BASE FUZE ACTIVATION PLATE THICKNESS MINIMUMS VERSUS IMPACT OBLIQUITY

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My article ***MISCELLANEOUS NAVAL-ARMOR-RELATED FORMULAE*** was written in 1998. I have learned a few things since then and have some more information to add to my discussion in that article concerning the computation of the minimum plate thickness needed to set off the typical AP/SAP projectile's undamaged base fuze when it hits its target ship. This does not change most of what the article talked about, but it does add some extra information that I estimate might be correct enough to use to apply to portions of this topic that were skipped over in that article.

Let us first compute some fuzing information for a typical 14" AP shell, based initially on the information in the article:

A single-plate-activated base fuze needs about 0.98" (0.07 x 14") of iron or steel plate at right angles (decreases with obliquity up to 60 degrees or so and then goes back up -- see below), while a double-plate-activated base fuze needs two 0.7" (0.05 x 14") parallel plates spaced at most about 10 feet apart at right angles (also decreases with oblique impact).

Note that all computations assume an undamaged fuze. If the fuze is damaged by slamming around during penetration or ricochet, all bets are off and the damage will usually result in a dud, though any other possible thing could happen, from lengthening or reducing the delay (usually to the non-delay circa-0.003-second value) and/or reducing the ability of the booster to work correctly, resulting in a less-than-full-power detonation (this is on top of any other estimated effect due to a poor booster/filler combination, such as not using tetryl for insensitive TNT or Explosive "D" fillers). Also, if undamaged by a ricochet, the shell can still function on another plate (assuming that you care about where the shell goes if it ricochets, of course.)

The decrease with obliquity in the minimum plate thickness to set off a base fuze, "Tfuze", is given by the formula below for obliquity angles up to 70 degrees (61-70 degrees have the same result). It is based primarily on numerous tests with the US Navy Mark 21 Base Detonating Fuze (BDF), which had no "graze" feature – nothing added to allow it to function better at extremely high obliquity impacts -- and required a single plate of the largest minimum thickness value calculated to set it off; no multi-plate hits do anything if all are too thin. I also have a few tests of two-plate-activated fuzes to get a crude idea of how much this changes things. The formula I came up in the article is as follows:

$$\text{Tfuze} = \text{Tfzmin} \times D \times \{0.5 \times [1 + \cos(2 \times \text{Ob1})] + 0.4537 \times \sin^{5.7019}(\text{Ob1})\}$$

where "Tfzmin" = 0.07 for the single plate case at right angles (Mk 21 BDF, most British WWII BDF, and most other US Navy WWII BDF) or = 0.05 for the two-plates-10-feet-apart-or-less case at right angles (US Navy Mark 11/23 BDF, most earlier US Navy BDF, many foreign BDF, and virtually all black powder "ignition" fuzes) -- thinner plates in-between these don't count and neither does a plate thick enough that is too far behind the first plate, though if a third thick-enough plate is spaced within 10 feet of the second thick-enough plate, the formula will work using the second and third as the setting-off pair, and so forth -- "D" is the projectile diameter (nominal gun bore unless a sub-caliber round), and "Ob1" is the impact obliquity up to 61 degrees, where it is frozen at that value until an actual obliquity of 70 degrees is reached (see below for what to do above 70 degrees). (Note that the Exit Angle after penetration is ignored here, but would be needed to calculate the successive plate impact angles up to the time the shell is finally set off, if ever.)

For a 14" shell and the single-plate case, typical minimum-thickness values are 0.74" at 30 degrees impact obliquity, 0.55" at 45 degrees, 0.46" at 55 degrees, and the 61-degree minimum is 0.44". This is more-or-less constant for up to about 70 degrees and then begins to rise, but I do not try to estimate by how much of a rise in the above formula (again, see below). The dual-plate base fuze case is 0.53" for 30 degrees, 0.39" for 45 degrees, 0.33" for 55 degrees, and 0.31" at 61 degrees (minimum). If the two plates are hit at different angles, each one has to be computed separately to see if it means the minimum for its impact angle.

Obviously, the increase in fuze damage-resistance that resulted in the US and British WWII-era single-plate-only base fuzes cost them noticeably in sensitivity when hitting light plating -- but then, the shell works more often correctly when punching through heavy armor. The problem is determining which is more important!!

Note that "graze" fuzes are usually multi-plate-activate fuzes, since they try to let the minimum impact force set them off at a highly oblique impact angle, which usually makes them more sensitive at a lower angle, too. German WWII graze-designed base fuzes have both the firing pin and the primer holder “floating” and held apart by light springs, so that if the primer hits the firing pin or the firing pin hits the primer, either case will set off the fuze. This kind of multi-path design makes it much less likely to be jammed due to high sideways forces on a ricochet at high obliquity. **BUT** these fuzes are also somewhat less robust at lower obliquity against heavy armor (they have to be with the extra moving parts and simple internal design to make it more likely the firing pin and primer hit each other) so damage that can blind them can occur more often (German base fuzes in WWII were rather unreliable in service -- that 15” dud from **BISMARCK** that hit the **PRINCE OF WALES** torpedo bulkhead deep underwater was an example -- and this may be part of the reason, though not in this particular case.)

If the shell ricochets at up to 60 degree obliquity, it is always set off, just as if it penetrated, no matter what the plate's thickness (the shell never finds out what the thickness is). **BUT** note that the chance of fuze damage goes up a lot against thicker plates at higher obliquities as the projectile base slams up against the plate during ricochet.

From my more recent estimates, I would say that, for complete penetration, the minimum thickness rises to equal the normal-impact thickness value if it penetrates at 80 degrees, being a straight line increase from 70 degrees (0.44", same as 61 degrees) to 80 degrees (0.98") in the 70-80-degree range, but again only if it penetrates. This rise in required thickness is due to the lower, longer-applied force of resistance at any moment, as the projectile makes a long slot in the plate, making it more difficult to move the firing pin or primer holder, whichever must move to set off the fuze, and the high sideways force that inhibits along-the-centerline motion required to make the primer and firing pin hit one-another, no matter which one moves.

Since I always assume a ricochet at over 80 degrees, the complete penetration case does not apply there.

To handle the over-60-degree obliquity range for ricochet, I do not care about plate thickness, as mentioned above, so I estimate the following:

(1) If the shell does not have a "graze" fuze, the chance of the fuze being set off on ricochet goes from 100% at 60 degrees in a straight line to zero chance at 80 degrees and above.

(2) With a graze fuze that works, a ricochet means no activation ever only at 89 degrees, so change from 100% activate at 60 degrees in a straight line to zero chance at 89 degrees.

This is probably giving the graze fuze too much credit, but I do not know where to draw the line at "never works" for this kind of fuze. Also, both of the above ricochet chance values probably lie on some kind of curve, rather than a straight line decrease in chance, but I do not know what it is and the above is just an educated guess, which is the best I can do at the moment.

In many cases, a light cruiser or destroyer can be hit by a large-caliber SAP or AP shell and the shell never go off or, with a regular battleship-size-target delay, only go off after it goes out the far side, which is the same thing.
