Training Center



SOURCE: U.S. Army.

57 Ibid., p. vi.

58 Ibid., p.13.

Leavenworth, Kansas.[59] Since the Persian Gulf War, observers at the NTC have had to fill out fratricide incident reports whenever MILES detects friendly free. Preliminary unpublished results show that observers on the ground attribute fratricide most often to identification failure, but that this accounts for just over a fifth of the cases, with another fifth due to failures of command and control, another fifth due to planning failure, and a combination of communication and navigation problems and simple mistakes making up the balance. Incorrect assessment of the tactical environment was cited as the most common contributing cause.

MILES is being expanded at other training centers and will no doubt provide increasingly valuable information about how fratricides occur and can be avoided.

FRATRICIDE DURING THE PERSIAN GULF WAR

The current surge in interest in fratricide is due largely to the experience of the recent Persian Gulf War. Wars are complex and no two are identical, so "lessons" from the war should not be considered universal truths. Although many conditions in the Persian Gulf were special, some argue that this war was a first example of the "high tech" wars of the future. It may also be representative of a type of war that will be more common for the United States in the future: one in which massive, overwhelming force is applied quickly and decisively. A primary appeal of these types of actions is that U.S. casualties are potentially very low considering the scale of the military operation. This report has pointed out already that one reason the fraction of casualties due to fratricide was high is that total U.S. casualties were so very low. Another way of looking at this is that if low casualties are characteristic of an important class of future conflict, then the *relative* importance of fratricide will be much greater.

There were 615 U.S. battle casualties in Operation Desert Storm, 148 of which were fatal. Of the 148 fatalities, 35-or 24 percent—were caused by friendly fire. Of the 467 nonfatal battle casualties, 72--or 15 percent—were caused by friendly free. These percentages seemed high at the time when compared to those assumed from wars past but the review of past rates of fratricide suggest that there has been a substantial underappreciation of the rate of fratricide in past wars.

Of the 35 soldiers killed by friendly fire, seven were on the ground while the 28 remaining were in vehicles. This distribution reflects the highly mobile, mechanized nature of the combat—that is, most U.S. forces were in vehicles so one would expect more casualties there-but it is also hopeful for those seeking a technical solution, since mounting combat identification equipment on vehicles is much easier than mounting it on individual infantrymen.

A case-by-case description of the known fratricide incidents is listed in table 2-3.[60] Few individual cases stand out as being unique to the modern equipment used in the Persian Gulf War. In one instance, a radar-seeking missile lost track of the Iraqi radar for which it was intended and-while attempting to reestablish a target track-locked onto a nearby U.S. radar. This type of technology-dependent mistake is, however, the exception; many of the descriptions of friendly fire—with a change of weapon designation—could have taken place in the deserts of North

59 At the time of this writing, CALL's research is still in draft form and unpublished but their results seem so far to confirm the RAND work. Major Rick Bogden, personal communication, February 1993.

60 This information is taken from "W@ Probes Friendly Fire Incidents," a news release from the Office of the Assistant Secretary of Defense (Public Affairs), dated Aug. 13, 1991. Note that some of the incidents are not ''fratricide' by the narrowest definition now used by the Training and Doctrine Command. For example, casualties due to faulty missiles or artillery rounds would be considered accidents because they did not result from a deliberate act of firing, believing one was firing at the enemy.

Table 2-3—Persian Gulf Friendly Fire Incidents—1 991

Ground-to-Ground

January 29-Four Marines were killed when their Light Armored Vehicle (LAV) was struck by a TOW missile which was fired from another LAV west of Kafji, Saudia Arabia.

February 14-Three soldiers were wounded in a small arms exchange during urban clearing operations in the town of Arky Amah Al Jadid, Saudi Arabia.

February 24-One Marine was killed when the convoy he was in received fire from a tank.

February 26-Three soldiers were killed and three wounded when their armored personnel carrier (APC) was hit by machine gun fire from a tank.

February 26-One soldier was killed when his vehicle was hit by a premature burst of an artillery round.

February 26--Five soldiers were wounded when their Bradley Fighting Vehicle (BFV) was incorrectly identified and hit by a TOW missile.

February 26--Two Ml Al Abrams tanks were hit by fire from another M 1 Al tank. No casualties occurred.

February 26-Two soldiers were killed and six wounded when their BFV, which was operating in reduced visibility, received fire from a M1A1 Abrams tank.

February 2&Two BFVs, while operating at night in reduced visibility, were fired upon by a Ml Al tank. No casualties occurred.

February 27—Six soldiers were killed and 25 wounded when five M1A1 tanks and five BFV's engaging enemy forces were incorrectly identified at night in reduced visibility and engaged by other M1A1 tanks.

February 27—Two soldiers were killed and nine were wounded when three BFVs were fired upon by a M1A1 tank because of incorrect identification.

February 27—Three damaged M1A1 tanks were deliberately destroyed by other Ml Al tanks to assure they could not be used by the enemy.

February 27-One soldier was killed and one wounded when 2 BFV's were incorrectly identified at night in the rain and fired upon by a Ml Al tank.

February 27-One soldier was killed and two were wounded when two BFV's were hit by fire from a M1A1 tank while operating in rain and smoke at night during an attack on a bunker complex.

February 27—Two soldiers were killed and two wounded when their BFV was fired upon by a Ml Al tank while operating at night in reduced visibility.

February 27----One soldier was killed and one wounded by machine gun fire when they were incorrectly identified as Iraqi forces.

Air-to-Ground

January 23-A USAF A-10 Thunderbolt fired on a Marine observation post with no casualties.

January 24--One Marine and one sailor were wounded when a USAF A-1 O strafed a USMC Hummvee and a five-ton truck about 60 miles west of Kafji, Saudia Arabia.

January 29-Seven Marines were killed and two wounded when a USAF A-1 O fired a Maverick missile which malfunctioned in flight and hit a LAV,

February 2-One Marine was killed and two were wounded during an air attack by a USMC A-6E using 500-pound bombs after their vehicles were incorrectly identified as Iraqi.

February 2—Two soldiers were wounded when a HARM missile fired by a USAF F-4G Wild Weasel did not properly acquire its intended target and locked onto the soldiers' radar.

February 4-A HARM missile is suspected to have landed close to the USS Nicholas (FFG-47) resulting in no casualties and only superficial damage to the ship.

February 17—Two soldiers were killed when a BFV was struck by a Hellfire missile fired from an AH-64 Apache helicopter. Six soldiers were wounded and aground surveillance vehicle was also damaged in the incident.

February 23-One Marine was killed and one wounded when a HARM missile from an undetermined source struck a radar unit.

February 24-A HARM missile is suspected to have landed close to the USS *Jarrett* (FFG-33) with no casualties or damage to the ship.

Ship-to-Ship

February 25--USS *Jarrett (FFG-33)* fired at a chaff rocket launched by USS *Missouri* (BB-63) resulting in superficial damage to USS *Missouri.* No casualties occurred.

March 27—USS *Avenger* (MCM-1) received small arms fire while in the vicinity of Ras Al Qalayah. No casualties occurred and the ship moved out of firing range.

Ground-to-Air

February 15-A USN A-6E pilot reported he was fired upon by a surface-to-air missile, resulting in no casualties.

SOURCE: Assistant Secretary of Defense (Public Affairs).

Africa in 1942 rather than the deserts of Iraq a half century later.

In one barely avoided fratricide, a group of tanks was waiting for a second unit to catch up. Radio communication confirmed that all of the second unit's forces were behind the frost unit. Two Iraqi T-55 tanks crossed in front of the first unit, which quickly destroyed the enemy tanks. Just minutes later, two more armored vehicles were detected, moving in the same direction as the original T-55s. From consideration of the tactical situation, they obviously seemed part of the same Iraqi group. An alert tank gunner noticed, however, that the vehicles showed on the thermal imager the characteristic 'hot wheels' of U.S. infantry fighting vehicles and called out to hold fire. In fact, these were the scouts from the other units reported behind-but showing up ahead of—the first unit and reported heading north but actually going west, which unfortunately was the same direction as the nearby enemy force.[61]

Another case did not turn out so well. Two units were traveling at night in parallel but not in constant visual contact because of a gentle rise between them. The units passed on either side of an Iraqi infantry force armed with rocket-propelled grenades. The Iraqis fired at U.S. infantry fighting vehicles to one side. The explosions were seen by U.S. tanks in the other unit, which mistook the explosions for gun flashes from Iraqi tanks. The U.S. tanks returned fire and hit some of the U.S. infantry fighting vehicles.[62]

There were no fratricides of airplanes. Air superiority was so complete and accomplished so quickly that very restrictive rules of engagement were possible, which might have hampered the effectiveness of the air arm but avoided any fratricide.

SUMMARY

A historian might wince at drawing lessons from a collection of anecdotes, but some general points come through. First, fratricide result most often from a complex chain of errors. The stories often read: identification was wrong, yes, but misidentification would have been unimportant if navigation had been reliable, navigation errors could have been overcome if communication had been adequate, and so on. Also, these anecdotes make clear that while misidentification often leads to fratricide, failures of command, communication, coordination, and fire discipline are at least as important. Although an accurate estimate of the overall frequency of fratricide is impossible to determine, the two percent rule of thumb presented by Schrader and others is almost certainly too low. In every case in which good data are available, the actual rate of fratricide turns out to be much higher than two percent and higher than most would guess. Finally, the types of fratricide change much less quickly than military technology. This suggests that technology is only part of the solution; reducing fratricide will always depend on the training and Skills of the combatant in the field.

61 Center for Army Lessons Learned, "Fratricide: Reducing Self-Inflicted Losses," *Newsletter* (April 1992) No. 92-4, p. 1.

62 This case is remarkably similar to one occurring at the National Training Center, described by Goldsmith. In that case the flashes were simulated incoming artillery, but friendly units on either side took them to be gun flashes from enemy forces and returned fire.

Avoiding Fratricide: General Considerations

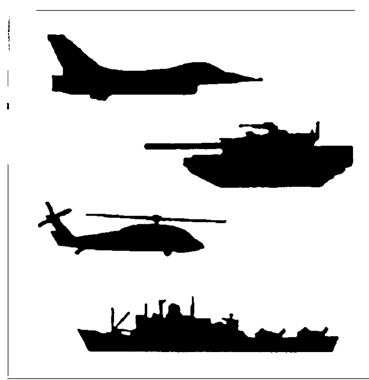
3

America's recent combat in the Persian Gulf War brought new attention to an old problem: fratricide. Twenty-four percent of all U.S. combat fatalities in the war were caused by friendly fire.[1] This figure seemed much higher than in previous wars and caused a sudden focus on avoiding fratricide in future wars,

The U.S. military and the American public are becoming increasingly sensitive to the human costs of military involvement, especially for contests of less than national survival. For this reason, the United States has invested much in energy and equipment to keep casualties low. As casualties from hostile action decrease, the relative importance of fratricide increases and fratricide should receive more attention.

The previous chapter found that only in a very few cases are reliable estimates of fratricide available but in each of those cases, the fratricide rate was much higher than the nominal two percent rate that frequently appears in the military literature, Fratricide has been, and probably will continue to be, a significant source of combat casualties.

Moreover, the political and psychological cost of losses due to fratricide will always be greater than those due to losses inflicted by an enemy. In military operations involving allies, fratricide between countries can cause international friction at a time when strong cooperation is of utmost importance.[2]



[1] This value derives from 35 friendly fire fatalities out of a total of 148 combat fatalities. "Military Probes Friendly Fire Incidents, " Office of Assistant Secretary of Defense (Public Afairs), Aug. 13, 1991.

[2] During Operation Desert Storm, 9 British soldiers were killed when Maverick missiles from A-10 ground-attack aircraft destroyed their armored personnel carriers, causing considerable political controversy in the United Kingdom. See Glenn Frankel, ''In Britain, Fallout from Friendly Fire, " *Washington Post*, May 18, 1992, p. D1.

Fear of fratricide has been a constraint on combat tactics and maneuvers. The previous chapter described how lack of effective identification during both World Wars limited the use of air power for close-in support of ground troops. In at least one case, danger of fratricide is the primary constraint on tactics: the joint use of air defense fighters and air defense missiles in the same area. Conversely, development of a good, reliable antifratricide system could open up new tactical options. Better identification could allow more rapid attacks on enemy strong points, more aggressive defense and covering fire by dug-in second-line defenders as first-line defenders withdraw, closer and more agile air-to-ground or artillery support, and so on.

Fratricide becomes increasingly important not just because of its *relative* increase due to the smaller numbers of total casualties, but because of the way that the United States wants to keep those numbers low. The U.S. military believes that the best way to win quickly and decisively with least loss is to apply overwhelming firepower against the enemy. However, if the only people on the battlefield shooting are Americans, then it follows that the only way for Americans to get killed is from fratricide. Indeed, some simple theories suggest that fratricide may blunt the advantage of overwhelming advantage in number (or "force ratio") so that the U.S. approach to decisive combat may require solving the fratricide problem to be viable.[3]

TRENDS IN THE FREQUENCY OF FRATRICIDE

Some incidents in the Persian Gulf show trends that may exacerbate the problem of fratricide as weapons' development continues to advance. First, the tempo of battle has increased, oftentimes allowing combatants only seconds to make life and death decisions. Second, engagement ranges have increased. Mistakes of identification were difficult at the close ranges needed in the age of sword, but many modern weapons' range far exceed the range at which the human eye, or even instruments, can distinguish friends from foes. Also, the destructiveness of weapons has increased. In the past, fratricidal attacks could sometimes be stopped if the mistake was realized quickly, but now the first shot is often fatal, making an initial mistake irreversible. Finally, a potential problem often overlooked during the Cold War is that future enemies may have weapons similar or identical to those of the United States or its allies.

Other technical developments make avoiding fratricide easier. A British investigation early in World War II showed that among strategic bomber crews reporting that they had attacked their assigned targets, only one-fifth had actually dropped their bombs within five miles of them.[4] Absolute rates of fratricide may have peaked in World War II because the destructiveness of ordnance increased faster than the ability to deliver it precisely. Clearly, improvements in navigation, communication, and weapons-delivery accuracy improve the control of fire, making avoidance of fratricide easier (at least in principle). This hypothesis is supported by experience in Operation Desert Storm where, contrary to past wars, there were no artillery fratricides.

Since estimates of past rates of fratricide have been unrealistically low, any telltale that allows unambiguously attributing a casualty to fratricide causes a jump in the number of *visible* incidents. This accounts for part of the picture coming out of the Persian Gulf experience. For example, only U.S. tanks were armed with depleted uranium (DU) antitank shells in the Persian Gulf. The shells leave a small but distinctive and easily detectable trace of uranium on any target they hit. Thus, after Operation Desert Storm, a quick test could reveal clearly any fratricide caused by U.S.

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3 Leonard A. Wojcik, "The Manchester Equations in Defense Policy Analysis," July 3, 1984, unpublished.

4 John Terraine, *A Time for Courage: The RAF in the European War, 1939-1945* (New York, NY: Macmillan, 1985), p. 292

tanks. In World War II, the same poor communication and navigation that might cause fratricide would allow it to occur in the midst of the confusion of battle without anyone, shooter or victim, ever realizing it. Today's improved communication could make fratricide less likely while also making it more likely to be discovered when it occurs.

By any *absolute* measure, fratricide was not worse in the Persian Gulf War-or in Panama and Granada-than in previous wars. *The fraction* of deaths due to fratricide was apparently high, but this was due in part to the very low *total* American fatalities from all causes and, in part, to past underestimates of fratricide rates.

MEASURES OF THE SEVERITY OF THE PROBLEM

Part of the challenge of evaluating any antifratricide effort is deciding on an appropriate measure of how bad the problem is. On the one hand, the most common—and most public—measure is the fraction of all U.S. casualties caused by U.S. weapons; that is, a comparison of the number of U.S. casualties caused by U.S. forces to the total number of U.S. casualties.[5]

On the other hand, some argue that U.S. casualties caused by U.S. forces are more appropriately compared to the number of casualties inflicted on the *enemy* by U.S. forces, In the case of the Persian Gulf War then, the dozens of mistaken fratricidal attacks by U.S. forces should properly be compared to the tens of thousands of appropriate attacks on enemy targets.[6]

Comparing friendly fire losses to losses inflicted on the enemy is probably more appropriate in cases of wars against comparable enemies where the outcome is uncertain, such as the Cold War contest between NATO and the Warsaw Pact. In this case, relative rates of attrition will determine, in part, which side wins. In contests of less than national survival, such as the Persian Gulf War, final victory is less uncertain-if the Nation is willing to pay the price. The question is what that price will be in lives lost. In these cases, casualties should be as low as possible and military planners should address the causes of casualties in their order of importance. Thus, in these cases, comparing fratricide to total friendly casualties is the more appropriate measure.

Neither of these simple measures is adequate by itself. Avoiding fratricide is never the sole objective of a military force; it must be balanced with other military goals and efforts to hold down overall human costs. Combat is inherently dangerous and casualties are inevitable, and some of those casualties inevitably will be due to fratricide. Moreover, some measures to reduce fratricide could be so stringent that they would reduce military effectiveness and, in the end, increase the casualties inflicted by enemy forces.[7] (See figure 3-l).

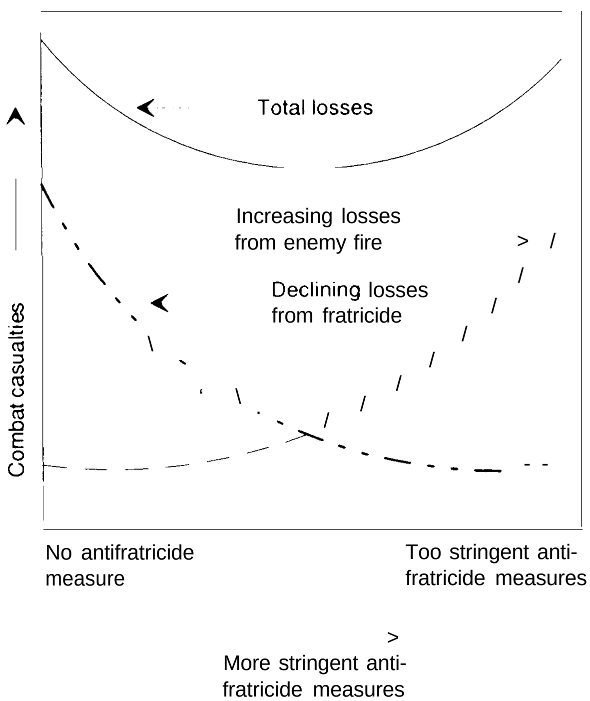
Yet a death due to fratricide will never have the same psychological effect as just another casu-

[5] When possible, this report uses fatalities as a measure of comparison rather than total casualties because of ambiguities of defining ‘‘wounded.

[6] For example, if the 35 Americans killed arc compared to the 20,000 or more enemy killed in Desert Storm, then the fratricide rate is well under one percent. See Center for Army Lessons Learned (CALL), “Fratricide: Reducing Self-Inflicted Losses, ” CALL Newsletter No. 92-4, April 1992, p. 5.

[7] This is precisely what some alleged happened during the opening phases of the air war against Iraq, that over-stringent IFF requirements allowed to go free an Iraqi fighter that later downed a U.S. jet. See Mark Crispin Miller, “Death of a Fighter Pilot, ” New York *Times,* Sept. 15, 1992, p. 27 and New *York Times, ‘‘Officer* Says Iraqi Jet Downed Navy Plane During Gulf War, Sept. 15, 1992, p. 5. The Department of Defense is uncertain but believes that the airplane was downed by a surface-to-air missile. See the rebuttal letter from Pete Williams, Assistant Secretary of Defense for Public Affairs, New York *Times,* Sept. 26, 1992, p. 20.

Figure 3-1—Casualties and Antifratricide Measures



SOURCE: Office of Technology Assessment, 1993.

alty. The destruction of morale, esprit, and military cohesion from a fratricide is far greater than that from a similar loss inflicted by an enemy. If fratricide's importance is measured simply by its effect on the outcomes of battles or wars, it seems of little significance: the historical review found no cases in which a fratricidal error clearly reversed the outcome of a battle. But incidents of fratricide can cause soldiers to become too cautious, too timid, and too conservative. These psychological effects may be intangible but every experience of combat shows how very real they are. In the end, military effectiveness is reduced. Thus, some military analysts believe that the secondary, hidden effects of fratricide on the psychology of the surviving troops may be greater than the direct effects of losses of forces.

THE ATTACK SEQUENCE

The review of fratricide incidents shows that very few result exclusively from mechanical malfunction; in almost all cases, fratricide results from deliberate-but mistaken-human decisions and actions that cause casualties among friendly forces.

The final decision to attack a target is the last step in a multistep process. If, at any stage of this process, the shooter could get information showing that his weapon is directed at friendly forces, then fratricide might be reduced.[8]

Attacking a target begins with the detection of something. That ''something' might be an intuition, a slight movement among the trees, a blip on a radar scope or other sensor, or even incoming free.

The next step is classification. The process of classification can itself contain several steps. At the moment of first detection, the observer is typically uncertain whether the small blob seen through the thermal sight is an enemy tank or a large warm rock. Is the object a rock or a vehicle? If a vehicle, is it wheeled or tracked? If tracked, is it a tank or armored personnel carrier? If a tank, is it foreign- or U.S.-built? And if U.S. forces are fighting alongside allies, can the foreign-built tank be identified as an allied or enemy foreign-built tank?[9]

[8] This discussion is based largely on the Defense Advanced Research Projects Agency briefing by Lt. Col. Joseph H. Beno, "Battlefield IFF'' (undated).

[9] Readers familiar with the intelligence and photointerpretation process should note that this sequence of identification is different from that used by photointerpreters of reconnaisaince images. They assume that all the vehicles parked in the interior of an enemy country are enemy vehicles. First, they want to know whether the spot on the photograph is a vehicle, if so is it a tracked vehicle, if so is it an armored personnel carrier or a tank, and finally, what type of tank and what are its capabilities. IFF can be in some ways a much harder problem. Combat identification is less concerned with the problem of whether a vehicle is a truck or a tank but in the potentially very hard problem of whether the truck is U.S. or enemy.

Once a target is identified as enemy, a decision to attack must be made. This decision is not automatic. For example, an air-defense missile unit may clearly identify an aircraft as hostile, but the aircraft may also be beyond the range of the units missiles. An infantryman may see a enemy tank but be armed with a shoulder-launched rocket that is effective against armored personnel carriers but not against tanks; a tank gunner may see several enemy targets and decide to ignore distant ones because those closer are more threatening.

Finally, after a decision to attack has been made, the attack must be carried out. Weapons must be aimed properly and ordnance delivered where it is intended and not elsewhere, With modern weapons, ordnance almost always goes whither the weapon is aimed; in the overwhelming majority of cases, fratricide occurs when the weapon is aimed at the wrong place.

Separating the attack sequence—which may only take a few seconds—into these individual steps may seem a more complex description than needed. But most fratricide are errors that could have been avoided if proper information had been available at *any one* of these steps. Thus, when fratricide is the result of a chain of errors, it could be avoided if the chain is broken at any link. Breaking a link in the chain requires that the shooter be given correct information about a falsely identified target.

THE COMBATANT'S SOURCES OF IDENTIFICATION INFORMATION

Three overlapping types of information affect each step of the decision to fire or not to fire on a potential target. The first and highest level of information is an overall, general knowledge of the tactical environment during the battle: where friendly units are-or at least supposed to be— and where enemy units are thought to be, plus the plan of action for the battle. The Army calls this knowledge ‘‘situational awareness," an awkward but useful term; other Services include it under “battle management.”

High-level, general knowledge is not adequate alone; people involved in the battle must also have specific information about whether any particular weapon or vehicle is friendly or enemy. This information is usually called the Identification of Friend and Foe, or IFF. The military calls the synthesis of these two types of information “Combat Identification, ” or CID.

Connecting these first two sets of information is another type of a priori information brought along to the battle: doctrine and rules of engagement. These rules tell those engaged in the battle how to treat information from other sources. In particular, rules of engagement contain assumptions about how to make decisions with imperfect knowledge; specifically, is an ambiguous target assumed friendly until proven hostile, or assumed hostile until proven friendly? Different forces under different circumstances will use different assumptions.

Because destroying a target is a multistep process and fratricide can be avoided by properly intervening at any step, more than one approach can be used to prevent fratricide. This must be kept in mind when comparing claims about the efficacy of various approaches. Those proposing solutions that improve knowledge of the tactical environment might claim that, say, 75 percent of fratricide could be avoided by improving situational awareness. While those proposing IFF solutions might also claim that 75 percent of fratricide could be avoided by improving IFF. Clearly, both systems will not eliminate 150 percent of a problem, but both claims might be true because *either* approach could reduce fratricide. One study using computer simulation of land combat illustrates this point in an interesting way: fratricide was eliminated entirely if forces were assumed to have either perfect tactical knowledge-provided by hypothetical perfect communications and navigation equipment--or if they were assumed to have perfect IFF—

provided by hypothetical perfect sensors or IFF transponders.[10]

Knowledge of the Tactical Environment

A sense of the tactical situation on the battlefield is so important to avoiding fratricide that it is sometimes taken for granted. A tank commander in a rear assembly area is surrounded by other potentially lethal tanks but does not even think of firing on them because of the firm knowledge that they are all friendly. This is a case of almost subconscious tactical awareness.

As the likelihood of encountering hostile forces increases, tactical information provides clues to make the search for targets more productive and helps in the classification of targets as friendly or enemy. Rarely does a ground force expect an attack from any direction; typically, their knowledge of the battlefield suggests to them the likely direction from which an enemy might approach. The tactical environment thus helps to classify potential targets as most probably friendly or enemy. For example, a unit approaching from the rear is first assumed friendly but a unit approaching from enemy-held territory is frost assumed hostile. Or, if a commander knows that his and all other friendly units have orders to advance in a certain direction, then a unit seen moving at right angles to that axis will be assumed to be most likely hostile.[11]

Before these types of presumptions can be usefully reliable, however, each unit must have confidence that it, and its neighboring units, are unlikely to be heading in a wrong direction and that wherever each unit is and whichever direction it is headed, nearby units can inform each other. This requires, in turn, reliable navigation and communication procedures and equipment.

Communication may be through some centralized clearinghouse. Tactical air forces typically use this approach. It allows the optimal allocation of resources across the entire theater of operations. Since airplanes travel so far and so fast, centralized control is almost required to respond to enemy attacks and to avoid unintended encounters among friendly forces. The disadvantage of a centralized system is that large quantities of information must be transmitted up and down the chain from the controllers to the units in the field.

Communication may also be through local networks that link nearby forces. Ground units are more likely to use this approach. It has the advantage of minimizing the required flow of information up and down the chain, Problems can occur, however, since ground units report up through a chain to some central commander but also need to communicate across the chain of command to units that might be remote in the command network but happen to be geographically close. Armies have long recognized this problem and have developed special procedures to ameliorate it. The simplest approach is to make major command divisions correspond to real geographic barriers-for example, rivers or mountain ridges—thus minimizing the *need* for communication across command lines. Failing that, command lines must be clear and special attention must be given to liaison between adjacent forward units that report up through different chains of command.

Navigation, like communication, can be global or local. The pilot of a long-range aircraft clearly needs to know where it is in absolute terms, that is, its latitude and longitude. World War II experience shows that when artillery fire was misplaced, the cause often was a forward observer

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10 See MIT/Lincoln Laboratories briefing by A.B. Gschwendtner, "DARPA Combat Identification Program at MIT/Lincoln Laboratory" (Aug. 28, 1992). In the extreme, perfect tactical awareness, that is, precise and complete information about the location of all nearby friendly forces, would provide as one benefit the equivalent of perfect identification of friends and, by the process of elimination, foes. Thus, perfect tactical awareness is equivalent to perfect IF'F.

11 Recall the case described inch. 2 from Operation Desert Storm in which lost U.S. armored personnel carriers were assumed to be Iraqi because they were cutting across the general direction of advance.

correctly calling in fire relative to his position but erroneously reporting his *absolute* position. In many if not most cases, however, position relative to nearby friendly forces is good enough or even better, Perhaps only the leader of a tank platoon needs to know his absolute position, while the rest of the tank commanders are primarily interested in local terrain features and the tanks' positions relative to each other.

Rules of Engagement

The criteria for deciding on the nature of a target and the response to it are called "rules of engagement. Military commanders, theorists, historians, and tacticians have long recognized the chaotic confusion of combat. No battlefield participant has perfect knowledge, and critical decisions must be made, sometimes quickly, with incomplete and occasionally flatly contradictory information. Of necessity, every combatant enters a battle with some a priori knowledge in the form of a set of decision-making rules to use under these difficult conditions. This a priori knowledge is learned through training, exercise, and indoctrination. At the tactical level, military doctrine provides rules or criteria that are used to decide when to attack, when to defend, and so on. Fratricide is affected more by some of the rules used by each individual combatant to determine whether an unidentified target is hostile or friendly, Targets are rarely classified by appearance alone but also by location, behavior, and recent experience. Thus, the combatants' tactical environment affects strongly their decisions about the danger posed by ambiguous targets.

Two kinds of identification errors are possible: friendly forces or neutrals can be mistakenly identified as hostile, and hostile forces can be mistakenly identified as friendly or neutral. Rules of engagement will also depend on a comparison of the consequences of each of these mistakes. For example, interceptor aircraft pilots typically use different rules of engagement in different tactical situations because of the differences in the consequence of each type of mistake. The differences are clearest when comparing point defense of an extremely valuable target and defense of a large area.

For example, Navy fighters fly from an aircraft carrier, which is a single asset of enormous value. The loss of the carrier implies the potential loss of all the aircraft and crew on the carrier. Carriers are heavily defended, but even a single attacker getting through can do substantial damage, perhaps disabling the carrier for an extended period. Moreover, the carrier is a' 'point" target, making the geometry of an attack unusually clear, Thus, the Navy's rule of engagement during hostilities is that an aircraft approaching the carrier must be able to prove that it is friendly, or at least nonthreatening, or else it is *assumed* to be hostile.

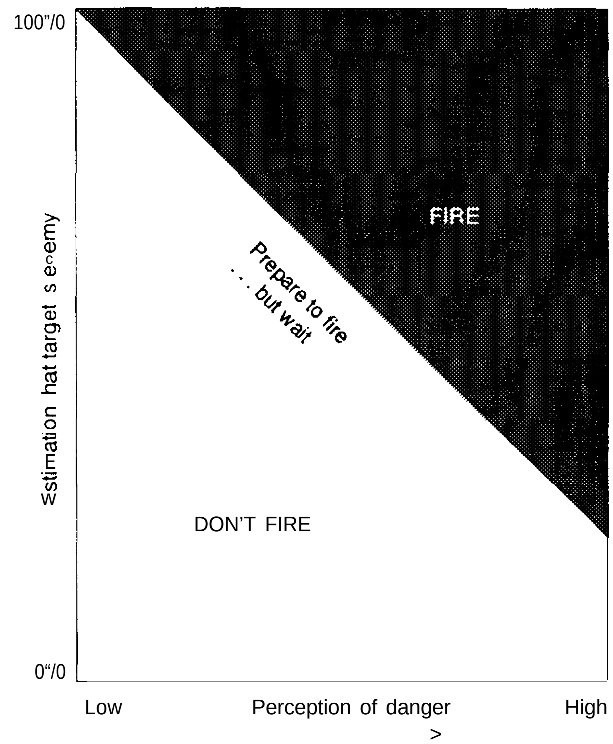
Tactical interceptors trying to defend a large area face a very different situation and respond with different rules of engagement. For example, the classic defense of NATO would have involved a large and confusing array of fighters over the battlefield. Air defenses of NATO were multilayered. The first ' 'defense" was attack against enemy air fields. Enemy intruders would then have to pass through a screening force of defending interceptor fighters. These aircraft might be backed up by a band of defenses composed of surface-to-air missiles (SAMs). Any intruders that survived could be attacked by defending fighters specifically left prowling in rear areas to catch these ''leakers. ' Finally, particularly valuable targets would be defended by their own local air defenses of short-range missiles or guns, Thus, the battle would include a confused and dense air traffic, with fighters coming from many places and heading toward many targets. Most of the defended combat assets—for example, Army assembly areas—would be more dispersed than an aircraft carrier, so that a successful attack on any one asset would be far less critical than a similar attack against a carrier.

The consequences of firing on a friend are as severe in the case of area defenses as in the case of defense of a valuable point target-a friendly aircraft gets shot down-but the consequences of passing up an opportunity to shoot at an enemy are much less severe—if the first layer of defenses does not get an intruder then the next will, and so on, until he approaches the target when he finally must make his intentions clear. Therefore, the rule of engagement for unknown aircraft during area defense is different from that used by the Navy when defending a carrier: area defenders assume that an unknown aircraft *might* be friendly unless some positive evidence is available to show that it is hostile.

Ground combatants have a slightly different perspective on the consequences of the two types of misidentifications. They tend to think of the problem as a comparison of the consequences of either shooting or not shooting. The situation facing a tank commander can provide a specific example. Historical evidence from World War II, training exercises, and testing show a substantial advantage to the tank that shoots frost in tank-on-tank engagements. To hesitate is to risk destruction. And the loss is not a vague, difficult-to-quantify overall loss of combat capability, but a loss that spurs the very compelling motivations of self-preservation: the tank that fails to aim and fire first will itself be receiving the fire that might cause the crew's death. Thus, ground combatants' rules of engagement frequently are closer to those appropriate for defense of a valuable point target; indeed, the shooter is his own ''high-value" target. A potentially threatening unknown target is generally assumed hostile unless there is some evidence that it is friendly.

The danger that a shooter perceives also affects his incentives to wait or shoot; the greater the perceived threat, the greater the urgency to shoot frost and the more likely a shooter is to assume an ambiguous target is hostile. This dynamic is represented in figure 3-2. The vertical axis represents the shooter's estimate that the target he sees is an enemy. His estimate can range from zero at the bottom of the axis, that is, absolute confidence that the target is a friend, to 100

F gu e 3 2—The Dec s on o F e



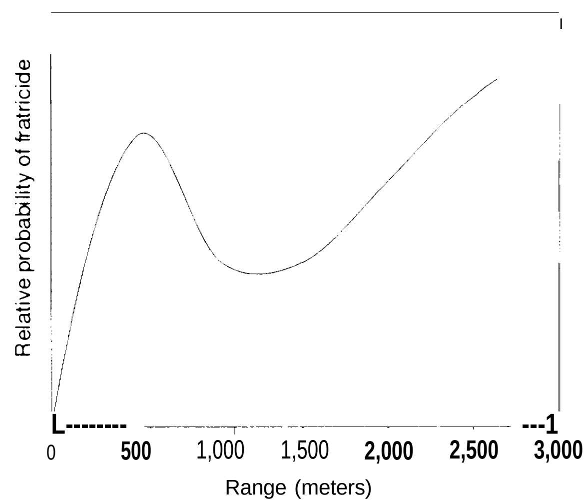
SOURCE: Office of the Assistant Secretary of Defense (C3I).

percent at the top of the axis, that is, absolute confidence that the target is an enemy. (Note that these estimates of classification confidence refer to the shooter's perception; these perceptions, in turn, may or may not be correct.) The horizontal axis represents the shooter's motivation to fire based on his perception of danger and urgency. It can range from a minimum motivation, represented on the left-hand side, to maximum motivation, on the right-hand side.

The motivation to fire will change due to several factors, but the most important variable is the shooter's estimate of his own danger. The graph lays out the different regions that result in decisions to fire or not fire. If the shooter feels reasonably secure, then he is willing to wait to make absolutely certain that the target he has detected is, in fact, an enemy. Thus, the "free" area of the graph occupies only the upper comer of the left-hand side, where confidence is high. Toward the right-hand side of the graph, the shooter's perception of danger increases and he becomes increasingly "trigger happy" until finally, at the extreme right-hand side, where he feels in immediate grave danger, the shooter may need high confidence that a target is not an enemy to keep from shooting. That is, ambiguous targets will be assumed hostile until proven friendly.

The effect of a shooter's sense of danger on his identification accuracy has, in turn, an indirect but interesting effect on the relationship of target range and identification accuracy. That increased weapon range makes IFF more difficult is a commonplace. The development of long-range weapons, especially guided weapons not requiring any form of forward spotting, has increased the range of engagement beyond that at which targets can be identified, thereby inviting mistaken attacks on friendly targets. Some military analysts have suggested that reliable IFF range be made a design *constraint* on weapon range.[12] Some data, for example, from tank combat training exercises at the National Training Center, show a clear relationship between range and likelihood of fratricide. Accidents are less likely at shorter engagement ranges, with an important exception: at very short ranges when the rate of fratricide engagements is again very high.[13] This phenomenon occurs because, all else being equal, identification becomes easier at shorter ranges—reducing fratricide-but all else is not equal. Engagements occur at very short ranges only under the desperate and chaotic conditions of a close-in melee. The effect of greater ease of identification is overwhelmed by the greater

Figure 3-3—Fratricide and Engagement Range



SOURCE: U.S. Army Training and Doctrine Command.

stress and confusion characteristic of close combat. See figure 3-3.

Similarly, air defense training shows that the highest frequency of identification errors occurs among those manning the shortest range weapons. A Vulcan gun crew cannot engage an approaching jet aircraft until it is virtually on top of them, thus forcing an ''us-or-them' approach to target engagement decisions. Increased weapon range certainly is not the solution to fratricide, but neither is its effect entirely negative: it might make quick identification more difficult, but it also can allow more time for decision and evaluation.

The rules of engagement include other tactical information. Some is explicit. For example, if a fighter plane determines from, say, detection of an enemy radar frequency that an approaching

[12] Some arguments in the debate about the usefulness of increasing weapon range have gone so far as to suggest that air-to-air missile range ought to be tied to accurate target identification range such that targets at greater ranges are impossible to engage. For example, from a congressional report on IFF: "Correcting this imbalance between missile and ID capabilities now requires an accelerated, closely coordinated, interservice and NATO-wide effort to concentrate resources on achieving the needed identification capability. A concomitant slow-down in tactical missile acquisition could support that effort. ' U.S. House of Representatives, Committee on Government Operations, "Identification of Friend or Foe in Air Warfare-A Capability Long Neglected and Urgently Needed' (Washington DC: U.S. Government Printing Office, Nov. 1, 1985), p. 3. However, an artificially imposed constraint on range persists even when identification presents no problem due to, for example, the clarity of the tactical situation.

[13] See ''CALL Fratricide Study'' (undated), Center for Army Lessons Learned (CALL), pp. 8-9.

aircraft is hostile, other aircraft flying in the same formation are also assumed hostile. (This is informally called "guilt by association.") This assessment is usually accurate, but scenarios in which a friendly fighter is in hot pursuit of an enemy are also easy to imagine. Some other "rules" are implicit and seem to result from human nature, or can be understood in terms of the effects of an increased perception of threat—whether real or not-discussed above. Analysis of training exercises shows clearly that a gunner's recent experience strongly influences his judgments about friend and foe. If, for example, an air defense unit has just been attacked by "hostile" aircraft in a training exercise, then the next airplane that flies over is much more likely to be judged hostile than it would have been if the previous overflight had been by friendly aircraft. Gunners are not, of course, taught to make these prejudicial assumptions, and this is not an explicit ''rule,' but few will be surprised by the observation.

IDENTIFICATION: FRIEND OR FOE

"The first requirement in warfare is the ability to distinguish friend from foe."[14] This statement from a World War II field manual makes clear the importance-but not the difficulty--of IFF. Even the most straightforward technique, looking at a potential target with human eyes, is neither simple nor reliable; combatants need training to identify forces quickly. Even with training, mistakes that appear egregious in the calm of peaceful retrospection are all too common in the confusion of combat. The great increase in weapon range-made possible primarily by developments in weapon guidance systems since World War II-has in many cases far outstripped the ability of human observers relying just on their eyes. IFF today requires additional information from longer range sensors.

Different weapon systems have different requirements for IFF systems. The IFF needed for short-range and long-range weapons, for example, may have very different reactions times, abilities to track multiple targets, likelihood of revealing position, and so on, as well as the obviously different requirements for range.

IFF and the Rules of Engagement

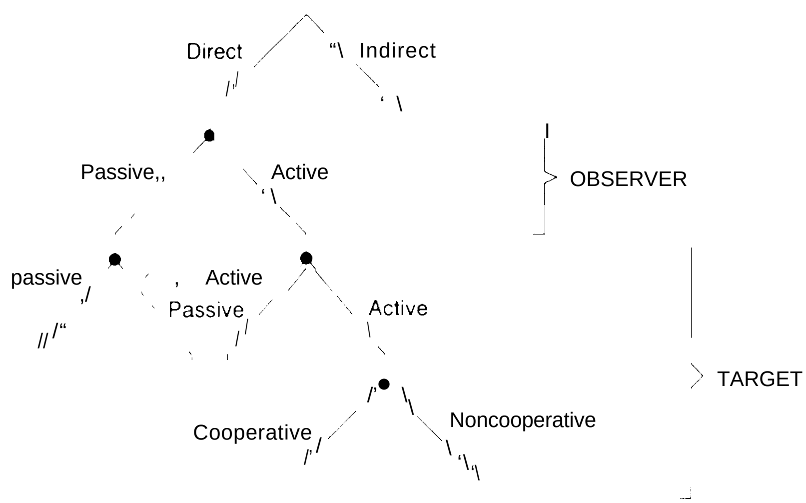
Differences in the rules of engagement will shift emphasis among technical approaches to IFF. There is no technical solution that is optimal for providing positive identification of friend *and* foe, where "positive identification" means identification based on positive presence of some evidence. For example, response to a reliable IFF interrogation system is positive evidence that the target is a friend, but lack of response is not positive evidence that it is an enemy.

In defense of critical point targets, aircraft carriers being the premier example, defenders must assume that ambiguous targets are potentially hostile until proven friendly. Thus, the emphasis is on systems that can prove a target friendly, such as cooperative question-and-answer systems. The rules of engagement for area defense will give relatively greater emphasis to positive identification of foes, hence, noncooperative foe identifiers will be relatively more important with question-and-answer systems providing frost-order sorting of targets into friends and unknowns.

Ground forces, when under extreme pressure to fire quickly, also find themselves in a situation where ambiguous targets must be assumed hostile until proven friendly. Thus, ground forces will concentrate on developing question-and-answer friend identifiers. (In addition, active IFF by ground forces is in a primitive state compared to that of air forces and question-and-answer systems, being easier to implement than noncooperative systems, are a good place to start.)

14 Recognition *Pictorial Manual,* War Department Field Manual 30-30 (June 1943), p. 1.

Figure 3-4--Sources of Information for Identification



SOURCE: Office of the Assistant Secretary of Defense (C3I).

Sources of IFF Information

Successful IFF requires that the shooter have information--carried by some form of energy—from the putative target. The sources of this energy and how it is collected can provide a general, overall classification of the various technical approaches to IFF. Figure 3-4 shows the possible combinations of energy and information sources. The first branch is between direct and indirect collection. A ''direct' system is one in which the shooter collects the information about a target, while in an 'indirect' system some other observer collects the information and passes it on to the shooter. An artillery forward observer is a good example of indirect IFF. The forward observer, or spotter, uses whatever technique he has to determine whether a target is friend or foe and then radios that information back to the artillery, which accepts it as accurate without any ability to confirm the information. The rest of the direct and indirect branches are identical to each other, so only the direct branch is shown in the figure.

The observers may be passive or active. Passive observers do not transmit any energy themselves but only collect energy normally transmitted or reflected from the target. An active observer transmits energy at the target to somehow affect the target in a way that can be observed.

The target as well may be either passive or active. A passive target only reflects energy from its environment. This energy may be natural, like sunlight, which a passive observer can detect or, in the case of an active observer, the energy might be artificially produced specifically to be directed to and reflected back from the target, as is the case, for example, with a radar beam. An active target transmits its own energy, for example, radio signals or sound.

Thus four possible observer/target energy transmission routes are available: passive/passive, passive/active, active/passive, and active/active shown in figure 3-5. An example of the first case is the simplest IFF system imaginable: a passive observer identifying a passive target by sensing reflected sunlight. Or, a passive observer might also sense energy that is actively transmitted by the target. This could be radio transmissions in a foreign language, or radio or radar transmissions

Box 3-A–The Electromagnetic Spectrum

Chapter 3 discusses in general terms-and the next two chapters discuss in much more specific detail--some oft he identification and communication techniques important for avoiding friendly fire. Many of these techniques depend on detecting some form of electromagnetic radiation. The figure 3-A represents the electromagnetic spectrum. Visible light is the most familiar part of the spectrum but radiation at higher and lower wavelengths is exactly the same physical phenomenon, just not detectable by the human eye.

Radiation of different wavelengths interacts with matter in different ways, which has two important consequences: first, the wavelength determines how easily the radiation passes through the atmosphere, including obscurants, such as fog, smoke, rain, or dust; second, the wavelength affects how the radiation is generated and detected. In general, radiation is little disturbed by particles smaller than the radiation's wavelength, thus longer wavelengths tend to pass more easily through airborne particulate like smoke or fog. Infrared radiation--with a longer wavelength than visible radiation--can be used to see through clouds of obscurants that appear impenetrable to the human eye and even longer wavelength radar waves can pass through rain that would stop infrared radiation.

at a characteristic frequency not used by friendly forces, or the sound of a tank that is different from that of friendly tanks.

The observer could be active and transmit energy to the target. Most commonly this is in the form of radio signals of some sort. Even if the target is passive, the shooter can still bounce radar signals off it—this is standard radar. Thus an active shooter can detect the radar return of a passive target and get some information about the target that might allow it to be classified as friend or foe.

Alternately, the target might actively transmit energy in response to the shooter's transmission. In such a system, the shooter sends a special signal to the target. If the target wishes to be identified, and is equipped with the proper transponders, then it sends back a signal signifying that it is a friend. This is the principle of ''cooperative' IFF systems, such as the MARK XII. These are often called ''question-and-answer" systems.

Finally, each branch of the tree shown in the figure can be cooperative or noncooperative. Painting special insignia on a vehicle for others to see is an example of a passive/passive cooperative system. Normal radar is an active/passive noncooperative system, but if the target adds special radar reflectors to enhance radar echoes, it becomes an active/passive cooperative system. Just because a target gives an active response to an active observer does not imply necessarily that the target is cooperative; it might be tricked into responding. Military electronics experts are always trying to find ways to cause an enemy to transmit energy revealing his position, intentions, or capability.

Figure 3-5—Examples of Approaches to IFF

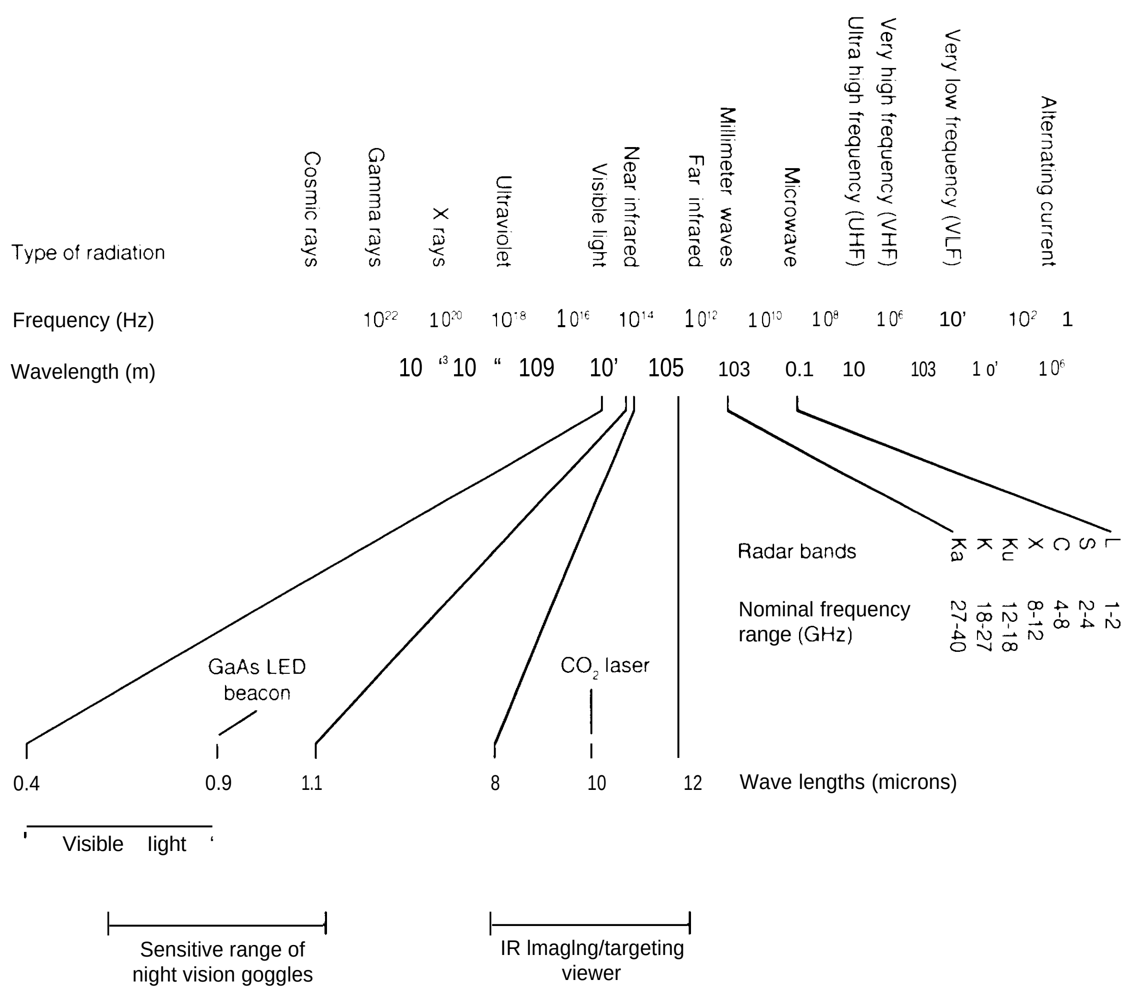
OBSERVER \ TARGET	Passive	Active
Passive	Visual ID of weapons type, painted insignia	Beacons: e.g., Budd-lights, DA RPA-lights
Active	Radar	Question-and-answer systems

SOURCE: DoD and OTA.

Longer wavelength radiation may be able easily to penetrate the atmosphere but another problem arises as longer wavelength radiation is used: the ultimate resolution of any imagining device is limited by the ratio of the wavelength and the size of the imaging optics. Radars using radiation with waves several centimeters or meters long may easily penetrate long distances, but to achieve any resolution requires proportionally large antennas. Thus, long wavelength radiation may be useful for communication and detection but is not much use for deriving an image.

Several parts of the spectrum are of importance to the problem of avoiding fratricide. Communication usually uses UHF and VHF radio bands. The radar bands shown are used to detect objects and perhaps identify them, The infrared bands are important because ground forces use them for seeing at night and under conditions of limited visibility. With increasing wavelength, infrared blends into the millimeter wave bands that will be used by the proposed question-and-answer identification system for ground combat vehicles.

The Electromagnetic Spectrum



Advantages and Disadvantages of Each Approach

Each approach to IFF has comparative strengths and weaknesses. The military prefers, at least as an ideal, systems that allow the shooter to remain completely passive because these pose least risk of revealing information about the shooter. But passive systems must exploit subtle difference in emissions, that is, the "signature," of a vehicle. Keep in mind that the objective is not to detect a tank but to distinguish one type of tank from another against a very complex battlefield background, and in spite of possible efforts by the enemy to hide or alter their weapons' appearance. Thus, purely passive systems may require sensitive hence expensive—sensors. Most IFF experts interviewed by OTA felt that no single passive sensor would be adequate but that the fused information from several may have future application.

Active IFF systems—the most obvious examples are radars and question-and-answer systems—can have longer range but they, of course, might be detected, providing the enemy information about friendly forces. This risk can be minimized by transmitting the least power necessary, transmitting intermittently, using and looking for special transmission patterns (or "waveforms' known only to other friendly forces, and so on.

In general, cooperative systems are cheaper per platform and have longer range; it is always easier to get information out of a target if it wants that information to get out. Cooperative systems have the cost disadvantage, however, of becoming useful only when virtually all of the platforms within a theater of action are equipped, making partial deployments unattractive.

Clearly, cooperative systems are really just friend identifiers, they do not positively identify enemy. If no reply is received, the shooter might *assume* that the target is enemy but perhaps it is a neutral or a friend without an operating transponder. The final classification in these cases will depend on the rules of engagement.

Noncooperative systems can, under some circumstances, positively identify enemy. For example, classification could be based on type of weapon. This approach was easy and reliable during the long NATO-Warsaw Pact confrontation; NATO forces had NATO weapons and Warsaw Pact forces had Warsaw Pact weapons. Thus, the *type* of weapon identified it as friend or foe. This approach can, with luck, still work but in general the world is much more complex today. For example, in the Persian Gulf War, Syrian allies were armed with the same Soviet tanks as the Iraqi enemy while the Iraqis also had the same French-made aircraft as the French allies. This profusion of weapon types does not make noncooperative IFF impossible, only more subtle and difficult. A weapon is much more than the shape of an outside shell; for example, the same type of aircraft in two different air forces may use different engines, have different weapons mounted, and have different radio or radar frequencies. Noncooperative IFF may even try to exploit the habitual tactical behavior of the enemy.

Under some circumstances noncooperative systems may have a cost advantage even when costs per platforms are higher since the anti-fratricide benefit is roughly proportioned to the extent of deployment in contrast to cooperative systems, which have little benefit until deployment is virtually complete within a combat group.

Differences in rules of engagement push toward different technical solutions to IFF. As was discussed before, area defense rules of engagement really require an enemy identifier since, without some positive evidence that a target is enemy, it will not be engaged. Thus, in the extreme, with no way to identify enemy, they would not shoot at anything. A cooperative question-and-answer IFF system identifies friends, but that provides little additional help to the interceptor pilot: he starts off *assuming* that the unknown target is potentially a friend. The pilot needs some system that can identify an enemy as an enemy; thus, the need for noncooperative IFF system.

In contrast, a Navy pilot returning to a carrier has to convince the carrier's defenders that he is a friend. Anything that identifies enemies does not give much additional useful information because the defenders start off *assuming* that unknowns are enemy. Thus, the Navy needs a fail-safe friend identifier and concentrates its attention on cooperative question-and-answer IFF systems.

Information Security

A potential danger with any question-and-answer system is that the enemy might exploit it. Of course, the occasional transmission of a query might reveal the shooter's position, but two even graver failures are possible. First, if an enemy could receive the query and then respond with the proper answer to make himself appear to be a friend, he could then penetrate defenses easily and cause great damage. Second, if an enemy could produce the proper query, he could fool friendly forces into responding, revealing both their positions and their identity.

Securely encrypting the query and the answer eliminates both dangers.[15] An enemy trying to exploit a question and answer IFF system could transmit queries to try to have U.S. weapons identify themselves, but if an encrypted message, which only U.S. or allied forces knew, were used as the query then friendly forces would simply not respond to any queries that were not properly encrypted. But what if the enemy could not create a valid query of his own but at least could recognize that it was a query? The enemy could respond with an answering signal to make himself appear to be a friend. This is called ''spoofing, Again, if replies were encrypted and only friendly forces knew the encryption technique, then the enemy might try to reply with some signal but it clearly would be counterfeit.

To be genuinely secure, an encrypted message must be sufficiently complex to foil enemy efforts to figure out a way to create a valid query and reply. Additionally, even without understanding the encryption method, an enemy could simply record valid queries and then retransmit them. Therefore, the encrypted form of the query must be changed frequently. The combination of these two requirements creates a burden of generating—and distributing to forces in the field-encryption keys and other materials. Transport and dissemination of these materials is further complicated because they must be protected during distribution; if the encryption keys fell into enemy hands, then the IFF system would be compromised until new keys could be created and distributed.[16] Some front-line forces in Europe, such as Army air defense units, claim that handling of the classified IFF encryption keys is so onerous that proper training with IFF systems is stifled.[17]

New technical developments allow easier handling and dissemination of secure information like cipher keys. Systems are under development, called electronic key management systems, that would allow the electronic dissemination of partial keys to regional distribution centers, and thither to a "Local Management Device" containing a "Key Processer. ' At the local level a "Data Transfer Device" is used to carry the key to the individual weapon. The partial keys alone would not allow any enemy to decrypt messages or IFF queries and answers. Instead they would

15 The words ' 'code" and "cipher" and, similarly ''encode'' and ' 'encrypt'' are often used interchangeably in the nontechnical literature. Experts, however, make a very clear distinction. Code is any set of symbols that represents something else and mayor may not be secret. Thus, "20500" is the ZIP code for the White House, but anyone that calls can get the code. If a message is encrypted, then anyone who knows the cypher can read the code but no one else. See Nationat Security Agency briefing, ''Cryptography and Security for Combat ID Systems, " May 6, 1992, p. 5.

16 See National Security Agency briefing, ''The Electronic Key Management System (EKMS)" (undated), pp. 3-4.

17 Monti Callero, "Combat Identification and Fratricide Analysis, " a briefing presented at the *Modeling and Simulation Workshop on Combat Identification* sponsored by the Defense Advanced Research Projects Agency (DARPA), Nov. 4, 1992. In fact the keys are only classified ''cotildential; part of the problem may be more the users' perception and lack of motivation,

provide an input to a computer that would generate the actual keys. Thus, the partial keys could be transmitted over the open airwaves for all to hear. The local computers could load the actual keys directly into the IFF question-and-answer transmitters so there would be no need to have the keys written on easy-to-steal paper and no person-or potential spy—would even need to know what the key was.

Advocates of noncooperative IFF systems are ready to point out the burden of handling encryption keys, but noncooperative systems have their own data-handling challenges. Noncooperative systems, especially ones that rely on a passive target, must have available stores of information on each weapon that might be encountered. Identifying aircraft from their radar return, for example, would require detailed information about the radar returns from dozens of aircraft, each with several different configurations or weapon loads, from all possible perspectives. This information might take the form of databases in which the characteristics of enemy aircraft would either be looked up or calculated quickly from models, but whatever approach is used the data required could be substantial.

Moreover, these data need to be protected just as much as encryption keys. Not every detail of a weapon's signature will be used for identification and loss of the data would help an enemy discover which particular attributes were being used. Updating data or adjusting for compromised information during combat could pose severe data distribution problems. Thus, using a noncooperative approach to IFF will alter but not remove the requirements for data security and handling.

Compiling the databases required for noncooperative IFF raises delicate diplomatic and intelligence questions. Would allies be willing to provide sufficient data on their weapons? (Would the United States be willing to provide comparable data to allies?) If not, would surreptitious attempts to collect data cause international friction? Would the very existence of data collected surreptitiously need to be kept secret from allies? How would information on enemy weapons be collected? If weapons data are available, could they be shared with allies during joint operations without revealing intelligence methods?

Whether using cooperative or noncooperative IFF systems, operations with allies pose special problems. In the new global strategic and political environment, the United States will almost always be engaged militarily with allies at its side, for political if not military reasons. Moreover, unlike the relatively stable allied relations in NATO, future alliances are more likely to be ad hoc, with even former-and perhaps future--unfriendly nations acting as temporary allied partners. The Persian Gulf War, which included the participation of Syrian forces, provides a perfect example.

Clearly, it is in the interest of the United States to help allies not to commit fratricidal attacks on themselves or on U.S. forces. But the need for both protection of identification techniques and allied cooperation creates dilemmas.

For example, encryption keys needed for question-and-answer IFF systems would have to be shared with allies. But today's allies might be hostile tomorrow. At the very least, the United States must be able to make any system secure again by changing the encryption keys. Thus, a temporary ally would not have irrevocable ability to trigger IFF systems on U.S. weapons.

Encryption keys that fell into the hands of other nations can be changed quickly-and thus rendered useless—but the same is not true for hardware and technology. Cooperative question-and-answer systems require that allies have compatible equipment. Presumably the United States would have to provide the equipment or at least explain the encryption systems in enough detail that other nations could produce their own comparable systems. Yet the United States has invested significant resources to develop reliable and secure encryption systems because expert opinion holds that the resulting capabilities offer profound tactical and strategic advantages. Even though keys are changed, if the equipment is left behind, other nations can generate their own keys and use the equipment for their own IFF with all of the tactical advantages that accrue.[18]

The United States must decide whether the benefits of having a unique technical advantage in IFF outweigh the benefits of allied interoperability. Without exchange of IFF technology, geographic areas of responsibility would have to be clearly divided among allies, with each responsible for fratricide avoidance within its area and special procedures used to reduce accidents at the boundaries between areas. This problem becomes particularly important in ad hoc coalitions; the United States may be willing to share technology with NATO allies that it is unwilling to share with temporary allies. The ideal solution might be a technically less sophisticated, or 'stripped down,' IFF system that could be shared with some allies and was compatible with, but not have all the advantages of, the complete system.

MAKING CHOICES ABOUT HOW TO AVOID FRATRICIDE

■ Criteria for Judging Antifratricide Technology

Any successful antifratricide system must meet several criteria. First, and probably of greatest importance to the combatants in the field, is that using the system must not significantly increase the users' danger. For example, transmitting an IFF query in a question-and-answer system must not give the enemy a chance to intercept the radio signal, thereby giving away the shooter's location. A second, and related criterion, is the difficulty of using the system. If it is too complex or time-consuming, then it will not be used at all. The whole process of using the IFF system must not take so long that the enemy can shoot first while friendly forces are still fiddling with knobs.

A third criterion is how widely applicable the system is. Can it tell the shooter something about everything on the battlefield from infantrymen to jet fighters? Or is the system limited to those platforms that can carry a large and expensive transponder? A fourth criterion, related to the third, is the system's reliability. This is more than simply a question of how long a piece of equipment will work without maintenance, but of how well it will work under a complex—and ultimately unpredictable--array of battlefield conditions that might include active measures by the enemy to undermine or exploit the system. For example, how reliably can a noncooperative IFF system identify an enemy if the enemy knows what characteristics are being observed and used for classification and then tries to alter those very characteristics? Required reliability also depends on how an IFF system is used. Human eyes and common sense avoid most potential fratricide; if another system is used *in addition to* current procedures as one last check, then 90 percent reliability is adequate, but if used *instead of* current procedures, 90 percent reliability would be disastrous.

The fifth criterion is cost, both total costs and costs compared to alternative requirements. In absolute terms, total cost is important because resources are finite and combat can never be made safe so decisions must be made about when a system is "good enough." Consideration of comparative costs is potentially less judgmental and more analytical. If the objective is to save lives while maintaining combat effectiveness and a better IFF system is just one way of doing that, then within a finite budget every dollar spent on IFF is a dollar not spent on other things that might also save lives, Perhaps casualties-including those from fratricide--could be lowered more effectively by using the same resources to buy reactive armor for tanks, or for more training, and so on. The relative importance of a fratricide casualty and a hostile casualty-which will determine the allocation of marginal resources—

18 National Security Agency briefing, "Survey of Target Identification," Sept. 9, 1992

is a difficult policy question that will not just be hard to decide but hard to discuss dispassionately.

Comparison of Different Approaches To Avoiding Fratricide

Awareness of the Tactical Environment v. IFF

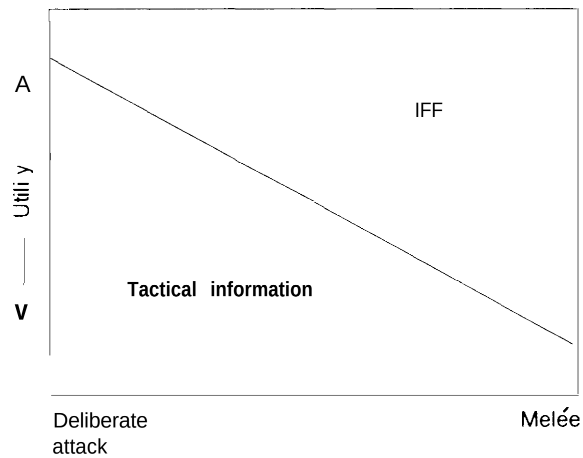
The main two broad approaches to preventing fratricide are increasing tactical awareness and improving target identification. Either approach offers benefits, each has areas of particular importance, and both will need to be pursued in parallel.

The differences are clearest for ground combat. In general, as ground units approach the enemy, knowledge of their tactical environment is most important to avoiding fratricide. This means that units have the navigational information needed to know where they are, know where they are supposed to go, and not stray across avenues of advance. Nearby units need to communicate to avoid confusion along their boundaries.

As the battle is entered, one-on-one identification becomes increasingly important. In the extreme of a melee, the tactical situation could become so confused and fluid that no person could keep up with the changes even if the technology were available to report them. In this situation, IFF would be of greater importance, (See figure 3-6)

When comparing costs of the two approaches, the multiple benefits of each must be weighed in the balance. A reliable point-to-point IFF system would be valuable for IFF but since identification range can set the limit of effective engagement range, it might also allow engagements at longer range. Any system that improved the knowledge of the tactical environment would reduce fratricide but also allow better control of maneuver groups, better coordination of fire and combat units, faster attacks, more efficient movement across country, and so on, thereby increasing the overall combat capability of the force. Thus, when comparing costs of reducing fratricide, only the appropriate portion of the cost of each system

Figure 3-6-Changing Relative Importance of Tactical Information and Identification



SOURCE: Combat ID System Program Office.

should be allocated to the antifratricide requirement.

Training and Simulation

The solution to the problem of fratricide is not just black boxes; training and combat skill are at least as important. Of course, the skills needed to avoid fratricide-alertness, unit coordination, and discipline-are exactly those needed for any unit to be effective in combat. However, the Services realize that the danger of fratricide needs special attention. The Army recently has begun to carry out separate after-action analysis of simulated “fratricides” at the National Training Centers. This includes a standardized format for an evaluation, called the Fratricide Incident Report, which allows comparison of cases and analysis of most common causes. Avoiding potential fratricide dangers are now an explicit part of battle planning. The Army promulgates this new emphasis through the Training and Doctrine Command (TRADOC).

Realistic training can reduce casualties in combat—including fratricide-but the inherent danger of training creates a connundrum. One military analyst has suggested that some of the problems encountered in the Persian Gulf occurred because the military did not train enough and not realistically enough.[19] Intense and realistic training results in better combat performance, no doubt, but it costs lives itself. For example, 1991 was the Air Force's safest year on record, with only ten noncombat deaths due to flying accidents, In one particularly unfortunate 24-hour period late in 1992, the Air Force lost four aircraft and 17 crew in three separate accidents.[20] Training for war will never be both perfectly effective and perfectly safe. Those that suggest more realistic live-fire training must weigh the possible reduction in losses in some future war against the higher annual peacetime losses incurred from the training.

Simulators are an important component of modem training. These need to be improved to better represent real combat identification problems. For example, most ground combat fratricide in the Persian Gulf War occurred at night, but tank training simulators do a much better job of reproducing daytime than nighttime conditions—that is, the world seen though infrared imaging devices.

On a large scale, simulation becomes combat modeling and, until recently, almost all computerized combat models simply ignored the possibility of fratricide. In fact, most computer models proceed as though both sides have perfect tactical information and fratricide never occurs. Indeed, no provision is allowed in most computer programs to investigate the effects or causes of fratricide. This past neglect of the problem is now being addressed.

Doctrine

Doctrine affects the causes and cures of fratricide. Avoiding fratricide has never been the sole, or even primary, determinant in doctrinal development and rightly so. As fratricide is becoming relatively more important as a source of casualties, however, it is receiving increasing emphasis, especially within the Army. Yet fundamental tenets are not being examined as closely as they might. For example, the Army emphasizes a very aggressive approach to ground combat, arguing that speed and ''momentum" are key to success and holding overall casualties low. Yet many fratricide in the Persian Gulf occurred at night at ranges where the enemy—because of inadequate sensors—was unable to shoot back. At least one civilian analyst has suggested that-with the shooters in less immediate danger-slower, more deliberate, attacks could have been carried out to reduce the risk of fratricide. The Army argues that doctrine and training are not something that one can turn on and off like a switch. ''Today, troops, we will use Doctrine B' will not work. Perhaps further development of the "weapons tight/ weapons free' approach would suffice.

Clearly, the Services must coordinate their approaches to avoiding fratricide. The interaction of the ground forces with the air, is one clear example. Close air support has never been the Air Force's primary interest and identification of ground targets has suffered. This is the time, with new interest in developing antifratricide technology, for careful coordination.

With the end of the Cold War, some military analysts are discussing quite radical suggestions for the reassignment of roles and missions of the Services. Avoiding fratricide will not be the primary determinant in these decisions, but it should be important in several cases, for example, whether to assign close air support to the Army or whether to assign ground-based air defense missiles to the Air Force.

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19 ''Training needs to change, too. Although our soldiers are of the highest quality, they still do not train realistically enough for war. There is too much emphasis on *safety*. [emphasis added] As a result, units do not train for integrated combat in a live-fire environment, where artillery, armed helicopters, close air-support jets, armored vehicles and soldiers replicate the violent and confusing conditions found on the battlefield. Col. David H. Hackworth, "Lessons of a Lucky War," *Newsweek*, vol. 117, No. 10, March 11, 1991, p. 49.

20 *Aviation Week* and *Space Technology*, "USAF Loses Four Aircraft, Including B-1B, in 24 Hr., " Dec. 7, 1992, pp. 24-25.

CONCLUSION

Fratricide is becoming more visible and may frequently be a *relatively* more serious source of casualties in modem U.S. combat because major military operations are now sometimes possible with remarkably few losses, as the Persian Gulf War demonstrated. Cures for the fratricide problem deserve serious, continuing attention, but fratricide is not a cause for panic and will not lose the next war.

Avoiding fratricide takes more than just identifying targets properly. And target identification is a complex problem that will not be solved by a "black box." Much of the information needed to avoid fratricide is exactly the information needed to be a coherent combat force.

Future wars will include joint operations among each of the Services and among the United States and its allies. Today, the military R&D community is pursuing several antifratricide developments. Existing efforts to coordinate with sister Services and allies should be vigorously maintained.

Avoiding Fratricide of Air and Sea Targets

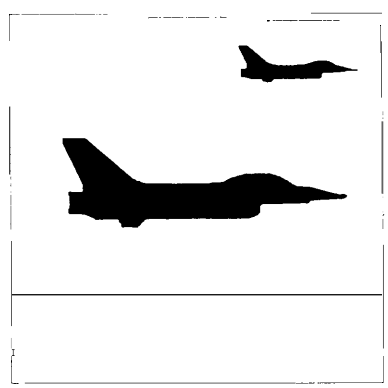
4

As described in the previous chapter, reducing fratricide requires more than improving identification. This chapter discusses ways to improve both tactical knowledge and identification to avoid air fratricide. There are several technical approaches to better identification; each of these is described briefly below with a discussion of its advantages and disadvantages. The chapter ends with a discussion of the interaction of military identification systems with civilian air traffic control and a brief discussion of avoiding fratricide of ships.

BATTLE MANAGEMENT

"Battle management' includes collecting information about where combat resources are needed, setting priorities, and allocating resources to needs. The tactical knowledge or ''situational awareness' provided by battle management is so integral a part of air combat that its importance to avoiding fratricide is easily overlooked, Yet the foremost antifratricide measure is properly coordinating friendly forces.

Any efforts that improve coordination also improve combat effectiveness—and that typically is their primary justification—but these same efforts can help reduce fratricide. The Navy and the Air Force discovered during joint operations in the Persian Gulf War that air tasking orders (ATOs) were difficult to transmit between the Services' strike planners. Air Force and Navy radios were not always compatible and the ATOs were so voluminous that transmission was time ,consuming. These and other uncovered communication problems are now being corrected. The resulting improvement in attack efficiency will be obvious, but better communication and coordination also will make fratricide less likely.



At the tactical level, long-range surveillance can sometimes track an enemy airplane from the moment of takeoff. If a fighter can be seen taking off from an enemy airfield, few would argue with the assumption that it is an enemy airplane. This capability is partially in hand today with the AWACS. The limitations of the system are range and, more importantly, tracking. Once the enemy airplane gets close to a friendly airplane the radar may no longer see them as separate targets or the radar may loose track of the airplane when it flies behind mountains. Then, when a distinct radar echo is again detected, the tracking radar cannot tell whether the aircraft came from an enemy airfield.

AWACS can hand down information, but greater benefits accrue with a two-way communication between some central coordinating point and forward shooters equipped with IFF capabilities. For example, to avoid fratricide, surface-to-air missiles are specifically allocated defensive areas in which friendly aircraft are not to fly. Tests are currently underway to evaluate the feasibility of transmitting target identification down to individual missile batteries so that missiles and fighters can operate in the same area. But much of the information handed down from the center could come from analysis of data collected by the individual missile batteries in the field.

The ultimate goal for any identification and command system would be an array of individual shooters equipped with point-to-point identification of friend and foe (IFF) capabilities, collecting information and sharing it through some network so identifications are based on a composite picture built up from all available information. With the possible exception of the missile-fighter coordination, none of the communications improvements currently proposed or underdevelopment are being justified solely-or even primarily—as antifratricide measures, but their contribution to avoiding fratricide could be substantial. If allies can tap into the information-sharing network, they can still get the benefit of U.S. IFF information without acquiring the technology.

NONCOOPERATIVE IFF

Chapter 3 discussed how cooperative systems really only identified friends; noncooperative techniques are able to identify foes as well. Noncooperative identification of aircraft varies from the very simple-visual recognition—to detection, analysis, and classification based on extremely subtle differences among target aircraft.

The end of the Cold War will change the equations governing noncooperative IFF. In those future Third World conflicts in which the United States has overwhelming air superiority, positive identification of enemies-and hence noncooperative IFF--will be important. After all, any unidentified aircraft picked at random is likely to be friendly under those conditions, so failure to respond to an IFF query will probably not be justification to fire. At the same time, the technical challenge now will be in many ways much greater than during the clearer confrontation between NATO and the Warsaw Pact forces, since both Western and Soviet equipment are now widely proliferated. Therefore, allies and enemies might very well be using the same equipment, as they indeed did during the Persian Gulf War. The Services agree that no single measurement will be adequate to identify enemies, rather that a composite picture formed from many sources of information will be needed to be definitive. Some are discussed below.

■ Radio-Emission Intercept

Perhaps the simplest noncooperative technique—short of visual identification-is passive interception of radio and radar transmissions. Each radio and radar system transmits at characteristic frequencies, with characteristic signal modulation, and-at least for radars--characteristic pulse shapes and repetition rates. Some aircraft will transmit radio-frequency energy routinely, while others will at least occasionally transmit. It is also theoretically possible to induce enemy aircraft to transmit signals, perhaps by sending false communications requiring answers or by appearing to threaten the aircraft in a way that forces the enemy pilot to turn on defensive radars or otherwise communicate with his command and control network.

Radar

Careful analysis of radar returns reveals much more about a target than just its bearing and range. Soon after the development of radar, operators noticed that the propellers of aircraft modulate the frequency of the radar return in a characteristic way. The modern equivalent is called jet engine modulation (JEM). The air intakes of jet engines reflect radar signals very efficiently. Some of the radar waves entering the inlets are reflected off of the rapidly rotating compressor or fan blades. The motion of the blades causes a slight Doppler shift in the frequency of the reflected waves. These subtle frequency shifts are readily detectable by sophisticated radars and are, moreover, characteristic of particular jet engines.

The principal limitation of identification by jet engine modulation is clear: the technique identifies engines, not aircraft. There are a limited number of military jet engines available worldwide and very different airplanes can be powered by the same type of engine, At the same time, individual aircraft in a particular fleet might have different engines. For example, some U.S. F-16s have been fitted with the General Electric F-1 10 engine while others have been fitted with modified Pratt and Whitney F-100 engine originally used in the F-15.

Jet engine modulation should at the very least distinguish fighter aircraft from transport aircraft, These two types of aircraft use very different types of engines: fighter engines typically have low bypass ratio engines and therefore have small, high-speed fans, while transports have high bypass ratio engines with much larger, slower fans. This method will not, however, necessarily distinguish military from civilian transports, For example, the commercial Boeing 757 and the military McDonnell Douglas C-17 both use the Pratt and Whitney F-1 17 turbofan engine.[1]

In addition, the technique is highly dependent on a proper geometry between the radar and the target. This dependence can restrict the technique's application in a dynamic air engagement.

More detailed information about the airplane structure itself will be available from high-resolution radars (HRR) under development. Radio or radar waves are just a form of electromagnetic radiation, like light, and travel at the same speed. Light travels about 300 meters in a microsecond. A typical radar sends out pulses, or bursts of radio waves, that are on the order of a microsecond in duration. This means that the radar pulses are many meters long. Resolving features much smaller than the radar pulse length is difficult; thus conventional radars are good at detecting objects but not much use for providing details of objects as small as airplanes. Targets appear just as blobs on the radar screen. If, however, a radar had a very compact pulse, perhaps the individual reflective surfaces of an aircraft could be resolved, which would allow identification. Such HRRs are currently in research and development. See figure 4-1.

The challenges facing high-resolution radar development are substantial. First, of course, is designing and building a radar that can emit pulses with duration of only several nanoseconds (billionths of a second). Proponents of high-resolution radar are confident that the technology is available or can be developed. In addition, however, are the operational challenges. For example, each target will have a different echo pattern depending on the perspective of the viewing radar. Side views will look nothing like head-on views and data catalogs must be developed of all potentially hostile aircraft seen from all possible aspects.

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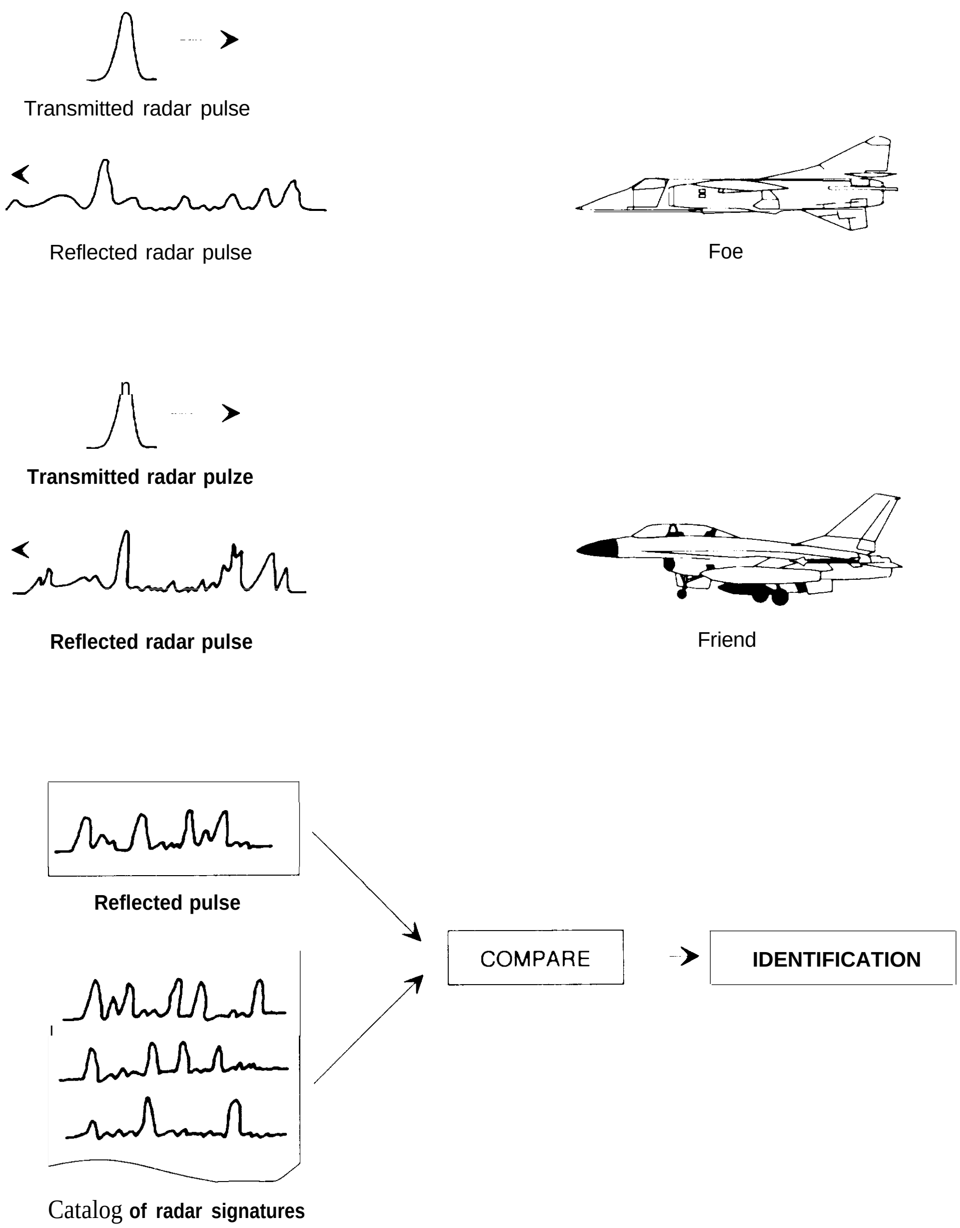
[1] Mark Lambert, cd., *Jane's All the World's Aircraft* (Coulsdon, UK: Jane's Information Group, 1990), p. 748. The civilian designation for the engine is "PW2040.'

Figure 4-l—High Resolution Radar

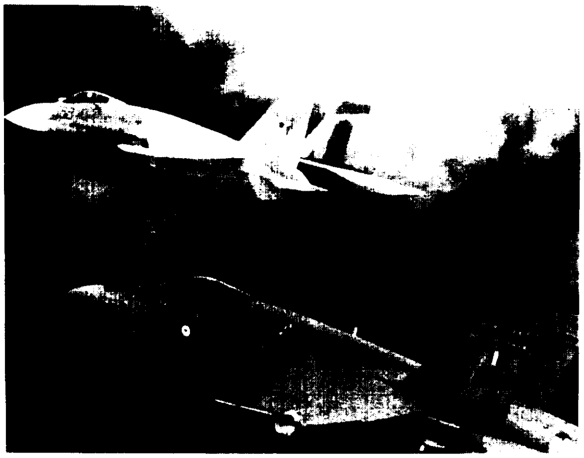
Identification with High-Resolution Radar



Office of Technology Assessment, 1993.

Moreover, different aircraft can look similar from particular directions. For example, from a trade journal review of the Soviet Su-27 fighter: “From a head-on or trailing position, the Su-27 resembles the Navy/Grumman F-14, but has a thinner profile and is therefore more difficult to detect. From certain attitudes, if the range is not known, the forward portion of the Su-27 also resembles that of the USAF/General Dynamics F-16 because of its prominent bubble canopy and

MCDONNELL DOUGLAS CORP.



U.S.-built F-18 from the Australian Air Force flies below a similar-looking Su-27 from the former Soviet Union. Superficial resemblances of weapons can make quick identification difficult and unreliable.

its forward aerodynamic strakes, which blend into the wing leading edges."[2]

The algorithms used to discriminate among aircraft will not look at every detail but will extract and concentrate on certain defining characteristics. If an enemy knew which characteristics were used for discrimination, then it could try to suppress or alter them. Thus, the algorithms will need to be strictly secret and cannot be shared with all allies.

Surface-to-Air Missiles and Noncooperative IFF

Difficulties of working out aircraft identification has forced surface-to-air missiles (SAMs) and air interceptors into different zones of responsibility. Typically, SAMs defend strips of airspace from which all friendly aircraft are excluded; thus, anything entering the zone could be considered hostile and attacked. These areas are called Missile Engagement Zones or MEZs. Undefended corridors through the strips allow friendly aircraft to pass from one side of the strip to the other. Since enemy aircraft can track friendly aircraft and soon discover the locations of the corridors, the corridors must be moved frequently. Areas outside the MEZs are left to the interceptors. SAMs would not routinely engage any aircraft within these Fighter Engagement Zones, or FEZs.

The introduction of the Patriot missile changed the utility of this allocation of responsibility between interceptors and SAMs. The range of the Patriot is so great that, at least in the European theater of operations, there would be little area that was not accessible to both interceptors and Patriot. The Army, which operates the Patriot batteries, could severely and artificially restrict the engagement range of Patriot, but that obviously eliminates much of its capability and the justification for the cost of the system. To resolve this conflict, the Army and the Air Force started a program called Joint Air Defense Operations (JADO) to test a concept known as Joint Engagement Zones, or JEZs. The test of the feasibility of

HUGHES MISSILE SYSTEMS

An infantryman prepares to launch a hand-held surface-to-air missile against an attacking aircraft. The combined-arms battlefield is complex and dynamic, with many different types of weapons able to engage enemy targets, thereby greatly complicating and broadening friend and foe identification requirements.

[2] Donald E. Fink, "Sukhoi, Australian Pilots Fly in Joint Maneuvers," *Aviation Week and Space Technology,* Mar. 5, 1990, pp. 64-67.

Box 4-A—History of Aircraft Identification

From the time aircraft were first used in combat in World War 1, fratricide has been a problem. Early fratricides motivated the application of national insignia on the wings and fuselages of aircraft and were at least part of the reason that some pilots-like the famed "Red Baron' 'resorted to garish color schemes.

Between the World Wars, the military gave some slight attention to the problem of identifying friendly aircraft beyond visual range, or in aloud or fog. As early as 1928, the British speculated on the possible use of sirens, whistles, or "singing" wires to create a signal that could be heard even if the aircraft could not be seen. Bomber command also considered schemes to use special light signals to identify returning aircraft.[1]

The problem of fratricidal attacks on aircraft and surface ships took its modern and familiar form with the development of radar. Early radar inventors foresaw immediately that radar-a device that allowed detection of aircraft and ships at long range, at night, and through clouds--created the difficult problem of identifying the detected object?

Early radar developers' first IFF attempts were to alter the radar returns of friendly craft in some characteristic way. Radar pulses are nothing more than radio waves that, when reflected from an object, create detectable echo pulses. The apparent size, or radar "cross-section," of an object determines the intensity of the radio waves reflected back. The cross-section in turn, depends roughly on the physical size, shape, and orientation of the object but also on the electrical characteristics of the object. For example, a conducting rod equal in length to half the radio wavelength will resonate with the radio waves, which causes a particularly strong reflection. If the resonant reflection could be turned on and off, then the radar return would vary in a way that could be used for identification purposes.

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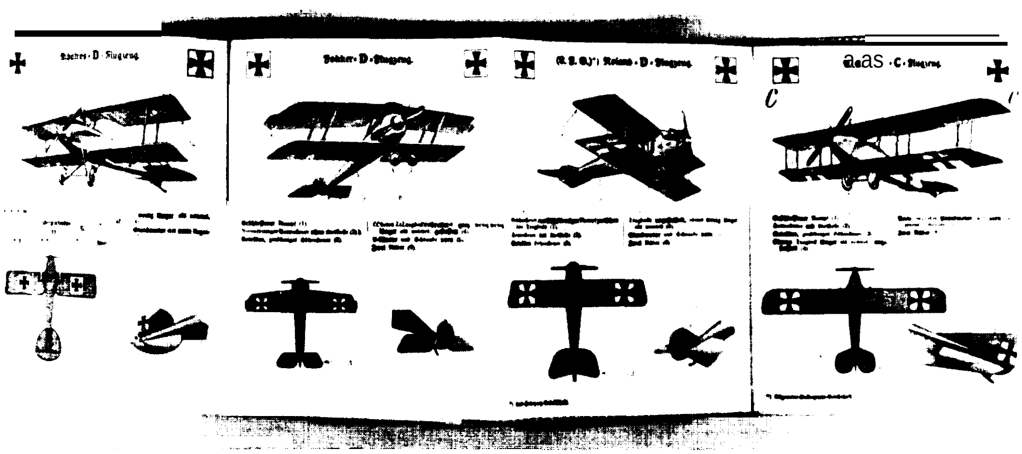

A German aircraft spotter's field guide used in World War I. From the very first uses of aircraft in combat, identification has been a challenge.

In 1937, the British mounted a few test aircraft with an antenna wire running the length of the fuselage. A switch at the center of the antenna was turned on and off in a regular pattern by a cam. Toggling the switch effectively changed the length of the antenna and hence the degree of resonance and the radar cross-section. Thus a radar operator would seethe "size' 'of the target changing in a pattern known to be characteristic of friendly aircraft. Tests on individual aircraft were very successful but the crude cams would not have worked for groups

1 Sean S. Swords, A *Technical History of the Beginnings of Radar,* Technical Report MEE1 (Dublin, Ireland: Department of Microelectronics and Electrical Engineering, Trinity College; 1983), p. 99.

2 Indeed, early radar developers coined the term "IFF" for "Interrogation, Friend or Foe" or, as some early operators referred to it, "Izzie friend or foe?" See Robert Morris Page, *The Origin of Radar* (Garden City, NY: Anchor Books, 1962), p. 166.

of aircraft: without perfect synchronization, one airplane's switch might open just as another's might close creating an indecipherable jumble and the system was never adopted.

In 1939, the U.S. Navy mounted atop a destroyer a set of half-wavelength rods on a pole. A motor rotated the pole and the rods along with it. The rotation changed the orientation of the rods, hence their degree of resonance with a distant radar and thus the strength of the radar echoes. The radar echo from the destroyer oscillated in an obvious way that identified it as a friend. This technique, while simple, had the same limitations as the aircraft system and because of its simplicity was easy for an enemy to copy.

The limitations of passive cooperative techniques led radar researches to active radar reply devices, now called "transponders." The first transponders operated at the radar's frequency; whenever the transponder detected a radar pulse it would transmit its own pulse at the same frequency. The radar would detect this pulse, interpret it as a powerful radar return, and the target would show up brightly on the radar screen.

The first transponders were the Mark I and Mark II developed in Britain and similar devices developed around the same time by the U.S. Naval Research Laboratory (NRL). These devices scanned all radar frequencies in use by friendly forces and retransmitted a pulse at the appropriate frequency whenever a radar was detected. In the early days of radar, this technique was possible because only two or three radars frequencies were common, but as more radar frequencies became available, this approach became untenable simply because the transponder could not handle the range of frequencies.

By 1941, the proliferation of available radar frequencies required that IFF devices go to a single frequency, independent of the radar's frequency. Thus, the radar could operate on whatever frequency was most appropriate and an *additional* signal, part of the so-called "secondary" radar, would query the target's identity. The Mark Ill was the first such device, sending and receiving signals in the 157-187 MHz (that is, megahertz or millions of cycles per second) frequency band.[3] The Mark Ill became the standard IFF device used by the American, British, and Canadian air forces during World War Il.

The Mark IV, developed at the U.S. Naval Research Laboratory (NRL), was the first IFF system to use different frequencies for the query and the response--470 MHz and 493.5 MHz-but it never came into widespread use.[4] In 1942, the NRL began development of the Mark V, also called the UNB or "United Nations Beacon," which was to operate near 1 GHz (that is, gigahertz, or billion cycles per second). This program was not completed until after the war but is important because the frequencies used-1.03 GHz for queries and 1.09 GHz for replies-are still used today on both civilian and military transponders.

The next set of refinements appeared in the Mark "X," which had a dozen query and response channels available.[5] Mark X originally allowed aircraft to identify themselves as friendly but did not allow different responses from different friendly aircraft. A capability, known as SIF,[6] allowed different responses from different transponders. This capability, plus an encrypted query and response mode added to the Mark X became the current Mark XII. (The Mark XII used for civilian purposes without the encryption capability is still frequently referred to, especially in Europe, as the Mark X-SIF.)

The Mark XII is today used by U.S. aircraft and ships but is not widely used among U.S. allies.

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3 The U.S. equivalent of the Mark III was called the SCR 595. See Swords, op. cit., footnote 1, p. 102. Transponders operating on this principle, now in near universal use on aircraft for civilian air traffic control as well as military IFF, are usually called "secondary surveillance radars." See Michael C. Stevens, *Secondary Surveillance Radar* (Norwood, MA: Artech House, 1988), p. 7.

4 Much of this and subsequent wartime development of IFF devices was a joint effort of U.S. and British scientists, called the Combined Research Group and headquartered at the Naval Research Laboratory.

5 The "X" was a place-holder until a decision could be made about whether a new Mark number was justified but it became, perhaps inevitably, the Roman numeral 10. Thus, there are no Marks VI, VII, VIII, or IX in the chronology.

6 U.S. sources state that the acronym stands for "Selective Identification Feature," but some British sources state that the "F' stands for "Facility."

this approach is called JADO/JEZ. Tests are now being carried out at or planned for Nellis and Eglin Air Force bases. Since the establishment of the test program, the Navy has become involved, to enable it to test operationally some noncooperative surface-to-air identification systems, such as the Shipboard Advanced Radar Target Identification System, or SARTIS. In February 1994, coordination of Army ground-based SAMs, Air Force interceptors, and Navy off-shore SAMs will be tested along the coast of Florida at Eglin Air Force Base.[3]

Patriot missiles belong to the Army but during joint operations their rules of engagement are typically set by the Air Force. The Air Force wants positive hostile identification before allowing the missiles to fire. Lacking any intrinsic capability to do so, Patriot batteries must depend on higher echelons to provide the information. During large-scale battles involving many potential targets, the transfer of information from high echelons down to individual fire control centers can saturate current data networks, causing delays in identification data transfer.

Any development of noncooperative IFF must consider SAMs from the beginning if they are to contribute to their full potential. For example, Patriot missiles, while gaining fame for their interception of Scud missiles in the Persian Gulf War, were on permanent weapons-hold status against aircraft targets. There were, therefore, no ground-to-air fratricides despite numerous violations of Army air defense areas,[4] but also, of course, Patriot played essentially no role in air defense operations.[5]

COOPERATIVE QUESTION-AND-ANSWER IFF SYSTEMS

Cooperative question-and-answer systems have been central to combat aircraft identification since World War II; indeed, some discussions of "IFF" really only treat this one approach. A description of the Mark XII and now-canceled Mark XV provides specific information on these two systems but also offer a convenient framework for presenting general design considerations for all question and answer IFF systems.

Although the early "Mark" numbers referred to specific types of hardware, the Marks XII and XV—and presumably future models—really refer to protocols. That is, "Mark XII" refers to an agreed format, or protocol, for sending and receiving information. This includes the relevant frequencies, the length of the radio pulses, the timing between them, the meaning of different pulses, and so forth. The Mark number does not specify the hardware configuration required, and Mark XII equipment has gone from vacuum tubes to transistors while using the same protocols. Of course, *some* hardware must embody the protocols, but any one of several interrogators and transponders can handle these formats and are, therefore, ''Mark XII" devices. For example, the UPX-23 and UPX-27 refer to two specific shipboard Mark XII interrogators while the APX-72 is an example of a Mark XII airborne transponder. Thus, the following discussion can combine specific questions related to protocols with general descriptions of hardware.

The current Mark XII sends out a query in the ''L" radar band, at a frequency of 1.03 GHz. The query is a pair of radio pulses. The time between the two pulses can be varied and the transponder will interpret the query differently depending on the separation time between the pulses. The immediate predecessor of the Mark XII, the Mark X, used three different pulse separations, each referred to as a ''mode. ' A pulse separation of 3 microseconds is "Mode l," 5 microseconds is

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[3] Capt. Rocco Ersek, N6X1, briefing titled: "Introduction: JADO/JEZ, " (undated).

[4] Briefing entitled, ''Combat Identification: TRADOC Briefing," Lt. Colonel Mike Brown, U.S. Army Training and Doctrine Command (March 12, 1992).

[5] U.S. Congress, General Accounting Office, *Aircraft Identification System(U)*, GAO/C-NSIAD-92-13, p. 13.

"Mode 2," and 8 microseconds is "Mode 3.' These modes are still in use today.

The reply signal from the Mark X contained at least a pair of 1.09 GHz "framing" pulses 20.3 microseconds apart. These pulses indicate when the reply message starts and stops. Between the framing pulses of the response from the original Mark X lay six time slots 2.9 microseconds wide, each of which may or may not contain a radio pulse.[6] A pulse in a particular time slot represents a "1" and lack of a pulse represents a "O,' thus allowing transmission of binary numerical data. The improvements implemented for the Selective Identification Feature, or SIF (see box 4-A), and Mark XII included an increase to twelve slots between the framing pulses to allow for 4,096 possible replies. With the available number of possible replies, airborne transponders can give a distinct reply that identifies not just whether the aircraft is a friend but *which* aircraft it is-exactly as in civilian air traffic control today.

A simple transponder can be exploited easily by the enemy. If the enemy could get the transponder to respond to a query, friendly aircraft would reveal their positions and identities. To avoid this weakness, a program to develop an encrypted query mode was started in 1954. Mark XII IFF devices have this encrypted question-and-answer mode, called Mode 4. The Mode 4 query starts with four time synchronization pulses followed by up to 32 pulses that contain encrypted information telling the receiving transponder that the query is a valid, friendly query. Invalid queries are simply ignored by the transponder. The response to a Mode 4 query is a string of three pulses. The reply can start after any of 16 possible time delays; thus by changing the delay the reply can convey limited information. See box 4-B for the specifications of the interrogations and replies.

The IFF interrogators and transponders cannot work by themselves. If the transponder sent out a query in all directions and got a response back, the IFF interrogator would only know that there is somewhere out there at least one friendly aircraft. To query particular aircraft, interrogator antennas are mounted along with conventional radar antennas to point in a particular direction. When a target is detected by the radar, the IFF interrogator can send out a query in the same direction as the radar beam asking the aircraft to identify itself. The information from the reply can then be displayed on the radar screen directly.

The transponder can be simpler than the interrogator. When it receives a query, the answer need not be directed to the questioning radar; instead a simple omni-directional antenna is adequate and the interrogating radar can determine which aircraft is responding by correlating the response with the radar beam's direction.

Because of the difference in complexity, interrogators are generally more expensive than transponders. This affects the extent of their use; for example, some aircraft are fitted only with transponders. Ships and control aircraft like the E-2 are routinely fitted with the more expensive interrogators, but many interceptors are not.

The different modes can be used for military air traffic control. For example, an aircraft carrier's radar will show all the aircraft in its vicinity but this may be over a hundred aircraft in some crowded air corridors, such as over the Mediterranean.[7] The radar operator can use IFF modes to highlight friendly military aircraft.

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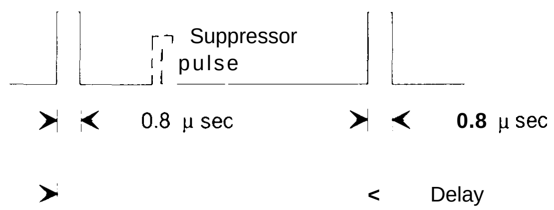
[6] Oral history at the Naval Research Laboratory holds that the time slots were intended to be an even 3.0 microseconds wide but the first delivery of delay lines for the prototype proved faulty, testing at only 2.9 microseconds. Rather than wait for new delay lines, researchers proceeded with what they had available. Thus, it came to pass that framing pulses of 20.3 (that is, 7x2.9) microseconds will be in use well into the twenty-first century. This tale illustrates how protocol standards should be developed carefully because they tend to stay with us for a long time.

[7] Briefing entitled ''Automatic Identification (AutoID), " Applied Physics Laboratory, The Johns Hopkins University, (undated).

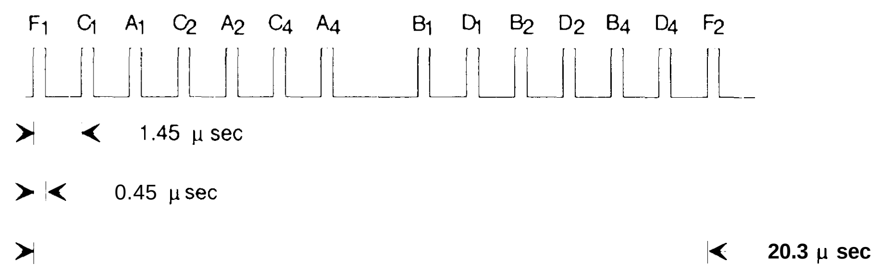
Box 4-B-Formats and Protocols for the Mark XII

Mark XII interrogations and replies are pulses of radio waves at 1.03 and 1.09 GHz. Information is conveyed by changes in the number and timing of the pulses. The interrogation for military Modes 1,2, and 3 and civilian Modes A, B, C, and D are a pair of pulses separated by a time delay, the length of which is specified by the particular mode. This format is illustrated in figure A.

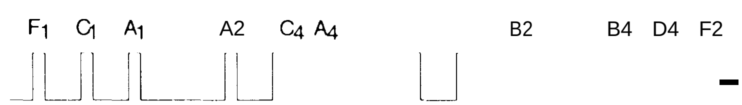
Mark XII interrogation format



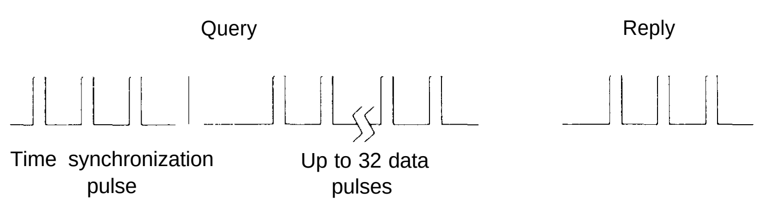
Mode 3/A reply format



Mode 3/A reply pulse 7654



Mode 4 formats



SOURCE: NATO STANAG 4193 (Part 1) (Edition 2), 1990.

Box 4-B–Formats and Protocols for the Mark XII

No antenna is perfect, sending signals only in the direction wanted and no other. Energy leakage through "side lobes" could cause transponders to f ire even when t he radar is not pointed directly at them. To avoid this problem, some interrogators send out a suppressor pulse in every direction except the direction the radar is pointed. A transponder can compare the size of the two signals and if the suppressor pulse is larger than the framing pulses, the query is ignored.

Table A—IFF Modes

Delay (μ see)	Military mode		civil mode	Use
3	1			Military Function ID
5	2			Military Function ID
8	3	=	A	Aircraft identification
17			B	Not used internationally
21			C	Altitude
25			D	Not used internationally

SOURCE: NATO

Each interrogation mode has a different time separating the pulses, except that military Mode 3 is equivalent to civilian Mode A. The various Modes are shown in table 4-1. The pulse separation in Mode 1 is so short that not ail interrogators and transponders can handle the insertion of a suppressor signal in Mode 1.

The reply format consists of a pair of framing pulses 20.3 microseconds apart with up to 12 signal pulses between them, although not all modes use all the availabie signal pulses for information. The format is shown in figure B. Numerical values are transmitted in the replies in the form of four-digit "octal" or base eight numbers of the form ABCD. Each of the these digits is the sum of three pulse values. in the figure, for example, three of the pulses are Iabeled Al, A2, and A4. The first digit in the four-digit number is A which equals Al +A2+A4 where Al has a value of one, A2 a value of two, and A4 a value of four if a pulse is present in the appropriate time slot, and zero otherwise. Thus the decimal number 4,012, which is 7,654 in octal notation, would be represented by A=7=A4+A2+A1, B=6=B4+B2, C=5=C4+C1, and D=4=D4. The resulting pulse pattern is shown in figure C.

Mode 4 pulses, the encrypted mode, have a different format. The interrogation pulse starts with four time synchronization pulses. These are followed by up to 32 data pulses. The arrangement of these pulses validates that the query is indeed from a friendly interrogator and transponders should send a reply. The reply is a set of three pulse delayed by various amounts. These formats are shown in figure D.

Passive Cooperative IFF Measures

Cooperation by friendly targets could enhance the discriminating ability of passive friendly observers using the noncooperative IFF techniques described above. Few of these ideas are beyond the conceptual stage. They include adding radar highlights that would stand out on high-resolution radar, inducing vibrations that would show upon Doppler radars,[8] and even modulating or doping exhausts to make them stand out to infrared sensors. Application of any of these techniques will require first the deployment of the appropriate noncooperative identification technique.

Limitations of Mark X11, Improvements in Mark XV, and Next Generation IFF

This section briefly discusses some of the current and potential short-comings of the current Mark XII IFF system. These problems were to be corrected with the development of the Mark XV. The Mark XV development was canceled in December 1990 and the still-to-be-defined successor question-and-answer system is now referred to as the Next Generation IFF, or NGIFF.

[8] Briefing entitled, ' 'Achieving Covert Communications and Ground-Combat Identification Using Modulated Scatterers, ' E.K. Miller and D.M. Metzger, Mechanical and Electronic Engineering, Los Alamos National Laboratory (Mar. 11, 1992).

ALLIED SIGNAL AEROSPACE

A typical Mark XII airborne transponder. IFF formats and protocols can be handled by any of several types of interrogators and transponders.

As discussed in chapter 3, the three ways in which an enemy can defeat the purpose of an IFF system are exploitation, spoofing, and denial. An enemy exploits an IFF system by getting information from it. For example, if an enemy could record queries from a Mark XII interrogator and then rebroadcast them, then he could trigger the Mark XII transponders and have friendly aircraft identify themselves and reveal their positions. Even if recording valid queries were impossible, an enemy could *guess* at queries, hoping to hit upon a valid combination. With thousands of possible queries this may seem daunting, but in fact modem electronic devices should allow transmission of scores of guessed queries per second.

The Mark XV would have reduced or eliminated the possibility of enemy exploitation by changing the query codes rapidly. Valid Mark XII query codes are changed regularly but the process is cumbersome, involving the use of printed keys and the mechanical insertion of key values into the transponder. In the late 1960s, the Navy flight tested a system called TACIT (Time Authenticated Cryptographic Interrogator/Transponder), which allowed the rapid, automatic changing of query codes. Indeed, codes could be changed so rapidly that an enemy could not record and retransmit a code before it became obsolete

The Mark XV was to have a capability like TACIT. This means that all transponders, at least within a theater of operation and ideally worldwide, would switch codes in an agreed pattern, say, every second on the second. Clearly the requirements for time synchronization across literally thousands of platforms around the world is a major technical challenge. But modem developments in electronics makes the task possible if not easy; modem electronic clocks have accuracies of a fraction of a second per year. The encryption computer contained with each interrogator would be supplied with a "seed" key that would allow generation of a query code, then algorithms embedded in the computer would generate the next code from that seed and so on until a new seed were supplied.

An enemy's ability to appear friendly to an IFF system is called spoofing. Just as an enemy could try to exploit the Mark XII by recording or guessing at proper queries, an enemy could also try to spoof the Mark XII either by recording or guessing proper replies. The Mark XV would have incorporated several improvements to inhibit spoofing. These included a greater possible number of responses creating a greater barrier to straightforward guessing. The Mark XV would have used "spread spectrum" pulses, that is, a sharp pulse converted by the transmitter electronics into a broad frequency pulse that has lower peak energy at any given frequency, making interception more difficult. The receiver has similar electronics that operate in reverse, compressing the spread pulse into a sharp information pulse. A receiver that knows the proper spreading and compressing function gets substantial receiver gain, but an enemy that does not know the details of the function will have a difficult time resolving the signal from background noise.[9]

9 Don J. Torrieri, *Principles of Secure Communication Systems, Second Edition* (Bestow MA: Artech House, 1992), pp. 95-99.

Also, the strength of the reply signal would have been adjusted for the distance of the interrogator, with the reply no stronger than it needed to be thus making more difficult the interception and retransmission of a valid reply,

An enemy might be able to deny the use of an IFF system, For example, jamming of the radio signals is one straightforward approach. Almost any radio can be jammed if an enemy is willing to invest adequate resources and can get jammers in the right places. Military radio and radar systems are designed to make jamming more difficult, but jamming can never be made impossible and the amount of effort that is appropriate to invest in electronic antijamming capability depends sensitively on 1) the presumed combat environment, 2) a judgment about the value of working in a jamming environment, and 3) a comparison with other approaches to solving the jamming problem (e.g., blowing up the enemy jammers).

Military users of Mark XII consider it easily jammed. Improvements contemplated for the Mark XV included significant antijamming capability. For example, the query and response pulses would be much longer than those of the Mark XII. Longer pulses mean the potential for greater total energy in the pulse and a longer signal integration time, which makes jamming more difficult, Each bit of information in a pulse would be spread over the whole pulse length, which makes reading the pulses in the presence of jamming more reliable. The spread spectrum electronics that contribute so much to communications security also make jamming more difficult. Finally, the structure of the pulses would allow for detection of transmission errors so that if jamming occurred, the operators would know that information received was faulty and should be rebroadcast.

Jamming is one potential threat, but an indirect form of denial is perhaps the most important: if the operators do not have confidence in the system, they turn it off. Several experienced pilots reported to OTA that during the Vietnam War, they turned off their Mark XII IFF systems as soon as they entered enemy air space. Other say that more recently, on missions flown near potentially hostile forces around the Mediterranean Sea, Mark XII were turned off. The reasons are the same in both cases: a fear that enemy-or even friendly--queries would trigger the transponders and thus reveal the aircraft's presence. Against the more sophisticated Soviet threat, pilots expected to turn off IFF transponders long before they crossed enemy lines. If the operator believes that an IFF system increases his danger, then it will not be used to its full potential, if it is used at all. Thus, the ON/OFF switch becomes another means of denial. Mark XV improvements would have mitigated the problem of inadvertent friendly triggering of the transponder but this is clearly more than just a technology problem and a solution requires careful coordination among the eventual users.

Despite its promised improvements, Mark XV development was canceled in 1990, both because of increasing technical complexity and the growing estimated cost of deploying the system. Over 40,000 Mark XII sets have been produced[10] and approximately 25,000 are still in use. With a huge number of platforms needing IFF devices—and a need for at least 17,000 Mark XVs was forecast—acquisition costs multiply rapidly. Indeed, the cost of the Mark XV would have precluded outfitting every vehicle with a device, which raises the distressing question of the value of an IFF system that is so expensive that it is not carried by all platforms.

The cancellation of the Mark XV program leaves the future of cooperative aircraft IFF uncertain. The original motivation for the program, obsolescence of the Mark XII, still stands, so some replacement capability is probably needed. Most studies by the military Services assume that

[10] Navy Briefing, "Defense Acquisition Board Milestone 'O' Review: Cooperative Friendly Aircraft Identification Presentation for C31 Systems Committee," July 22, 1992.

a cooperative IFF system will provide some part of that needed capability.

Perhaps the most obvious Mark XII replacement is a system with performance that is a compromise between that of the Mark XII and of the Mark XV. By backing off on the Mark XV performance goals, costs could be reduced for any replacement. Antijamming capability was one of the major determinants of costs. Justifying any particular antijamming requirement is difficult for any piece of electronic equipment. No one can ever be entirely sure what resources a future enemy might devote to jamming, how its jammers might operate, be deployed, and so on. Thus, making very conservative assumptions is enticing but has substantial cost consequences for electronic systems. Options for future IFF systems range from using the current Mark XII protocols and radio wave forms-that is, making no antijamming improvement to the Mark XII-to using the spread spectrum waveforms proposed for the Mark XV. In between are compromise solutions that include using a modified and reduced spread spectrum waveform or using directional antennas to reduce jamming interference. The Germans have made proposals for moving to a different frequency band altogether, in the S-band, which covers the range from 2-4 GHz. One advantage of S-band is that the airwaves are less crowded at those frequencies. As a general rule, however, the higher the frequency of radio transmission, the shorter the range. Thus, an S-band system has shorter range than an L-band system. The shorter range of S-band actually has one advantage: it is harder to jam with a few distant but powerful jammers. Short range is less of a handicap in the crowded European theater in which the Germans operate but it makes S-band unattractive for the worldwide operations needed by the United States.

Maintaining communications security was a secondary contributor to the cost of the Mark XV. The Mark XV was to have anew cryptocomputer, the KI-15, that would have provided very good security through electronic handling of cipher keys and rapid, automatic changing of keys that would have saved operational costs. While the cryptographic security component of the Mark XII is quite old, the whole system need not be junked. For example, according to the National Security Agency, new cryptocomputers could be added to the current Mark XIIs or to similar follow-on models. These would provide better security without the full cost of the Mark XV's capability.

The important point is that the Mark XV improvements were not all-or-nothing; compromises in performance are possible. DoD could build a system better than today's Mark XII but cheaper than the Mark XV. The performance goals for the Mark XV were established during the Cold War. Now that war with Russia seems far less likely and the more likely opponents are far less challenging, backing off on the performance requirements of the Mark XV should be given serious consideration. The exact emphasis is, of course, subject to judgment, but technical experts interviewed by OTA felt that the end of the Soviet threat has probably reduced the need for antijamming improvements more than the need for communication security improvements.

COORDINATION WITH CIVILIAN AIR TRAFFIC CONTROL

Civilian Airborne Transponders

A mid-air collision on December 16, 1960 between a United DC-8 approaching Idlewild (now Kennedy) airport and a TWA Super Constellation approaching LaGuardia killed the 128 aircraft occupants and eight others on the ground and highlighted the limitations of the air traffic control system even when aircraft were under positive control.[11]

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[11] Richard J. Kent, *Safe, Separated, and Soaring: A History of Civil Aviation Policy,* 1961-1972 (Washington DC: U.S. Department of Transportation, Federal Aviation Administration; 1980), pp. 6-7.

The New York City mid-air collision accelerated adoption of several technical improvements for civil air traffic control, for example, secondary radar transponders on civilian aircraft. By 1953, Mark X frequencies and protocols had been released for international civilian use.[12] The civilian airliners were given use of Mode 3, which in civilian use is called Mode A. Civilian airliners use the 4,096 possible combinations of reply signal to identify the aircrafts' flight numbers, with some numbers reserved for special messages; for example, any aircraft that responds to a Mode A query with a "flight number' of octal code 7700 is saying that it has an emergency.

Additional civilian modes called, not surprisingly, Modes B, C, and D have been added subsequently, but only Mode C, with a 21-microsecond delay between query pulses, is commonly used. Ground-based radars can determine ground coordinates directly but are not able to determine aircraft altitude. Therefore, most aircraft now have transponders connected to the aircraft altimeter allowing the transponder to report automatically the aircraft's altitude in response to a Mode C query, The use by civilians of military IFF frequencies and protocols has important implications anywhere the two types of aircraft expect to share the same airspace.

Mode S

Secondary surveillance radar has become so useful and important to civilian air traffic control that it has become a victim of its own success. In some particularly heavy air corridors-for example, Europe and the east and west coasts of the United States—aircraft can receive identification requests from dozens of radars. This may include air corridor radars and overlapping radar coverage from closely spaced airports. Moreover, not all nations' air traffic control procedures are identical or even particularly well-coordinated, so neighboring countries may simultaneously query the same aircraft for information important to their air traffic control.[13]

The multitude of interrogators can result in hundreds of queries each second. This volume can saturate the airborne transponders, making them unavailable when essential radar queries come through. Moreover, all of the aircraft are sending out identification calls more or less continuously; interrogators are receiving the replies from properly designated aircraft and a multitude of stray replies that are picked up as interference.

The ongoing, but gradual, adoption of a new mode-Mode S, where 'S' stands for 'select"—is the internationally agreed technical solution to these problems. In Mode S, interrogating radars will *not* routinely send out a general ' 'who's out there" query with every sweep. Mode S requires that each aircraft have a unique, permanent identifying number. A Mode S interrogator will occasionally send out an ''all-call' message to establish the identities of all of the aircraft within its coverage. The radar and interrogator can then send out specific messages to specific aircraft, requesting altitude, for example. As an airplane leaves the coverage area of one radar, the information about that specific airplane can be sent by land lines to the next radar, which will be expecting it.[14]

Proponents of the Mode S system claim that it will reduce transponder information loads by at least two-thirds. It will also allow denser air traffic near airports. One current constraint on traffic density is the resolution of air traffic radars, not just safe separation distances. Two closely spaced aircraft will respond to the same Mode A or Mode C query and their answers will overlap when received by the interrogating radar, which

12 Michael C. Stevens, *Secondary Surveillance Radar* (Norwood, MA: Artech House, 1988), p. 9.

13 Lief Klette, "Europe's Crowded Skies: Managing Civil-Military Airspace, " *International Defense Review,* July 1992, pp. *659-662.*

14 *Radio* Technical Commission for Aeronautics, " Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRBS/Mode S) Airborne Equipment, " Document Number RTCA/DO-181 (March 1983).

will not be able to make sense of either of them.[15] With Mode S, a radar could interrogate one airplane and then, a millisecond later, send a separate interrogation to the second airplane. This time lag is so short that it will not affect air safety but will allow electronic separation of the replies. Thus, while Mode S is not needed by the U.S. military, it is part of a much-needed world-wide civilian standardization and modernization effort, of particular importance in Europe.

Mode S will allow messages longer than the current Mode A and C 12-bit messages. The greater number of message bits plus the unique identification numbers for aircraft allow limited two-way digital and text data transfer between aircraft and the ground that would be impossible with today's free-for-all interrogation system. For example, just as Mode C now queries altitude, Mode S could, in principle, query aircraft speed, bearing, rate of decent, destination, even fuel load. These data would be used by air traffic controllers to better manage aircraft in dense traffic.

Information can also be sent up to the aircraft. For example, changes of air traffic radio frequency could be sent automatically when aircraft move from one control zone to another. Weather advisories or changes in flight plan instruction could be sent up, then written or otherwise stored so they would be available to the pilot at a time of her choosing.

The basic Mode S is called "Level l;" "Level 2' includes the ability to receive short commands of 56 bits; "Level 3" includes the ability to receive longer command sets of 112 bits and transmit short ones; "Level 4" includes the ability to receive and transmit long commands. Since the system is not yet operational, all of the ultimate uses for the data transmission channels of Mode S are not clear but enough is known now to see that they will be useful to civilian pilots, but less so to military pilots.

Mode S will be adopted in phases in the United States. Large commercial passenger carriers must have Mode S transponders operating by the end of 1993. Commuter carriers and general aviation will acquire Mode S capability more gradually. Perhaps within 10 years, all aircraft, even general aviation, will need Mode S if they are to operate in dense air-traffic areas of the United States.

The military must operate in a world where the overwhelming majority of airspace is under civilian control (at least in peace time). This means that the military must adopt at least some of the Mode S capability into any future IFF system. The Services have two major problems with Mode S, neither of which is insurmountable but each of which must be handled. First is cost.

The cost to the military of Mode S will be more than just the cost of the equipment. Another black box can always get squeezed into a transport, but every cubic inch on a fighter plane is already occupied. That means redesigning existing equipment, placing antennas, dealing with waste heat from more electronics, and so on. Mode S was to be an integral part of the Mark XV. With its cancellation, DoD must find some other way to outfit its aircraft with Mode S or come to some accommodation with civilian air traffic control.[16]

The benefits of Mode S are greatest in the densest air traffic. Service resistance to the cost of Mode S is easy to understand because dense traffic areas are just those in which military aircraft are *least* likely to fly, at least in the United States. But since commercial aircraft can hardly avoid these areas, they will need Mode S. Then,

15 This is due to the finite speed of the radio waves sent out by the transponders. Since radio travels about 300 meters per microsecond, a 20-microsecond reply is 6,000 meters long and any two aircraft whose distances from the interrogator differ by less than that will send messages that will overlap, or be 'garbled,' at the receiver. Note that the aircraft need not be dangerously close; since air traffic control radars normally do not discriminate aircraft altitude, two airplanes with substantial vertical separation can still have very close ground tracks.

16 Letter from Barry Lambert Harris, Deputy Administrator, Federal Aviation Administration, U.S. Department of Transportation, to Richard G. Howe, Acting Chairman, Policy Board on Federal Aviation, Office of the Secretary of Defense, Apr. 20, 1990.

when Mode S is widespread, it doubtless will be used-even if not essential-in the less heavily traveled airspace where military aircraft *do fly.*

The FAA does not foresee Mode S message capability as a requirement for operating in general U.S. airspace, but requirements will be imposed on aircraft that wish to operate near the Nation's busiest airports. In principle, military flights could simply avoid those areas. Currently the DoD foresees that fighters eventually will be outfitted with Mode S/Level 2 and cargo transports will be outfitted with Mode S/Level 4.[17]

The second problem is more subtle: the information that Mode S might provide to potential enemies. This is not a wartime problem—pilots would just turn civilian modes off in war theaters and the military would take over air traffic control. It is, rather, a problem of long-term peacetime intelligence information loss. Current Mark X-SIF identifies an airplane by its flight number for that day. Mode S will identify each airplane uniquely by its tail number. The Services will not tolerate this since it would allow a potential enemy to build up over time a valuable database. For example, long-term compilation of aircraft tracks might reveal how often particular aircraft shuttle between deployment areas and depot maintenance sites. One solution is to allot to the Services a block of numbers that they could mix around at random. Civilian and foreign air traffic controllers would then know that the aircraft is a U.S. military aircraft but not which one,

The military may object to even this much information being available, but presumably the United States is also interested in clearly identifying civilian airliners as such. Any system that loudly proclaims all civilian aircraft inevitably identifies military aircraft as well, at the very least by default, since any airplane not proclaiming loudly will be assumed military. Thus, this weakness may bean inevitable price that has to be paid for the protection of civil aircraft from accidental attack.

Other Areas Requiring Civil-Military Coordination

Today the military and the FAA jointly operate air traffic control (ATC) systems covering the United States and the air approaches to it, with the military providing about a fifth of the ATC assets. The Nation is in the process of converting to a unified system, called the ARSA-4, to be operated solely by the FAA. The unified system should be more capable and cheaper. The Air Force will receive data from the FAA radars and interrogators, which will be used for the identification of aircraft approaching the United States .[18] Some of the current Air Force air traffic control computers cannot keep up with the high traffic densities in the Nation's busiest corridors, but sections of radar coverage can be systematically blocked out from the Air Force data link to allow the Air Force system to concentrate on only those sectors that are important to it. In the future, all Service ATC equipment and computers will be comparable with FAA equipment.

The FAA plans also for the gradual adoption of an automatic system to help pilots avoid mid-air collisions. Currently, aircraft pilots have visual information, on-board radars, and secondary information relayed up from ground radars. Ground radars can interrogate the transponders carried on aircraft but currently the aircraft cannot interrogate each other's transponders. The Traffic Alert and Collision Avoidance System (TCAS) will allow aircraft to use Mode-S transponders to get information from other aircraft in the area which will allow on-board computers to calculate and recommend collision avoidance maneuvers. TCAS will be in place for airlines by the end of 1993. TCAS may eventually place some requirements

17 Frank Colson, OSD liaison to FAA, personal brief.

18 Tom McNiff, *'Air Force, FAA Working on New Radar System, ' *Journal of Commerce* (Sept. 21, 1992), p. B3, (and personal briefings from Richard Lay, FAA in-route radar manager)

on military aircraft even if none are in place now. The first phase of TCAS for general aviation or commuter carriers is planned for implementation in 1995.[19]

If cooperative IFF systems are to be used by allies or even by U.S. forces operating in allied countries, then frequency allocation problems must be resolved. For example, the current Mark XII transponders can cause interference in Germany, where their use comes under some restriction. The converse problem is getting everyone onto the *same* frequency. For example, communications between military and civilian aircraft are not always easy since military fighters primarily use UHF frequency bands for communication while commercial airliners use VHF bands.

IDENTIFICATION OF SHIPS

The problems of identification of friendly and enemy ships are more like those of airborne targets than they are like those of land surface targets. Ships use a combination of tactical information and direct target identification to separate friends from foes.

Navy ships now have both Mark XII interrogators and transponders that allow positive friendly identification. The ships are equipped with sophisticated navigational and communications equipment, thus antifratricide efforts among ships through sharing of tactical and navigational information comes naturally.

Chapter 2 related several historical incidents of friendly fire between ships, and these are not unknown today.[20] With the strong emphasis on carrier-based airpower, however, U.S. ships probably face a greater fratricidal danger from friendly aircraft. The consequences would be much more severe than for attacks on other aircraft but fortunately the likelihood may not be as great. Since the United States and its European allies will have total control over the sea in most foreseeable conflicts, there may be theaters in which there is no reason for a friendly aircraft to attack any ship.

There are several reasons to believe that avoiding fratricide of ships will be easier, or no more difficult, than avoiding fratricide of aircraft. Modem warships are not as widely proliferated around the world as are aircraft. Ships can afford to carry more powerful transponders, surveillance, and communications equipment. Ships are larger and slower than aircraft so some approaches to noncooperative identification of aircraft, for example, high resolution radar, should work at least as well. Some noncooperative techniques, for example, analysis of radio emission should work for ship identification just as they do for aircraft identification, although ships and aircraft will have different rules about radio and radar silence. Other techniques, jet engine modulation, for example, are simply not applicable. But still others might work better for ships than aircraft: examples include, synthetic aperture radars, laser radars, and high resolution infrared imaging. Because the country has far fewer ships than aircraft, cost per platform is less important for ships than for aircraft. Furthermore, while perhaps not spacious, ships have much less of a problem with packaging, power supply, waste heat removal, and antenna placement than do fighter aircraft.

Submarines

There is little current concern about fratricide of submarines. Few nations possess them and most that do are U.S. allies, so all submarines could be assumed friendly in most limited conflicts. Furthermore, U.S. submarines are substantially different from those of other nations. In the future, the problem may become worse, however. Some countries hope to export small diesel-electric submarines. One can easily imagine a

[19] U.S. Department of Transportation, Federal Aviation Administration, "Introduction to TCAS II," March 1990.

[20] During NATO exercises in October 1992, the U.S. aircraft carrier *Saratoga* accidentally fired missiles at the Turkish destroyer *Muavenet*, killing five and wounding at least 15. See Eric Schmitt, "U.S. Missiles Hit Turkish Ship, Killing 5," *New York Times*, Oct. 2, 1992, p. A8.

conflict like that in the Persian Gulf War, taking place perhaps a decade hence, in which both local allies and local enemies are equipped with the same German- or Russian-built submarines.

In principle, submarines could use cooperative and noncooperative IFF systems analogous to those used on aircraft. But whereas the aircraft systems would depend primarily on radio-frequency electromagnetic energy, submarines would use sound waves, magnetic fluctuations, or some other signature. But submarines are different. The hard part of killing a submarine is not attacking and destroying it—although that can be a challenge under some circumstances; the hard part is finding it. Submarine designers devote considerable attention to further increasing the difficulty of detecting submarines, largely by making them as quiet as possible. Submariners would strenuously resist any effort to have submarines actively broadcast in response to some identification hail, or to somehow increase their boat's signature to make cooperative-passive identification easier.

For the foreseeable future, therefore, avoiding submarine fratricide will be based on the current procedures for careful command and control of areas of operation. Submarines now patrol individual, well-defined areas; any other submarine that enters that area is considered hostile and open to attack. Moreover, within assigned patrol areas, surface ships do not engage in antisubmarine activity (that is left to the resident submarine), but any submarine found outside of assigned areas is assumed hostile and could be attacked by surface and airborne forces. This approach works but is very flexible only with good communication between submarines and surface ships. If assigned patrol areas can be reliably updated several times a day, ships above and below the surface can cooperate smoothly.

A COMPREHENSIVE IDENTIFICATION SYSTEM

No cooperative IFF system is perfect, so pilots and ships' crews hesitate to fire based solely on the assumption that *lack* of an IFF reply means a target is an enemy. Any shooter would prefer to have positive evidence that a target is an enemy, hence the motivation for noncooperative IFF systems. Yet neither are noncooperative systems perfect. Exercises on test ranges indicate that with current technology a few percent of targets identified as hostile are, in fact, friendly. This error rate may be acceptable in a struggle for survival, as was expected between NATO and the Warsaw Pact. However, if in the future the United States is engaged in a lesser conflict with overwhelming force ratios, then most of the aircraft in the air at any given time will be friendly and even a small rate of mistakenly identifying friends as foes can result in the loss rates from fratricide being as high as those from enemy action.

Cooperative and noncooperative systems can work together to make each more effective than either could be alone. Assume that a cooperative question-and-answer type system were, say, 90 percent reliable. If this system were used to sort all targets, then 10 percent of targeted friendly forces would be classified as hostile, clearly an unacceptably high value. But if a noncooperative system were also 90 percent reliable, that is, it classified friendly vehicles as hostile 10 percent of the time, and all hostile-classified targets were also queried by the cooperative system, then only 10 percent of 10 percent, or 1 percent, would slip through both, assuming the two systems are independent.[21] These numbers are picked only to be illustrative, whether a 1 percent error rate is acceptable will depend on the tactical situation and political and military judgment.

Cooperative systems can even help identify enemies, if operated in conjunction with noncooperative systems. Many noncooperative identifi-

21 In the real world, the systems may not be independent. Battle damage, for example, might both change the noncooperative signature and put IFF transponders out of commission. In war, nothing is neat.

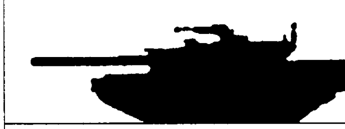
cation techniques will discriminate friend from foe on the bases of subtle differences, but will require expensive, hence perhaps scarce, equipment. If this equipment is unable to examine all possible targets, then cooperative question-and-answer systems could concentrate efforts on ambiguous targets. For example, only those targets that do not respond to a cooperative IFF queries would be examined by noncooperative techniques.

Currently, the technology required for cooperative question-and-answer IFF systems is more developed than that for most noncooperative systems. The Services see the advantages of noncooperative IFF but that longer term goal should not erode efforts to improve the reliability of cooperative question-and-answer IFF by the application of technology that is near-term or in-hand.

5 Avoiding Fratricide of Land Surface Targets

All of the U.S. fratricidal casualties in the Persian Gulf War were among land forces. Near-absolute dominance of the air and Iraq's inability to project power to sea allowed conservative rules of engagement in those media, which avoided accidental attacks on friendly forces except in a couple of cases that did not result in casualties.

The fratricide of the Persian Gulf War was unusual compared to that of past wars. As pointed out in chapter 2, the most striking aspect at first was the apparently unprecedented high fraction of total casualties resulting from fratricide. In addition, however, the importance of each type of fratricide was different from other large mechanized land battles. In World War II, for example, the most deadly fratricide were the result of aircraft bombing friendly troops. Surface-to-surface fratricide resulted most often from indirect fire in which artillerymen fire at a target that they could not see, The Persian Gulf War, in contrast, had an unusually high fraction of fratricides from direct-fire weapons, such as tanks, shooting mistakenly at other land targets.



Most of the U.S. personnel were mounted in vehicles; thus, not surprisingly, most of the fratricide occurred when vehicles were hit, so that current emphasis is on protection of vehicles, not on that of individual infantry. Helicopters are included in this chapter; although helicopters are aircraft, their operation and employment gives them more in common with surface vehicles than fixed-wing airplanes, at least as far as fratricide technology and equipment are concerned.

The next sections discuss general approaches to avoiding fratricide of ground targets, a number of specific technologies available to implement these approaches, and some of the advantages and disadvantages of each approach and technology, U.S. ARMY

US. armored vehicles destroyed by friendly fire during the Persian Gulf War were recovered and collected,

INCREASING KNOWLEDGE OF THE TACTICAL ENVIRONMENT

Reviews of past cases of fratricide, including those from the Persian Gulf, show that a prime culprit is the shooter's poor understanding of where friends are, and even where he is himself. A unit spreads further confusion among neighbors when—instead of being flatly lost—it believes it knows exactly where it is and reports an incorrect location to other units. Thus, navigation and communication are two vital keys to avoiding fratricide.

Navigation

Current multimillion dollar U.S. tanks do not have compasses. This may seem astonishing until considering that magnetic compasses are useless inside 60-ton metal boxes. Alternatives-like gyrocompasses—have been prohibitively expensive in the past and were often unreliable in the rough environment of a tank. Nevertheless, the first step for improving tactical knowledge of mobile units requires improving their navigational tools. Fortunately, new technical developments make this easier.

During the Persian Gulf War, tanks used equipment—including some off-the-shelf commercial equipment—that calculated latitude and longitude from data received via radio pulses from a network of satellites, the so-called Global Positioning System or GPS. If desired, the same principle could be applied on a local tactical scale using airborne transmitters.[1] Gyroscope compasses provide direction, and some, in particular ring-laser gyroscopes, are improving in accuracy and coming down in cost. Current plans call for broad use of GPS and compasses, or azimuth indicators, as the Army calls them.

Chapter 2 showed location uncertainty to be a prime cause of fratricide from artillery. Global or local positioning systems could provide artillery batteries and their forward observers with accurate, consistent coordinates. Some proposals call

[1] Briefing "Very Low Frequency Identification Friend or Foe," Willie Johnson, U.S. Army Communications and Electronics Command, Mar. 10, 1992.

for use of positioning systems to increase fire accuracy and perform last-instant IFF.

Communication

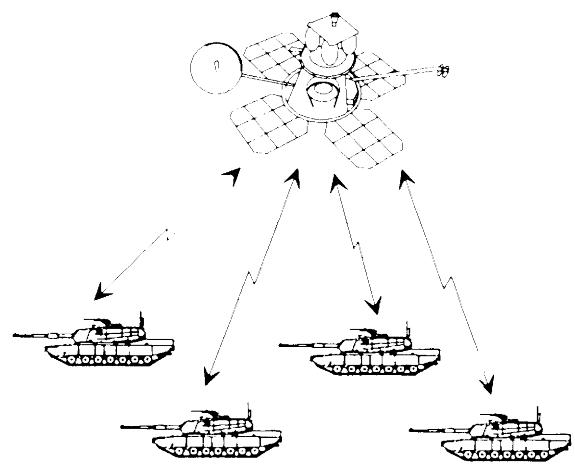
Knowing location is just part of the job of avoiding fratricide; each individual and unit must inform nearby units of its location. One approach is for each unit or vehicle to send its location to some central distribution point. This might be a ground-based or airborne communications node, or it could be a satellite, perhaps the same one that provides the location broadcasts as illustrated in figure 5-1.

Communication of location could also take place through shorter range networks, as illustrated in figure 5-2. Each vehicle could be a node in a interwoven network of communicating vehicles. Each vehicle would transmit information about itself as well as its neighbors. Thus, not every pair of vehicles would need to be in constant *direct* communication, In the figure, for example, tanks numbered 3 and 5 might not be able to communicate directly because of intervening terrain, but they can communicate by messages relayed via numbers 1 and 4. When tanks 3 and 5 then come into sight of one another around the ridge, neither should be surprised. Systems using these principles are now in development.

As one analyst has pointed out, this is a reversal of how sensor networks have operated in the past: sensor systems have been developed to find information about the enemy, they collect information about the enemy *and all the* friendly forces within range, and then-with only slight exaggeration—the information about friends is thrown away.[2]

Networks would allow the propagation of information about foes as well as friends. Thus, information about a hostile or ambiguous vehicle sighted by any member of the network would be available to each member of the network. In principle, this type of communication allows observers to ''compare notes, ' develop a composite picture, and thus get a better overall identification. For example, one observer might see an ambiguous vehicle, then try, and fail, to get a reply to a IFF query. Another might have limited information on its appearance, another detected some suspicious radio signals, and so on. No piece of information by itself is definitive, but all of it together might be. The range of the communication links is not a problem; indeed, considered strictly from the point of view of avoiding fratricide, the range does not need to be much more than, say, double the range of the vehicles' weapons.

Figure 5-1—A Satellite Navigation and Communication Schematic



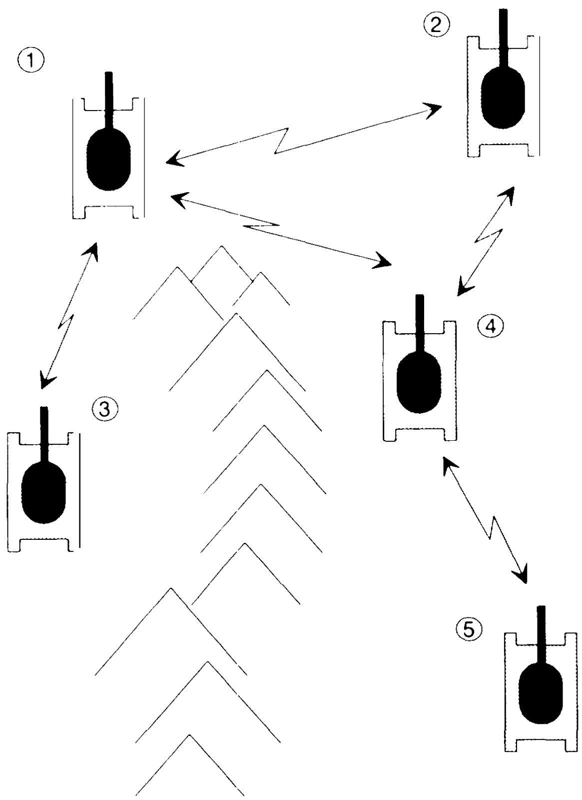
SOURCE: Office of Technology Assessment, 1993.

A simple navigation-communication system could be based on the current standard Army tactical radio, the Single Channel Ground and Airborne Radio System (SINCGARS).[3] More elaborate data exchanges will require radios with higher data rates. Almost any system would be most useful with some way to display the location information inside the vehicle graphically.

[2] Briefing entitled, "Fratricide Prevention, " Mark Fine, U.S. Army Communications and Electronics Command, Mar. 10, 1992.

[3] See ''Combat Identification, Data Pose Battlefield Awareness, " *Signal*, November 1992, pp. 37-39 and Mark Tapscott, ''SINGARS Upgrades Moving to Full Battlefield Communications, ' *Defense Electronics, vol. 25, No.* 1, January 1993, pp. 29-32.

Figure 5-2—A Ground-based Communications Net for Exchange of Location and Identification Information



SOURCE: Office of Technology Assessment, 1993.

IFF Through Exchange of Location Information

Navigation and communication systems can be used as a type of IFF device, one in which identification is based not on vehicle characteristics or the exchange of codes, but on location information. Take as an example a direct-fire weapon like a tank. A navigation system could provide each tank with an accurate position, and a communication system could provide the positions of all friendly tanks within range. As part of the current firing sequence, the tank gunner uses a laser range-finder to determine the target's range. While current standard equipment on tanks does not provide gun bearing, that is, the direction in which it is shooting, the navigation system could provide that information as well.

The tank gun's computer or free-control system, knowing its own location and the range and bearing of the target, can quickly calculate the exact location of the target. This location can be compared to the locations currently reported by friendly vehicles and, if there is no match, the target could be assumed hostile. (One might want further conflation in case it is a friend with malfunctioning equipment.)

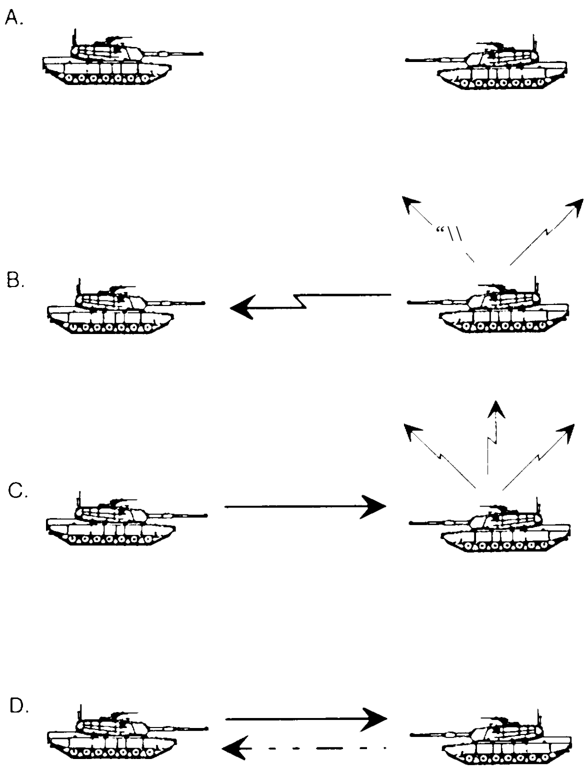
If the current register of locations shows a match, the answer is somewhat ambiguous. A match only means that a friendly vehicle is at the same location, *within the accuracy of the system,* not that the target in the gun sights is a friend. The accuracy may be dozens of meters and the true friend may be obscured behind a clump of trees.

Other approaches following this general theme are possible. For example, just before the gun frees, a radio or laser signal could be sent out containing the message: "Attention! I am about to shoot at a target at the following coordinates, if you are sitting on that spot, you should tell me now." Obviously, the message, and reply, would have to be encrypted to keep the enemy from exploiting the system. The speed of the system is also important. Tank crews are trained to get a round off within ten seconds of first detecting a target; good crews can do it within six seconds. Any IFF procedure that takes "only" a second significantly increases engagement time.

IDENTIFICATION SYSTEMS

Even a very effective navigation-communication system probably will be unable to offer perfect friend and foe identification; an additional system devoted to IFF may also be needed. The simplest cooperative IFF system allows the observer to remain passive, as illustrated in figure 5-3a. The target vehicle might use characteristic markings to identify itself as friendly. In the Persian Gulf War, the vehicles were marked with an inverted 'V' made with an infrared-reflective

Figure 5-3-Approaches to Identification of Friend and Foe



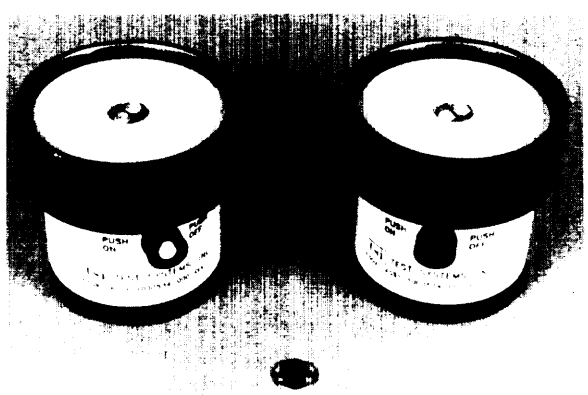
SOURCE: U.S. Army.

tape or paint that showed up on infrared imaging devices while being fairly unobtrusive visually.

■ Beacons

The target vehicle might instead *broadcast* a signal in all directions, identifying itself as friendly, as illustrated in figure 5-3b. This is the principle of the so-called “DARPA Lights” and “Budd Lights.”[4] Attaching flashing lights to combat vehicles may seem unwise, since they reveal the vehicles’ position to the enemy as well, but these particular lights are only visible in the near-infrared. In the Gulf War, the Allied forces were widely equipped with infrared image-intensifiers and the Iraqis were not. In addition, the DARPA Light is fitted with an adjustable shroud that blocks ground observers’ views of the light while keeping it visible from aircraft. This simple security measure was useful, again, because of limitations of the enemy: the Allies had total air dominance leaving no Iraqi airborne platforms to observe DARPA Lights from above. (DARPA Lights were acquired and ready to deliver to the Gulf, but the conflict ended just before shipment.)

The Thermal Identification Device, or TID, is another beacon system in limited current production. The TID is a simple bent metal sheet in the shape of a roof. The sheet is heated electrically on one side to generate a thermal signal. The other side reflects the cool thermal image of the sky. The sheet is mounted on a short mast and an electric motor rotates the sheet. Thus an observer seeing the TID through an infrared image will see an alternating bright and dark spot.[5] See figure 5-4. The disadvantages of the TID include lack of



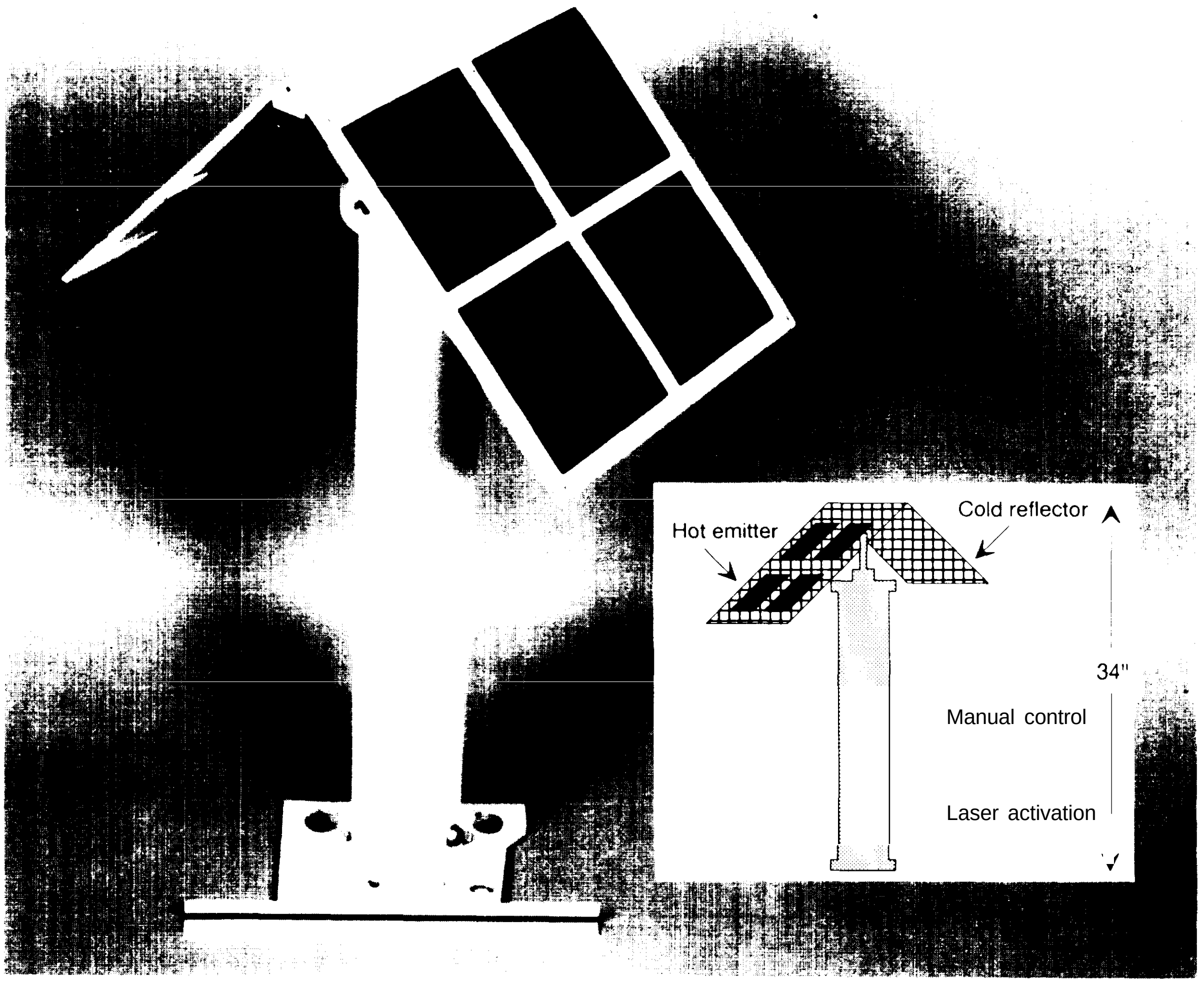
U.S. ARMY

The ‘‘DARPA Light’ is a simple infrared beacon visible only through night-vision goggles.

4 The name @@t have stuck because of its similarity t. that of a popular malt beverage, but the transmitter was originally so named after its inventor, Henry ‘‘Bud’ Croley at the U.S. Army Night Vision Laboratory who, along with Wayne Antesberger, holds U.S. patent number 4862164 on the device.

5 Briefing entitled, ‘‘Thermal Identification Device (TID) for Combat Identification,’’ John R. Gresham, Night Vision and Electro-optics, Night Vision Laboratory, Ft. Belvoir, Virginia (undated).

Figure 5-4-The Thermal Identification Device (TID)



SOURCE: U.S. Army.

security (any enemy with the proper thermal sights can see it as well as other friends can) and unreliability (apparently the exhaust plume from the engine of the M-1 tank can obscure the TID from certain angles).

Near-infrared blinking lights, such as the DARPA and Budd Lights, have two related drawbacks. First they are visible to anyone, friend or foe, with near-infrared night-vision image-intensifiers, which are cheap and widely available through the mail for about a thousand dollars. Thus, any enemy might have at least a few devices that could detect the beacons. Second, they are *not* visible to the far-infrared imaging devices used to aim the guns and other weapons on U.S. armored vehicles. The TID avoids these short-comings. Whereas the near-timed image intensifiers are relatively inexpensive, far-infrared viewers are a hundred thousand dollars or more, and correspondingly fewer countries have the devices widely deployed. The TID also radiates at the wavelengths at which the far-infrared targeting viewer is most sensitive.

Future systems operating on the same principle could use continuous omnidirectional *radio transmissions*. Signals sent by radio would have longer range than visible or infrared light, especially in fog, rain, dust, or smoke. Of course, special provisions must be made to keep an enemy from intercepting and exploiting the signals. Possibilities include spread-spectrum signals-described in the previous chapter--or time-synchronized signals. Either approach forces an enemy to listen to radio noise over a wide range-of frequency bandwidth or time-and filter out a signal, while friendly forces, knowing the waveforms or the time sequence pattern, can listen only for the signal.

Question-and-Answer Systems

Having friendly targets broadcast only when interrogated by another friendly shooter provides additional security against enemy intercept and exploitation of identification signals. This approach is illustrated schematically in figures 5-3c and 5-3d.

Queries

The query signal could be a laser or some radio pulse. The query pulse should be directional, otherwise on a complex battlefield each tank's query would set off all tanks' responses and matching up queries and responses would be hopelessly complicated.

The queries should also be encrypted to authenticate them as coming from friends. This keeps the enemy from exploiting the system. The enemy might, for example, suspect that U.S. vehicles lie camouflaged along a tree line but not know where. If sweeping the whole treeline with a laser or radio pulse caused all the U.S. weapons to send out IFF replies, they would reveal their positions, so the response must come only after receipt of a valid, encrypted query.

A potentially cheap IFF approach would be adapting the existing laser range-finders now fitted on U.S. tanks. A danger of this approach is that the laser signal will not reliably penetrate smoke, fog, and dust. This may not cause a problem for the laser's range-finder function—after all, ranging the target, the dust cloud around it, or the tree next to it is good enough to get a hit with a flat trajectory weapon like a tank gun. But if the laser did not penetrate intervening dust, then the target would never get the query and would never send off a friendly response.

The query signal would be sent through a simple directional antenna aligned with the weapon. It could be, for example, fixed to the barrel of the tank gun or to the turret much as the laser range-finder is now. The same simple directional antenna would then naturally be lined up to pick up the signal from the particular target in question and not any other.

The Army's current near-term solution will use a millimeter wave radio beam as the query signal. Millimeter waves can penetrate obscurants, like dust, and they can be fairly narrowly focused.[6]

Replies

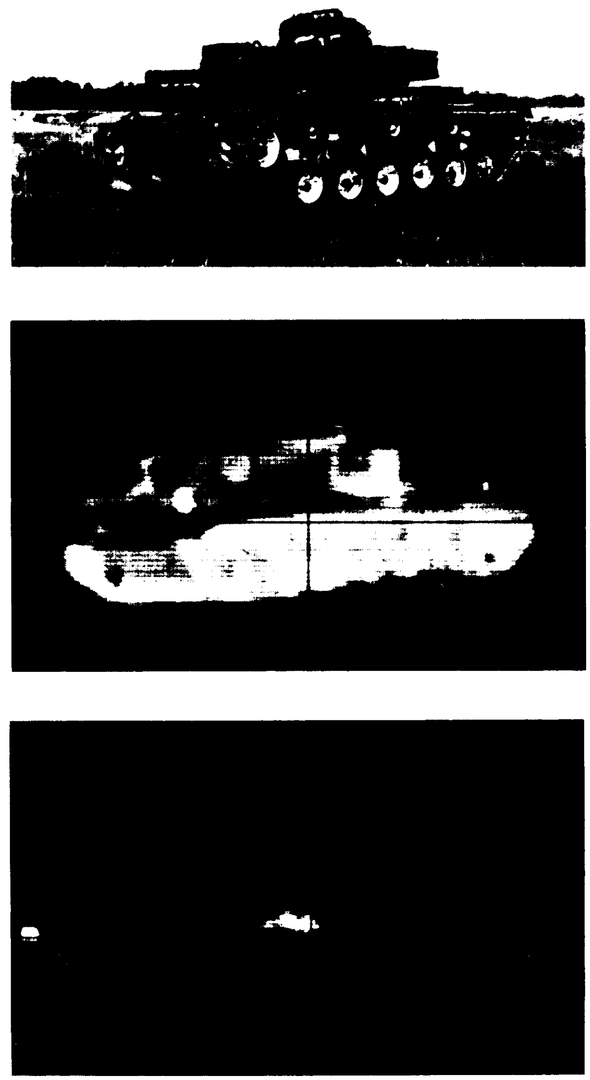
The reply signal could be any of those described above for a passive observer with much the same advantages and disadvantages. Like the query, the reply signal would have to be encrypted in some way that the enemy could not reproduce,

Since the reply would be sent out only when the system is properly queried, somewhat less attention could be given to avoiding intercept by the enemy. For example, some proposed systems would determine the general, but not exact, direction of the query and return a bright, broad laser beacon to show that the target is friendly, accepting that the beacon would sometimes be

[6] U.S. Army, Combat Identification System Program Office, Ft. Meade, MD, ''Report to the Committees of the United States Senate and House of Representatives on the Combat Identification Program, " January 1993.

seen by enemies. Alternately, omnidirectional radio beacons, illustrated in figure 5-3c, could announce that the target is friendly. Omnidirectional broadcast is much simpler because it removes any requirement for steering an antenna—very quickly!—in a particular direction.

A directional reply, shown schematically in figure 5-3d, would provide additional security by making enemy intercept less likely. One clever approach would use the interrogating laser as its own reply signal by reflecting the laser back to its origin using a comer reflector. (A corner reflector is just a set of reflective surfaces in the shape of the inside of the comer of a cube. The geometry of the surfaces is such that no matter which direction a light beam enters, it is reflected back out in exactly that direction.) The reply would be authenticated by modulating or chopping the query pulse in some way, for example, by turning on and off liquid crystal windows covering the comer reflector. This particular approach, using lasers, would be unreliable in smoke or dust. Radio frequencies could penetrate better and could use the same principle with the authentication provided by vibration of the reflective surfaces to produce a detectable Doppler shift in the return signal or by rapidly changing the impedance of the reflecting antenna-similar to the pre-World War II proposals for varying dipoles on aircraft.[7]



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These three images are of the same tank on a test range. The top is a close-up taken in visible light at midday. The tank as seen at night through infrared ''image intensifiers' at a range of 500 meters is shown in the middle image. The bottom image is the tank seen through the same device but at 1500 meters. Modern optics and electronics allows the detection of vehicles beyond the range at which they can be reliably identified.

DISMOUNTED INFANTRY

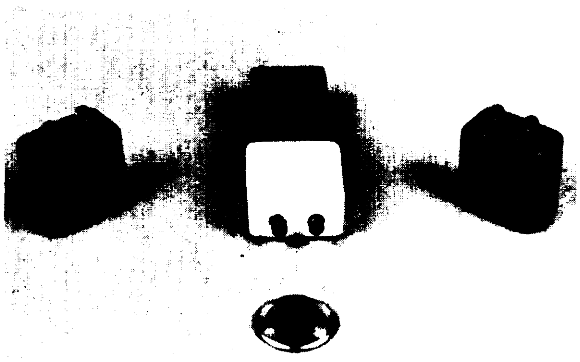
Most of the effort for IFF devices has centered on the identification of *vehicles,* not people. At present, programs examining exclusively the problem of identification of dismounted infantry are in the planning stage. The Army intends to fund dismounted infantry IFF programs in the coming and subsequent fiscal years. Infantry almost always work closely with vehicles of some sort and any vehicle-mounted system will also help prevent mistaken attacks on friendly infan-

[7] Briefing entitled, "Achieving Covert Communications and Ground-Combat Identification Using Modulated Scatterers,' E.K. Miller and D.M. Metzger, Mechanical and Electronic Engineering, Los Alamos National Laboratory (Mar. 11, 1992).

try. Moreover, navigational and communications improvements that increase tactical knowledge will reduce fratricide of infantry as well as vehicles, even without specific new IFF capabilities.

One of the quick fixes used in the Persian Gulf and mentioned already was the small, battery-powered blinking infrared light called the Budd Light. Its flashing is invisible to the unaided human eye but shows up clearly at night through night-vision goggles or other near-infrared image-intensifiers. The device is cheap and easily produced by components from retail electronics stores. Being so widely available, it hardly counts as an IFF device but it can be a useful command and control device. For example, one combat unit may know that another unit is somewhere in front of it in a group of trees but not know exactly where. Getting the two units coordinated by describing features at night over the radio is difficult, but a request to turn on the infrared blinkers for five seconds could make relative positions clear in an instant, and thus help avoid fratricide.

Future research will include work on techniques specifically directed toward infantry identification. Some of these ideas are modern incarnations of World War I infantry identification efforts that included sewing mirrors on the backs of trench coats to aid identification by friendly aircraft overhead. Notional proposals include: fabrics that reflect millimeter waves or fabrics and dyes that reflect only very specific wavelengths chosen to match up with the wavelengths detected by targeting sensors; fabrics and **dyes** that luminesce under specific laser illumination; retro-reflectors on combat uniforms; and active infrared displays on the uniforms.[8]



U.S. ARMY NIGHT VISION LABORATORY

''BuddLights' are invisible to the naked eye but show up clearly through night-vision goggles.

NONCOOPERATIVE IDENTIFICATION

Development of noncooperative identification of ground targets is perhaps at an even earlier stage than it is for air targets, but some ideas have surfaced. Just as for air targets, the simplest identification technique is based on the outward appearance of the vehicle. Again, as for air targets, this simple approach is made very complex by the proliferation of U. S., British, French, Russian, and other weapons throughout the world.

A straightforward improvement in identification capability would come from improvement in imaging devices, for example, higher resolution for infrared detectors, laser radars that provide three dimensional images, and so on.

More subtle clues to identity might be provided by, for example, vibrations of the surface of the vehicle, detectable by Doppler radar. Doppler radar shows some promise for the identification of helicopter because of the characteristic Doppler shifts caused by the rotating blades.[9]

Sensors might be able to pick up characteristics of the vehicle exhaust, even detecting differences in fuel type,[10] or sensors could look at the

8 ''Information Paper: Identification Friend or Foe for the Individual soldier, ' Robin St. Pere, U.S. Army, Natick RD&E Center, Oct. 6, 1992.

9 Briefing entitled, "Radar Helicopter Identification, " Gerardo Melendez, EW/RSTA Directorate, Us. Army Communications and Electronics Command (undated).

10 Briefing entitled, ' 'Laser Radar Effluent Sensor," Guil Hutcheson, Los Alamos National Laboratory (undated).

reflectivity of the vehicle in several spectral ranges.[11] For ground combat application, each of these techniques that depend on detection of subtle spectral differences should be approached with a healthy skepticism, since transmission of radiation through the dirty, dusty, smoky, foggy air of the battlefield will often be the fundamental limit to their performance. In addition, one must consider the effects of trees, buildings, and intervening terrain.

Some sensor systems have been developed to detect enemy vehicles on the battlefield. For example, the Remotely Monitored Battlefield Sensor System, or REMBASS, uses a combination of acoustic, seismic vibration, magnetic, and infrared sensors to detect vehicles. With some added sensitivity, each of these techniques might be able not just to detect, but identify, vehicles. These sensors are typically short range and fixed so they are probably better at providing tactical intelligence about enemy vehicles to a communications network than at providing the information directly to a shooter.

CURRENT PROGRAMS

A quick review is worthwhile to repeat what is hypothetical and what is under active consideration or development. The Army divides its development efforts into four time categories. The "Quick Fix" was intended to get something into the hands of troops immediately. Quick fixes include the Budd and DARPA Lights, receivers for satellite transmissions of global positioning data, and the infrared-reflective "thermal" tape that were rushed into service during the Persian Gulf War. The Thermal Identification Device described above is another quick fix.

After the Persian Gulf War, the Army acquired 20,000 Budd lights, which are to become logistic stock items, and contracted for 120,000 square feet of thermal tape. The Army also has the 8,000 DARPA Lights acquired during the Persian Gulf War. The Army will acquire 300 TIDs, or the parts required for rapid assembly. Production will beat Tobyhanna Army Arsenal. This will provide enough TIDs for an armored brigade. (Note also that the extreme simplicity of the TID should allow rapid surge production.) The Army also has bought, or is in the process of buying, over 10,000 global position receivers called Small Lightweight Global Positioning Receivers, or SLGRs (pronounced "slugger").

The near-term program aims to get something in the field in five years or so. The ideal near-term system should require little or no additional research and development. A request for proposals sent to industry solicited numerous responses. A test at Ft. Bliss, Texas examined many of the proposed systems using actual combat vehicles under realistic desert conditions.[12] The result of that test was selection of a millimeter wave question-and-answer system for near-term development and deployment. One of the disadvantages of a millimeter wave system is that it will be difficult to incorporate into airplanes, but compatibility between aircraft and surface vehicles is only a desirable characteristic for near-term solutions and a *requirement only* for far-term solutions. The Army has set a limit of $100 million for total costs to produce approximately enough identification devices for 1,500 vehicles, not enough to outfit the whole army but enough for a substantial contingency force.

Mid- and far-term solutions are intended to provide a more permanent solution in seven or more years. These programs are now in the exploratory stage.

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11 These notional approaches are taken for a briefing presented by Wayne Grant, "Electro-Optics (E-O) Technology for Positive Target Identification%" United States Arrny, Night Vision and Elecro-Optics Directorate, Fort Belvoir, VA (undated).

12 Training and Doctrine Coremand, *Combat ID Tech Demo,* June 9, 1992. Because of limitations of the desert test sites, performance in fog, rain, or forest could not be tested.

TACTICS, DOCTRINE, AND TRAINING

The Army has not given as much explicit attention to avoiding fratricide in the past as might be expected, but this is because troop safety was a natural, integral part of coordination and planning. The Army now believes, however, that friendly fire requires special treatment in tactics, doctrine, and training.

Some changes in tactics are possible. For example, most of the Persian Gulf fratricides occurred under conditions of reduced visibility, either darkness or dust and haze. If the goal were to reduce fratricide, then one easy solution would be to never attack except under clear daylight conditions. Remember, though, that low visibility for U.S. forces often translates into no visibility for enemy forces not equipped with infrared or image-intensifying viewers. Night attacks reduce the enemy's effectiveness, including his ability to inflict casualties, and thus reduce casualties overall.

Nevertheless, technical advantages enjoyed by the United States, compared to a wide spectrum of potential adversaries, could allow changes in tactics. For example, in the Persian Gulf, U.S. forces could often see, hit, and kill Iraqi targets that could not even see the forces shooting at them. Under these conditions, more cautious, deliberate attacks might be able to keep both fratricidal and enemy-inflicted casualties down.

Training is extremely important to avoiding fratricide in future conflicts. The Army's training centers now pay special attention to fratricide incidents and collect the information for an on-going "lessons-learned' study. Firing ranges are now equipped with both enemy and friendly targets to practice ' 'Don't Fire! situations.

Simulation is an important part of modern training. In the past, simulators have been much better at depicting the day-lit world than the night world seen through infra-red viewers. Yet most of the fratricide in the Persian Gulf occurred under some sort of reduced visibility. Simulation for training is a rapidly progressing field and simulation of poor-visibility conditions must be supported in future programs.

CONCLUSIONS

Ground combat illustrates most clearly the vital importance of tactical knowledge of the battlefield to avoiding fratricide. Indeed, by some estimates, the majority of fratricide could be avoided by improvements in navigation and communication without a dedicated IFF system. For the foreseeable future, however, IFF devices will probably also be desired to compensate for gaps in tactical knowledge.

Navigation-communication systems and IFF systems will be pursued in parallel but, when comparing costs, one should keep in mind that avoiding fratricide is just one advantage of improved knowledge of the battlefield. Better information will increase maneuverability, flexibility, control and coordination of units and fire, and, hence, overall combat capability.

The Army's preferred near-term solutions will be difficult and expensive to incorporate into fixed-wing aircraft, This alone might make it unacceptable as a permanent solution if fixed-wing aircraft are expected to continue to provide close air support. One of the important policy questions is how to allocate resources between solutions that provide quick, but limited, results and more permanent solutions, which admittedly will take longer to implement.

The Army's technology and equipment to avoid ground combat friendly fire is primitive compared to Navy and Air Force equivalents. Army programs may need preferential funding for several years just to catch up to the level enjoyed by its sister Services today. The distribution of fratricides in the Persian Gulf argues for this relative shift in effort, at least until imbalances are less pronounced.

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