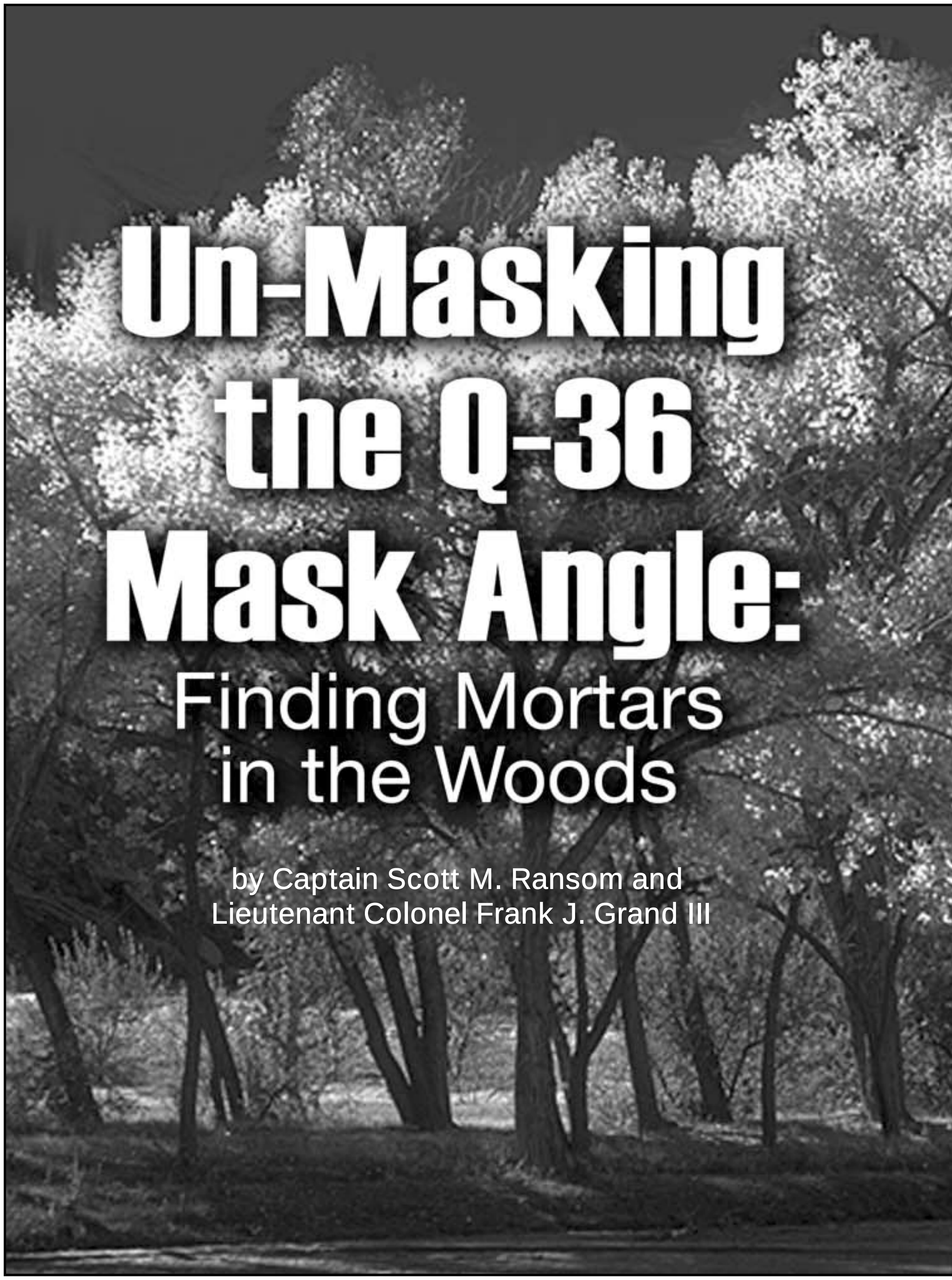
Un-Masking the Q-36 Mask Angle: Finding Mortars in the Woods

by Captain Scott M. Ransom and Lieutenant Colonel Frank J. Grand III



The Joint Readiness Training Center (JRTC), Fort Polk, Louisiana, has time and again shown the effectiveness of enemy mortars during search and attack operations. The fire support coordinator (FSCOORD) must use the Q-36 Firefinder radar to kill these mortars for his brigade. Careful positioning of the radar in such a heavily wooded environment maximizes its survivability and enhances its ability to acquire mortars. The result is increased force protection for the brigade.

This article discusses how to position the Q-36 radar to increase the probability of detecting the enemy's mortars in wooded terrain.

Positioning. The FSCOORD must position the Q-36 to accomplish the mission. Staff officers' misunderstanding positioning and failing to integrate the radar warrant officer (WO) into the planning process have made this a difficult task.

Also, the Field Artillery community has yet to define the operational requirements of the Q-36 for many of the missions found in light, low-intensity operations, such as the detection of a solitary mortar near the radar. Instead, we have focused on the traditional linear battlefield and the detection of indirect fire weapon systems far beyond the forward line of own troops (FLOT). We have taught radar technicians and FSCOORDs that radar positions must meet certain technical requirements for successful operations, based on this traditional battlefield. In actuality, the radar often can complete its mission in a light, wooded environment without meeting these "linear battlefield" requirements—albeit with somewhat degraded detection probabilities and increased target location errors (TLEs).

During traditional light infantry search and attack operations, the FSCOORD's primary requirement lies in finding 82-mm mortars with a firing range of approximately 3,040 meters. These mortars, usually used in guerrilla-style raids, often lie within seven or eight kilometers of the radar. Dense vegetation, a small area of operations and many other assets competing for terrain reduce the number of doctrinally "perfect" locations for the radar. Using some trigonometry and knowledge of the radar's mission, we can determine actual positioning requirements and usually increase the number of radar sites available.

When a radar technician examines a site to position the radar, he tries to maximize the radar's performance by taking into account various positioning suggestions or requirements found in the Q-36 radar specifications and in *FM 6-121 Field Artillery Target Acquisition*. One suggestion involves trying to keep the radar at least 200 meters away and slightly uphill from the nearest screening object to the radar's front to minimize multi-path errors that decrease the radar's range and accuracy. If we position the radar within 200 meters, these multi-path errors increase, and we must accept degraded radar operations (decreased detection probability and increased TLE).

We must remember, though, that 200 meters is not some magic distance where the radar ceases to work, but is a "default value" assigned to maximize the radar's performance. *FM 6-121* uses this same idea of a "default value" when discussing another positioning suggestion involving minimizing the radar's mask angle.

FM 6-121 defines mask angle as "the vertical angle from the radar to the top of the mask, or screening crest, at a given azimuth." According to the *FM 6-121*, the mask angle should not exceed 30 mils and should optimally equal 22 mils. But the manual doesn't explain why. Mask angles under 30 mils

system, the maximum ordinate of the rounds it fires and the amount of time the rounds spend in the radar beam. If the terrain allows a mask angle under 30 mils, these factors will not significantly affect the radar out to its maximum range.

The Q-36 was designed to track and acquire most mortars only between ranges of 750 meters and 12 kilometers. At ranges greater than this, the Q-36 will detect fewer and fewer rounds, and the rounds it does detect will have a much larger TLE. These effects are due primarily to the decreasing signal strength of the returning radar signals. If we have mask angles larger than 30 mils, the radar, while degraded, *may* still observe rounds.

We must analyze the other three factors mentioned to determine how much the mask angle degrades our operations. To do this, we use a modified version of the track volume computation found in appendix H of *FM 6-121*. The track volume computation lets the radar technician determine if the radar can observe artillery rounds if he knows or assumes the Q-36 mask angle, the location of the artillery, the artillery muzzle velocity and the quadrant elevation fired by the artillery. Our version of the calculation applies primarily to mortars and uses slightly different assumptions.

Mortar Detection Calculations. We first assume a range to the indirect fire weapon system and the maximum ordinate it fires based on the mission, enemy, terrain, troops and time available (METT-T). For light operations, we use the maximum range of 3,040 meters for an 82-mm mortar and choose a typical maximum ordinate of 1,000 meters. For the time the round spends in the radar beam, we make a worst-case assumption that applies to almost all indirect fire weapons systems. The Q-36 needs to track a round as it ascends on its trajectory for approximately two to six seconds to accurately determine a weapons' location. The higher the radar tracks the round on its trajectory, the more TLE we'll have.

optimize the performance of the radar out to its maximum range of 24 kilometers. Mask angles near 22 mils allow this optimum performance yet still provide enough screening to help protect the radar from detection and jamming from ground-based enemy electronic intelligence (ELINT) systems.

During operations in heavily wooded areas, though, the radar often must emplace in small clearings. These clearings, while affording a more protected radar, usually cause large but relatively constant mask angles over the full search sector of the radar. According to *FM 6-121*, large mask angles greatly inhibit the effectiveness of the Q-36.

Assuming we orient the radar in the right direction, three other factors impact whether the radar observes an enemy round or not: the range to the observed indirect fire weapon

To make things worse, the Q-36 specifications state that the target round's velocity should be at least 50 meters per second during this full six-second track to separate the round from radar clutter. To achieve a velocity of at least 50 meters per second while inside the beam for six seconds, the round must enter the beam traveling about 100 meters per second vertically (allowing for some horizontal velocity as well). This causes the vertical length of the track to be, at a minimum, approximately 400 meters long.

It's important to remember that the mortar round's significant horizontal component of velocity usually causes the track lengths to be quite a bit longer than this. We use the 400-meter track length as our worst-case scenario.

The one formula we need involves the *tangent* function *tan()*. (See Figure 1.) Trigonometry defines *tangent* as the side opposite to some angle *x* divided by the side adjacent to angle *x* in a right triangle. If we know the lengths of the opposite and adjacent sides, we can determine what value *x* must have, using the *inverse tangent* or *arctangent* function, $tan^{-1}()$, where $x = tan^{-1}(opposite/adjacent)$. Note that all but the simplest calculators will compute these functions.

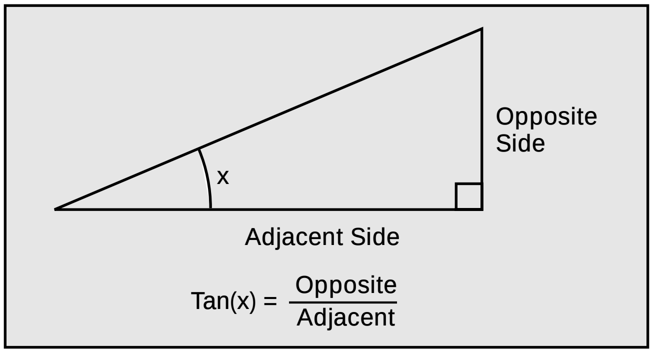


Figure 1: Tangent Function Formula

Now we ask, "What mask angle can we accept and still detect an 82-mm mortar?" As shown in Figure 2, the range to the maximum ordinate of the mortar round, which we assume to be approximately the range to the mortar, represents our *adjacent side* for the formula in Figure 1. Note that for artillery weapon systems that have a much flatter trajectory, we can't assume the maximum ordinate is approximately equal to the range of the weapon.

The maximum ordinate of the round minus the 400 meters the round travels up into the beam, makes our *opposite* side for the formula in Figure 1. This side equals the height of the bottom of the radar beam at the range to the round's maximum ordinate. The radar automatically adds 15 mils to the inputted mask angle and places the bottom of the beam at this angle to ensure it clears all screening crests. The angle of the bottom of the beam represents our angle *x*.

Now, using the *arctangent* function we can determine our acceptable mask angle as 15 mils.

$$\text{Mask Angle} = 17.78\tan^{-1}\left(\frac{\text{Maximum Ordinate} - 400\text{m}}{\text{Range to Maximum Ordinate}}\right) - 15 \text{ mils}$$

The 17.78 converts from degrees to mils. Substituting values from our example, the allowable mask angle equals 183 mils.

$$\text{Allowable Mask Angle} = 17.78\tan^{-1}\left(\frac{1000\text{m} - 400\text{m}}{3040\text{m}}\right) - 15 \text{ mils} = 183 \text{ mils}$$

This means we can place the radar anywhere with a mask angle below 183 mils and still detect the mortar out to a range of 3,040 meters.

We might also wonder, "At what range can we detect the mortar if our radar has a certain mask angle?" By inverting the equation for the "Allowable Mask Angle" and remembering that the range to the maximum ordinate approximately equals the range to the mortar, we get the following formula.

$$\text{Range to Maximum Ordinate} = \left(\frac{\text{Maximum Ordinate} - 400\text{m}}{\tan\left(\frac{\text{Mask Angle} + 15 \text{ mils}}{17.78}\right)}\right)$$

For our example, assume our radar technician finds a position with a mask angle of 120 mils. Therefore, we can detect the mortar out to a range of 4,500 meters.

$$\text{Approximate Detectable Range to Mortar} = \left(\frac{1000\text{m} - 400\text{m}}{\tan\left(\frac{120 \text{ mils} + 15 \text{ mils}}{17.78}\right)}\right) = 4500\text{m}$$

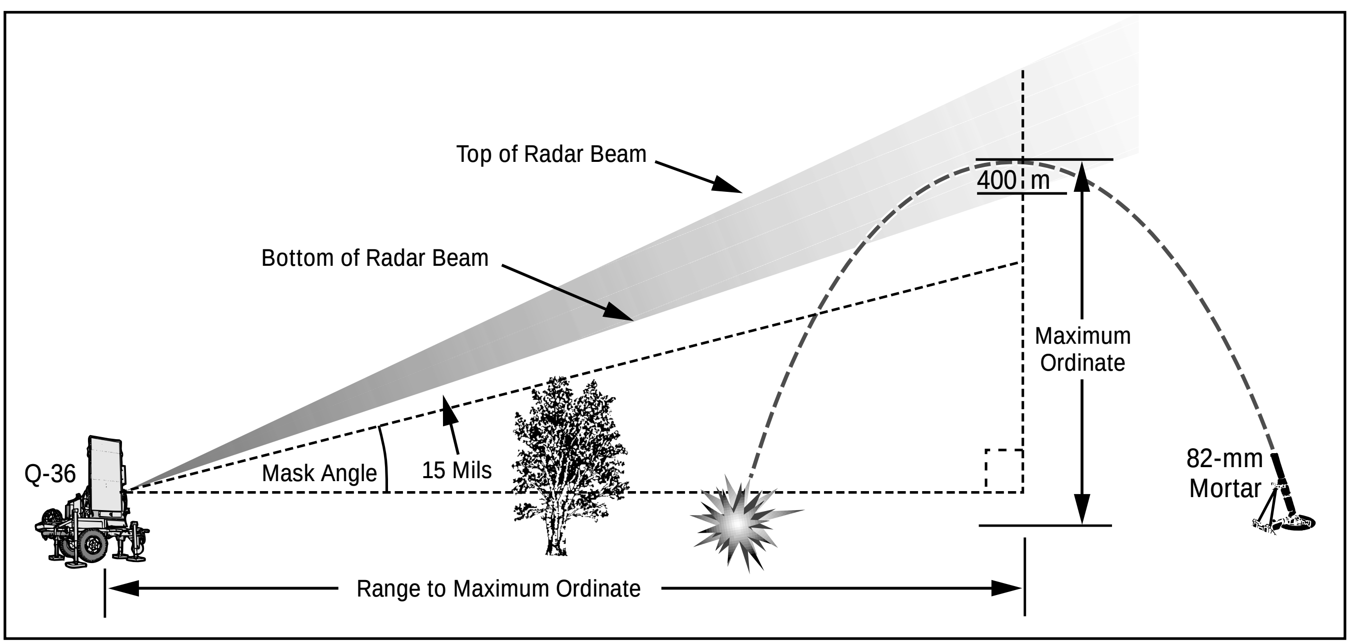
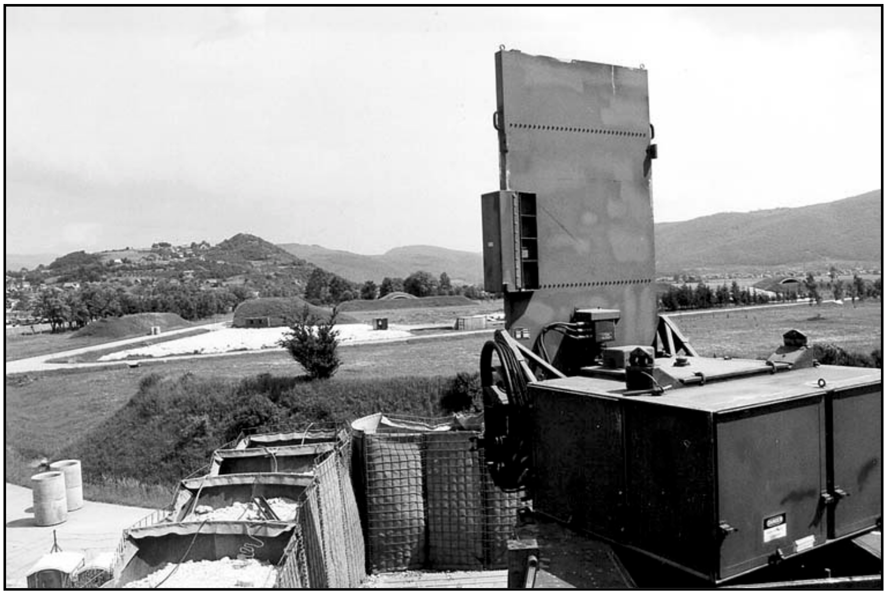


Figure 2: Example Scenario. The 82-mm mortar's maximum range is 3,040 meters, and it was fired at a typical maximum ordinate of 1,000 meters, which results in a 400-meter Q-36 track length.



Q-36 in Bosnia. The formula in this article gives the radar WO positioning options for radar survivability and enhances his probability of detecting mortars.

If we enter this formula into a spreadsheet with various values for the maximum ordinate and mask angles, we get a table showing detection ranges for indirect fire weapons (see Figure 3). The radar technician and the FSCOORD can use this table or one like it to determine the applicability of various radar sites, given the mission of the radar.

The table does *not* eliminate the need for the radar warrant to perform a thorough analysis of his site using either track volume computations from *FM 6-121* or the new Firefinder position analysis system (FFPAS) to begin fielding in mid-1999. FFPAS is a computer program that enables the operator to fully analyze his position based on a terrain database, various threat weapon characteristics and radar operating conditions. It provides a very accurate estimation of the expected detection probabilities and TLEs the radar can expect from each site. But even though the table in Figure 3 is simply a rule-of-thumb and doesn't provide the full accuracy of the FFPAS, it does allow the radar warrant to quickly determine if he can detect enemy mortars from his position. This allows him greater flexibility in positioning his radar and increases his radar's survivability without significantly decreasing its ability to acquire targets.

When we realize that the positioning requirements of the Q-36 depend as much on the mission requirements as they do the technical aspects of the radar, we can increase the survivability and potential of the radar significantly. The radar warrant becomes much less constrained when positioning the radar to accomplish his mission, and he gains access to more survivable positions. Simultaneously, he increases the probability of his radar's detecting mortars and protecting the force.

Mask Angle (Mils)	Max Ordinate (Meters)				
	500	1000	2000	3000	4000
10	4.07	24.00	24.00	24.00	24.00
30	2.26	13.57	24.00	24.00	24.00
50	1.56	9.39	24.00	24.00	24.00
70	1.20	7.17	19.13	24.00	24.00
90	0.97	5.80	15.47	24.00	24.00
110	0.81	4.86	12.97	21.08	24.00
130	0.75	4.19	11.16	18.14	24.00
150	0.75	3.67	9.79	15.91	22.03
170	0.75	3.27	8.71	14.16	19.60
190	0.75	2.94	7.84	12.74	17.65
210	0.75	2.67	7.13	11.58	16.03
230	0.75	2.45	6.52	10.60	14.68
250	0.75	2.25	6.01	9.77	13.52
270	0.75	2.09	5.57	9.05	12.53
290	0.75	1.94	5.18	8.42	11.66
310	0.75	1.82	4.84	7.87	10.90
330	0.75	1.70	4.54	7.38	10.22
350	0.75	1.60	4.27	6.94	9.61

Figure 3: Q-36 Radar Detectability Range of Indirect Fire Weapons (Kilometers). The maximum range of the Q-36 is 24 kilometers; however, the radar reliably can detect 82-mm mortars only between the ranges of 750 and 12 kilometers. The shaded portion of the table indicates ranges outside of the Q-36 specifications for detecting mortars where it is technically possible to detect a mortar but with a greatly increased target location error (TLE) and greatly reduced detection probability. This table is used only as a "rule of thumb." It does not substitute for thorough site analysis using manual (Track Volume) or automated (Firefinder Position Analysis System) methods.

Captain Scott M. Ransom is a Gunnery Instructor for the Officer Basic Course at the Field Artillery School, Fort Sill, Oklahoma. He previously served as Battalion Fire Direction Officer, Firing Battery Executive Officer and Reconnaissance/Survey Officer, all in the 3d Battalion, 6th Field Artillery, 10th Mountain Division (Light Infantry) Artillery in Fort Drum, New York. He holds a Master of Science in Astrophysics from Harvard University as part of a Hertz Fellowship Award received at the US Military Academy at West Point in 1992. He will complete the fellowship at Harvard, starting this summer to work on his Doctorate in Astrophysics.

Lieutenant Colonel Frank J. Grand III until recently commanded the 3d Battalion, 6th Field Artillery at Fort Drum. Currently, he is a student at the Army War College in Carlisle Barracks, Pennsylvania. In other assignments, he served as S3 of the 1st Battalion, 320th Field Artillery and Fire Support Officer for the 2d Brigade, both in the 101st Airborne Division (Air Assault), Fort Campbell, Kentucky. He also was an Exchange Officer with the British Army's Field Artillery School at Lark Hill and served a joint tour as the Operations Officer for the Nuclear Threat Reduction Division, On-site Inspection Agency, in Washington, DC. He holds a Master of Arts in Management from Webster University.