HMS HOOD: British 1919 Tests on Upper Belt and Deck Armor

by Nathan Okun

Introduction

When HMS HOOD fought with and was destroyed by KM BISMARCK in its famous one and only battle at sea in 1941, the British had some idea of the effectiveness of the armor on its battlecruiser from calculations and several actual tests done just prior to freezing the final design of this ship.

These tests were (1) against mock-ups of the multiple deck plating arrangement of HOOD above the forward magazine, both actual and proposed, and (2) against mock-ups, both actual and proposed, of the 7" Cemented Armor (CA, the latest, at the time, British form of the face-hardened side protection steel armor used in virtually all battleships and some large cruisers from the mid-1890s to about 1950) lower portion (strake) of the inclined upper belt, here bolted to a 1" High Tensile steel (HT, a modified mild/medium construction steel used by British ship-makers with an added small amount of nickel to allow higher hardness and strength without the steel cracking under stress during bad weather) ship outer hull construction bulkhead with 1" of cement in-between to act as a cushion and to seal out water. The latter also included all of the decks and the single thin vertical bulkhead plate between the rear surface of that CA plate and the upper spaces of the gun propellant powder magazine. The aft magazine was the same except for the lack of the uppermost weather deck, the forecastle deck that extended from the tip of the bow, and the lack of the associated upper 5" CA strake of the upper belt armor, which ended in a wedge shape just in front of the raised aft battery 15" "X" turret to allow the lower aft battery "Y" turret to fire somewhat forward of amidships, making the next deck under the forecastle deck , the upper deck riding on the upper edge of the 7" CA side armor, into the weather deck from there to the tip of the stern. This upper belt and the 12" inclined CA main waterline belt ended a few feet forward of the most-forward main armament turret, "A", and ended, minus its 5" top portion, as mentioned, a few feet aft of the aft-most turret, "Y"; this was the armored "Citadel" of HOOD. The original thicknesses of the various HT steel decks and internal unarmored bulkheads that were extended into the bow and stern regions never changed much, for the most part, from what I can see.

Outboard of the waterline 12" CA main belt, covering all but the uppermost couple of feet of that belt and extending vertically down to the bottom of the hull was a relatively lightly-constructed outer hull with, just outboard of the belt-supporting strength bulkhead, a block of densely-packed rows of steel tubes below the waterline, designed to soak up the blast, shock, and water-hammer effect of a torpedo hit as they were crushed and torn -- the entire outer region was called the anti-torpedo "bulge" due to some older ships having this added after they were completed, so that a new, wider, outer side hull had to be layered onto the existing ship structure below the waterline. Thus, HOOD was one of the first ships to have in its final pre-construction design a recessed waterline belt spaced behind the visible hull made up of this bulge. (In WWII, many new battleships from several nations had this inclined-and- recessed belt concept in their side belt designs, with variations.)

Below the lower edge of the inclined 12" main waterline belt amidships, the outer hull continued vertically down until it rounded inboard to form the bottom hull, this rounded portion being about two deck-heights from the flat bottom and extending about the same distance inboard from the side, making it a portion of a circular arc. Inboard of this, with a widening gap between it and the outer hull, was a continuation of the inclined HT steel bulkhead that supported the main belt to the bottom, meeting the bottom in that curved region just outboard of the flat bottom. A few feet inboard of that, also inclined the same way, was a second HT steel bulkhead, and spaced a few feet inboard of that, with a large gap at the top where it ended at the level of the bottom edge of the main belt, was the side vertical bulkhead of the powder and shell magazines. There were obviously other bulkheads and supports in all of those spaces, but these were the main structural vertical/inclined longitudinal plating below the waterline. Inside the magazine space was another thin HT steel deck, cutting it into two levels, one for powder and one for shells, with two more narrowly-spaced HT-steel decks underneath forming a three-spaced-plate bottom hull for high structural strength. Inside the spaces of this bottom hull box were stored the ship's fuel oil, crew drinking water, and the distilled water needed by the ship's boilers. It also acted as ballast to keep the ship stable in bad weather or if it had battle damage and flooding, so as the fuel was used up, sea water was used to replace it. This liquid storage, with empty spaces used as air gaps, was also used in the outer side hull spaces adjacent to the magazine and amidships propulsion plant, forming the ship's anti-torpedo side protection system amidships. Note that the deck arrangement above and inside the propulsion plant, wedged between the two magazine spaces at each end of the ship and forming the major portion of the protected vitals, was different due to the large size of the boilers and engines requiring them to extend upward into the spaces above the waterline somewhat, which of course made them more vulnerable to enemy hits that punched holes in the side armor or protective decks. Since the ship had four engines and a large number of boilers, it could lose some and still function, if not at maximum speed, so such lower protection was accepted.

HOOD thus had no portion of the amidships Citadel (powerplant and magazines) that was not on its side surface from about 5' below the standard waterline to the upper edge of the weather deck (either the long forecastle or the aft upper deck) protected by rather thick CA armor. (Underwater hits were considered unlikely at the time and thus not protected against if they occurred very far down the side hull, but this was true for virtually all warships when HOOD was built and even many later designs, which knew better, did not address this well, so this is not a major design flaw compared to many other major warships.) On top of that, the side hull form was such that the CA plating was sloped top-over- bottom by 12 degrees for the 12" recessed main belt, 20 degrees for the 5" uppermost strake of the upper belt, and by a curved 7" lower strake of the upper belt that was 12 degrees at its lower edge where it met the top edge of the 12" main belt and 20 degrees where it met the lower edge of the 5" upper strake (this was due to the lower hull narrowing near the ends of the ship but the weather deck kept as wide as possible as the ship narrowed to keep waves from flooding it). The entire 5" and 7" upper belt was at the same 12-degree tilt as the 12" waterline belt along the amidships propulsion plant length where the outer hull was closer to vertical. This high sloping of the side protection, even where it was not mandated by the waterline hull, such as near the bow, was also a new concept, designed to make the side armor significantly more resistant by requiring incoming enemy projectiles to hit the armor at a significantly increased oblique angle, which increased the resistance of the armor considerably at longer ranges, largely due to the hard face being much more able to break a penetrating projectile's middle and lower body as it slammed its side into the armor, even if the armor-piercing (AP) cap on the projectile nose worked to protect that portion of the shell. Face-hardened armor, while not as resistance to a hole being punched entirely through the armor plate as the softer homogeneous armors used for deck protection in later battleships to a well-designed AP shell when the AP cap worked properly, could much more severely damage a projectile as it tried to punch its way through the hole that its nose had made in the hard face, so forcing oblique hits can save the ship where a more right-angles hit would not, even if the velocity to punch through the plate was the same in both cases.

Hardened AP caps were originally developed by the French circa 1911, I believe. They improved penetration of weaker-bodied AP projectiles over soft-capped designs and, when improved shells were also adopted, were found to work at any impact angle where they hit the armor first, causing these hardened AP caps to be continuously enlarged and thickened until they covered almost the entire shell nose by WWII and were, in some cases for WWII US Navy cruiser AP shells, as thick as the projectile diameter. During WWI, hardened AP caps were adopted by the British after they finally realized that their AP shells were not penetrating very well at any significant oblique angle, since they had been previously testing them at right-angles almost exclusively. This is strange since the Germans in 1911 had added testing at 30 degrees, even though against rather thin (only half projectile diameter or "half-caliber" in thickness) face-hardened armor plate, well before adopting a true hardened cap. The British hard-capped shells in several tests showed that they could remain intact against half-caliber CA plate even at 40 degrees obliquity and, in one US Navy test, one of their shells remained intact after penetrating almost a full-caliber-thickness US face-hardened armor plate at 30 degrees. These shells were, to my knowledge, the best all-round AP shells in the world at that time, though the US Midvale-designed shells adopted in 1916 were roughly as good when up to 15 degrees obliquity and many remained intact in the 15-20-degree range.

The US Navy had adopted a 10-degree obliquity test for its soft-capped AP shells shortly before WWI. When the Navy required all new 14" AP shells meet it against near-caliber-thickness face-hardened (Class "A") armor (13.5" battleship belt armor plates), The Midvale Company had all of its shells pass easily, the then-new Crucible Steel Company AP shell designs had most pass (with the allowed retests, almost all shells manufactured by them were accepted for the then-new 14"-gunned battleships), but the Bethlehem Steel Company had all of its 14" shells fail with no shells accepted (I have no idea if they ever fixed this problem before the Washington Naval Treaty of 1923 cut production short for all US battleships), with the latest soft-capped "Midvale Unbreakable" AP shells specified as standard in 1916, mentioned above, for all US Navy guns firing AP shells at that time (8"-16", though the 8" was dropped and replaced by a base-fuzed Common round shortly after 1923).

The side protection of the amidships hull on the "battlecruiser" HOOD -- which supposedly sacrificed thick armor for higher speed (31 knots here) -- was therefore equal to and, in many cases, superior to the protection of so-called "battleships" of the period that nominally had thicker side plates that were not sloped: A 12" 12-degree-sloped plate is noticeably better protection than a 13-13.5" vertical (not sloped) plate, typical of foreign and earlier British battleships, even near point-blank range, and it gets more and more superior as range increases and the impact slope differences really kick-in as to the effects of obliquity on resistance and, even more, to projectile damage on impact.

However, the main problem with HOOD was its deck protection or, to be exact, the lack of it.

HOOD was the last British capital ship designed to the pre-WWI short-range/non-delay-fuzed AP shell standard, which during WWI was found to be no longer true, with the advent of reasonably accurate range-finders and director-and-calculator-controlled gun aiming systems in what were now true all-ship fire-control systems to allow a reasonable hit chance even at long range (for the time, then limited by the narrow gun elevation restrictions), so that decks were now vulnerable to relatively steeply-falling shells (by prior standards) of up to maybe 35 degrees angles of fall. Before this, the expected maximum angles of fall were at most 20-odd degrees and a deck hit, even near the closest part of your ship to the enemy that just missed the upper hull's side armor, would usually (1) punch straight through and out the far side without coming near the propulsion plant or magazines recessed down near or even totally below the waterline, or (2) be set off by the upper side hull or weather deck and explode during or just after penetrating the outer plate because the shell fuzes were not fitted with any kind of delay mechanism, so only chunks of the broken-apart shell would get far into the ship and thin "protective" decks and "splinter" bulkheads, in spaced layers, would keep almost all such pieces out of the "vitals". Indeed, the many smaller rapid-fire guns on an enemy ship were considered more dangerous than the few big guns at such short ranges.

It seems that much of HOOD's design work during WWI was done prior to the major naval battles, particularly the Battle of Jutland in 1916, that showed that the ranges and impact angles and necessary armor plate thicknesses to stop the shells under those conditions were now significantly different than had been thought prior to WWI. When final design and construction of HOOD was OKed (with all other sister ships cancelled due to the Washington Naval Treaty of 1923) just after WWI, not much could be done to change HOOD's design without such a major rework that the ship might not even ever be built, so only rather minor armor protection improvements to the decks amidships was possible, allowed by deleting some weight in secondary guns, torpedo tubes, and so forth. The tests being discussed here are what caused those few possible changes, minor as they were, and showed the weakness of the deck protection that could not be addressed at the time (and ultimately never were, possibly being the cause of the ship's loss from hits from BISMARCK).

HMS DREADNOUGHT launched in 1906, with 10 big (for the time) 12" guns of which 8 could fire at most targets at one time, changed things drastically and made all other large warships obsolete in one stroke. This kind of ship now was practical due to hydro- or electro-mechanical assisted powder and projectile handling and loading systems allowing rates of fire fast enough to make calculated target tracking and prior-shell-splash spotting capable of rapidly getting a properly designed aiming and gun-control system and a well-trained gun/director crew on target and keeping it there, even when the target was trying to maneuver and change speed to fool them. It took somewhat longer to come up with efficient and reliable range-finder and spotter systems and rapid and reliable methods to transmit the target data to the calculators and from them to those crewmembers actually aiming the guns, but by the beginning of WWI much of this was being developed and installed and battle experience even more rapidly caused improvements to be designed and installed, so by the end of WWI, hitting a target at near maximum gun range was at least theoretically possible (in reality, ranges against actual moving enemy targets were somewhat less due to the ability of the targets to maneuver during the rather long time-of-flight of the shells at such ranges). Deck armor was now important, since such hits, completely bypassing the side belt, were now quite possible. When aircraft started appearing with AP bombs, deck armor became MUCH more a requirement; in fact, it drove deck armor designs more than shell hits did by WWII, leading to many ships with two armored decks, one thinner weather deck to set off the fuze of an AP bomb and/or cause a high-explosive (HE) non-AP bomb to go off prior to getting inside the ship, and a much thicker lower deck to stop AP bombs and gun projectiles, if possible, or, failing that, to completely stop any bomb or shell effects if the shell explodes between the decks due to the first deck or upper side hull plating (construction steel or armor, depending on what thickness is needed to cause the fuze to activate) setting off its fuze -- this last only worked if the bomb was going relatively slowly or the shell was hitting at a shallow angle and thus moving a long distance sideways, but this could reduce the chance of a major hit considerably in some cases.

Delay-action fuzes, the other major driver toward thick deck protection, had a rather complicated story. With the advent of face-hardened armor (Harvey or, later, Krupp Cemented (KC) armors), unless something could prevent nose shatter on impact, most projectiles (this was very irregular in effects) would not retain an intact explosive charge when passing through the plate, even when possible (shatter also greatly increased the striking velocity needed to penetrate at near-right-angles impact on top of rendering most projectiles "not fit to burst", to use the British phrase). Even a non-delay fuze was of little use then, so delay-action was not even an issue. This was so bad that the German Navy did not even try to use an explosive filler in its otherwise high-quality AP shells, which did not use an AP cap prior to 1902, when the first soft caps were finally adopted and a less-expensive mass-production method of making the explosive TNT started to be used (its uncapped Common shells -- equivalent to what the Army called "semi-armor-piercing" (SAP) with a base fuze and a rather larger explosive charge inside -- designed for penetration of thin armor or any non-armor plates, had used explosive fillers since the early 1890s, so they did understand that an explosive filler made a shell more destructive). The advent of the original soft-steel AP cap "crash helmet" in the late-1890s through early-1900s finally allowed intact penetrations of heavy face-hardened armor at reasonable velocities (that is, longer ranges), but only if the shells hit at most 20 degrees from right-angles on the plate. Higher angles always shattered as though the cap was not there (the cap was being partially torn free from the nose and the now bare regions of the projectile nose's impact area could no longer offload their impact shock energy into the cap, so it reflected back into the nose and cracked it, after which the nose would shatter like glass on the extremely hard plate face surface). Improved "tough" caps increased some capped AP shell designs hitting thinner plates up to about 30 degrees, but this was not really a fix against the main thick side hull or turret armor of the enemy ship. Only when hardened AP caps were developed, first by the French and later by the British, prior to the end of WWI (these eventually became the norm by WWII), did impacts up to 40-50 degrees with intact explosive fillers become possible enough, if the shell body was toughened enough to take the strong twisting forces, to make using a delay-action fuze a realistic improvement.

To my knowledge, the first large-scale use of delay-action fuzes was by the US Army Coast Artillery in 1906 with their then soft-capped AP shells. They had perfected calibrated firing techniques even for long range, using both long-barreled guns for flat-trajectory fire and high-angle, short-barreled mortars for deck hits. In this case, they were one of the first artillery services to have a good chance to get deck hits on enemy ships prior to the enemy even being able to shoot back effectively with their low-elevation guns. This made it extremely important that such long-range hits be effective and that meant going through all of that spaced thin decking to reach the enemy vessel's vitals near or even below the waterline with a high probability for each hit. Such hits were so dangerous at high angles of fall that even chilled-cast-iron projectiles, with AP caps added to allow penetration of thin mild- or high-tensile-steel decks, were considered effective for a number of years, before being replaced by thinner-walled steel shells with larger explosive charges. Delay-action fuzes and, shortly thereafter, the rather inert Explosive "D" (ammonium picrate) filler were introduced to allow a shell to remain whole even when going through rather thick armor and still be set off by the fuze later-on, rather than being partially exploded as it broke up during the penetration or partially or completely exploding due to impact shock prematurely. The British standard armor-piercing projectile explosive filler from the late 1890s through about 1917, when the much more insensitive and somewhat reduced-power explosive "Shellite" and delay-action base fuzes were introduced after the results of the Battle of Jutland, was the powerful explosive trinitrophenol or picric acid, termed "Lyddite", which was later found to not be able to remain unexploded when penetrating plate more than about one-third caliber or more due to impact shock, precluding the use of any kind of delay in the fuze. The very short delay between the impact and the Lyddite exploding due to shock was very close to the mechanical delay time from the inertially activated non-delay fuzes then used, so the results with or without the fuze using this filler were almost identical against thick armor.

The German Navy introduced improved AP shells in 1911 that formed the basis of all new shells that they used through the end of WWI. These had a form of tough cap that allowed no shatter at up to 30 degrees, but the shell bodies were still too weak to penetrate face-hardened armor more than about half-caliber (more than the projectile radius) in thickness at above 20 degrees. This, plus their own improved fire-control designs, caused them to also go to inert fillers (they used pre-cast blocks of TNT covered in felt stacked in the cavity with a large wooden block at the upper end as an impact shock absorber) and a modified non-delay base fuze with a thin black-powder-layer delay element attached to the back of the picric-acid booster sticking into the TNT filler like a long finger. Instead of making a new, from-scratch base fuze, the original detonator set off by the firing pin on impact was retained. This was very powerful to make sure that it set off the booster and, thus, the main filler charge most of the time (picric acid was a poor booster for TNT or, for that matter, the even more inert US Army/Navy Explosive "D" and a lot of the shells, even without the delay element, did not explode properly). It was so powerful that it destroyed the thin black powder layer, even when that was shielded by a metal plate with many very tiny holes in it. Instead of making a lower-power detonator, they kept that part of their old non-delay base fuze and inserted a triangular-cross-section spiral tube with several twists in it in-between the detonator and the plate with the black powder on its far side, pressed into the picric acid booster. This caused the detonator blast to ricochet around a lot of corners and drastically reduced its power so that many more delays now worked. But due to the variation in the explosive power of the detonator from fuze to fuze, now they had a lot of duds due to the black powder not being set off by the remaining energy going through those tiny holes in the metal plate. They partially fixed that by putting loose black powder in the gap between the end of the spiral tube and the metal plate, but this of course meant that a lot of the fuzes were now going off way late. No matter what they did to this "Rube Goldberg" fuze design, it was very unreliable as to going off at all or as to its delay when it did so, which was intended to be 0.025 second.

During the Battle of Jutland, this German AP shell fuze did work properly a few times and this was enough to convince the British that they too needed a delay-action base fuze, replacing their current AP shells that used Lyddite, so they created a form of their existing non-delay Number 16 base fuze, used in their pre-WWI and WWI AP shells, with a delay option (that could be turned on or off just prior to loading the shell, as directed by the fire-control officer), also of 0.025-second, I think (it gave in some test I have seen average delays somewhat shorter than the average 0.033-second delay used by most US Navy WWII AP shells, so I think that was the one used, a copy of the German spec). They, unlike the Germans, did this the correct way in their new Number 16D AP shell base fuze, with a new low-power primer hit by the firing pin inserted in front of the delay so as not to damage it and the now-separate powerful detonator only then exploding due to the delay's final flame to set off the booster. Here a black powder booster was retained from the older shells with Lyddite fillers since the new insensitive filler, Shellite, could usually be set off by such a booster, though both WWI tests and WWII experience showed that Shellite was not very reliable if set off by black powder and eventually in WWII they used the same much-more-powerful booster, tetryl or "CE", that they had adopted in 1928 for their smaller TNT-filled AP/SAP, capped or not, shells -- this same booster was also adopted by the US Navy in the same year for their Explosive-"D"-filled AP and base-fuzed Common shells, though they used a different design of the booster itself.

The use of Lyddite by the British and any nation using British-designed ammunition and the identical French Melanite high explosive, both of which were so sensitive that no practical delay-action fuze was possible when thick armor was hit, was done due to the fact that at the time, prior to WWI and actual major battle experience, picric acid was the most powerful explosive known that was safe to fire out of a gun in a high-velocity projectile when handled and packed properly. The extreme sensitivity of picric acid to armor impact was confirmed by the Japanese during the 1920s when they tried and finally failed to design any way to shock-proof "Shimose" -- their adopted form of Lyddite after they got KONGO from the British in 1912 -- and were forced to use a somewhat less-sensitive, but almost-as-powerful explosive trinitroanisol (TNA or "Type 91 Explosive") in their new diving Type 91 AP shells of 1931. (Why the Japanese were so stubborn about picric acid when everyone else had written it off as no longer of use is not clear, but I think it is due to "tradition" -- it was the explosive used in the ammunition that they used when they won the Russo-Japanese War and some Japanese seemed to think that honoring the past is the thing to do, no matter what problems it causes in the present.) Since picric acid could not use a delay-action fuze and they did not want to use anything less powerful at that time, the British did not even try to develop such a fuze. The US Navy had been using the insensitive Explosive "D" as their standard explosive since 1911 -- and the US Army had adopted it as such even earlier -- replacing older Navy black-powder-with-granulated-TNT fillers, but they didn't add a delay either, even though the US Army, using that same insensitive explosive, did, as was mentioned above. (Sometimes, logic is of no use when trying to figure out what people do...)

After WWI the US Navy also worked on and finally adopted delay-action base fuzes for its AP shells and the larger base-fuzed Common shells (the small shells did not need a delay, since the built-in roughly 0.003-second inertial mechanical delay was enough against small targets; you did not want to act like solid shot by passing through an enemy ship like a Civil War cast-iron cannon ball), which seems to have been adopted not long before the introduction of tetryl boosters in 1928 finally made using Explosive "D" truly reliable (before this, using TNT or picric-acid boosters with Explosive "D" had resulted in a lot of duds and lower-power explosions, but, just like British Shellite and its black-powder booster, these results were simply lived with as "par for the course"). The smaller base-fuzed Common shells that used a delay used 0.01 second -- the same base-fuze delay was also adopted later in WWII for the larger- caliber High Capacity (HC) shore-bombardment projectiles when the nose fuze was removed and replaced by a solid steel nose plug to allow them to get some deep penetration into protective earth and rock fortresses in Japanese island defenses -- and the larger base-fuzed Common and AP shells used 0.025 to 0.033 second (the latter was the actual average for the widely-used US

Navy WWII Mk 21 Base Detonating Fuze for AP shells based on its nominal 0.035-second design goal). The US Army had adopted tetryl for the base-fuze booster charge in 1918, but the Navy did not consider it safe (it was extremely sensitive and powerful, even in tiny quantities) for ship use until they could get the smallest possible pieces of tetryl to work, here compressed into two small rocket-nozzle-shaped pits in the upper opposite sides of the lipstick-can-shaped fuze for increased reliability, to form needle-jet amplifiers to blast the Explosive "D" around the fuze tip. Even then it took them ten more years after the US Army to finally agree that these fuzes were safe. Ordnance safety in the US Navy is a religion...

Main Magazine Deck Arrangement of HOOD

The decks of the ship as originally designed prior to these tests above the forward main magazine were spaced about 8-10' apart (the spacing was not the same between all decks), being:

(1) The 1" HT steel forecastle deck from the tip of the bow until it ended just in front of "X" turret aft, touching the upper edge of the inclined 5" CA uppermost strake of the upper side belt;

(2) The 2" HT steel solid upper deck that became the weather deck in the aft part of the ship, touching the upper edge of the 7" CA lower strake of the upper side belt;

(3) The 3" HT steel laminated three-ply (0.75" over 1.25" over 1") main deck -- this was the closest to an "armored deck" that HOOD ever had -- that was level with the upper edge of the inclined 12" main waterline belt, but which did not reach it, being folded down at a steep (roughly 30 degrees tilted back from the vertical) slope a few feet inboard of the belt and reduced in thickness to only 2" solid HT steel to act as an enhanced splinter screen bulkhead against pieces of the main belt or fragments of a broken projectile if a hole was punched in that armor by an intact projectile with a non-delay base fuze or which exploded on impact as it was broken up by the belt armor (this thickness would do virtually nothing to stop an intact AP shell or the heavy nose pieces plus the punched-out armor plug of a broken-up shell that got entirely through the main belt and was still moving at any but the lowest possible velocity). Note that there is now no horizontal deck plating whatsoever on the main deck level in the gap between the sloped 2" plate, usually called a "turtleback", and the back of the joint of the 7" upper and 12" waterline belts.

(4) The 1" HT steel lower deck that formed the bottom support of the main side waterline belt and the top (roof or "crown") of the magazine spaces below it and the top anchor of the anti-torpedo side protection system plates (it wasn't very thick but was reinforced considerably to support all of the important side armor bottom end and spaced underwater protection plate upper ends).

The inclined outer side bulkhead on which the various thicknesses of side belt armor were stacked, with 1" of cement in-between, was only 1" HT steel and it ran all the way from the forecastle deck or, aft, the upper deck to the bottom of the ship, forming the outer hull plate to which the side belt armor was attached amidships to the bottom edge level of the main waterline belt and it formed the first inboard bulkhead of the anti-torpedo bulge system behind the outer hull below the waterline from one end of the ship to the other. It thus formed the side support for the entire armored amidships Citadel with the above decks.

No other major side vertical bulkheads or decks existed in the space above the bottom edge of the 12" waterline belt, with only some thin 0.75" or less HT or mild steel vertical bulkheads separating various spaces, but these had a rather small protective function (they could stop, layer by spaced layer, many of the tin, fast fragments thrown from the side an exploded shell, but that was about it).

Protection Afforded by Plating against Various Projectile Damage-Causing Effects

Projectiles cause direct damage (not counting flooding or secondary steam- or magazine-caused blast or fire effects) due to their metal bodies in one or many pieces punching into and sometimes through parts of the ship surrounding the impact; by blast pressure and concussive shock and incendiary effects of its explosive filler, if any, against nearby and, by transmitted shock, occasionally farther-away ship structures (these are limited by the rather small size of explosive used in even the largest gun projectile, with only large aircraft bombs or torpedo warheads being able to do widespread damage due to this); and by punching out pieces of the armor plate hit to act like more shell fragments or by deforming the plate near the impact so that it interferes with surrounding ship operations (jamming a turret, for example).

Thick armor, if heavily reinforced, can stop blast and fragments completely and even, up to the ballistic limit of the plate against the projectile under the given impact conditions, stop the shell itself. Only somewhat-deadened transmitted shock, plate deformation effects, and/or some broken pieces like nuts or bolt heads not strong enough to resist the huge projectile impact shock will directly affect anything behind the armor if the shell is stopped without making a large hole in the armor (properly mounted equipment can be immune to indirect shock damage, though crewmembers in such spaces directly behind an armor plate can suffer severe concussion injury from such a hit). Later smoke, fire, and flooding effects can still occur due to the damage caused, but delayed from the actual impact itself. However, thick armor, if holed, can add its fragment damage to that of the projectile in the spaces directly behind the armor hit, so armor is not always a benefit if penetrated by a significantly-sized projectile, though it can limit the volume of space inside the ship that the damage reaches even if holed, by absorbing energy that otherwise would allow the projectile itself to penetrate deeper into the ship.

Thin steel plating, of armor grade or not, while one layer cannot stop many projectile fragments, when used in spaced arrays can be quite effective in limiting the spread of damage from a gun projectile impact on a ship. This varies with the kind of damage that the shell creates, as follows:

(1) The entire, unexploded projectile in more or less one intact piece passes through the ship, whether or not it had hit an armor plate on its way through. Such a projectile will be going in most cases at quite a high velocity and will tear through a large number of thin plates unless it hits them at a rather highly oblique angle. In a large number of cases, the shell, possibly deflected to and fro somewhat by the thin plates it hits, will simply pass entirely through the ship and out the other side. Thin plating has rather limited effect on such a shell's motion through the ship, with the shell only being stopped inside the ship if it hits thick armor somewhere along its route that slows it down considerably. However, such projectiles have the least effect on a large warship unless by shear accident they punch through some critical piece of equipment, since they only cause damage down a very narrow, projectile-diameter-width tunnel through the ship. Even a small warship is very large compared to such a hit and the damage inflicted in the vast majority of such cases is virtually nil as to the short-term current fighting ability of the ship so hit, though long-term effects may occur if the hit does damage some critical component that cannot be repaired or replaced (fuel pumps, food storage, fuel storage, etc.). Note that this time, however, the chance of such an intact projectile after it had punched through even the relatively thin upper side CA belt armor was small, since the AP projectiles then in use in most cases had non-delay fuzes, excessively-impact-sensitive explosive fillers (based on black powder or picric acid), unreliable soft AP caps at all but the lowest angles of oblique impact (0-15 degrees reliable, 15.1-20 degrees sometimes (I assume half the time), and never over 20 degrees) so projectile nose and, usually,

body shatter occurred that reduced much of the shell to pieces (this form of shell nose-tip-shock damage from an impact with face-hardened armor greatly reduced the ability of the shell to penetrate armor when the impacts were under 45-degrees from right-angles), or rather weak-bodied shells that even if the AP cap worked, the twisting or compression forces from the armor would break the shell apart unless it hit at a high enough velocity to pass through the plate very quickly after making a hole. Most AP shells suffered from more than one of these defects simultaneously. On the whole, one could expect these kinds of shells to be in pieces within at most 5' after exiting the far side of the CA plate it had just impacted, if even that far.

(2) Large, heavy nose pieces of an AP or base-fuzed Common projectile and/or chunks of armor thrown behind a heavy armor plate that is holed, with the projectile broken up by damage from the plate or by the detonation of its explosive filler during or shortly after punching through the thick side CA plate. Such pieces will be moving forward in a narrow cone-shaped cluster along the trajectory of the shell when the break-up occurred, at the relatively slow speed of the shell on the far side of the CA plate, having most of their energy absorbed by the plate as it resisted the punching of the hole through it. These kinds of fragments are the ones that are most dangerous to the ship hit since the thin spaced internal hull bulkhead or deck plating, though much more effective at slowing, deflecting and ultimately stopping them -- compared to an intact shell noted in (1), above, due to their smaller size and weight and their irregular shapes greatly increasing the resistance that even a thin plate can cause to being penetrated, especially at an oblique angle -- cannot stop them unless they have been slowed down to a very low velocity by prior impacts. At best they can deflect the heavy chunks sideways if hit at a highly oblique angle by still-fast-moving chunks, which makes reinforced decks important. Indeed, tests after Jutland by the British showed that the rather lightly-built Common, Pointed, Capped (CPC) black-powder-filled shells designed originally for use against smaller armored ships were much more effective than Lyddite-filled (fuzed or not if heavy armor hit) AP shells against even large battleships if they punched through the outer armor and exploded during or just after penetrating, even though the CPC shells usually broke up during penetration and had very low explosive power effect in the spaces behind the plate, because these supposedly low-blast-power/less-dangerous shells did not break up most of the projectile body behind the nose into the many tiny, high-speed, sideways-moving pieces due to the explosion of a high-explosive-filled (Lyddite in the British case) AP shell and the many, but much fewer than the pieces of the HE-filled APC shells, large chunks of CPC body and nose could fly in a narrow cone forward deeply into and through the target like a shotgun blast (unlike the APC shell nose pieces only, the entire CPC shell body would become part of this shotgun blast), spreading damage and some enhanced incendiary effect from the burning remnants of its black powder being thrown about over a much larger volume in the target, even though the damage at any given place was reduced compared to the powerful concussive blast and the many tiny, fast fragments the AP shell filler detonation could produce to completely pulverize the area immediately surrounding the AP shell when it went off. These large, heavy, but only moderately-fast-moving fragments are the very ones that the several internal spaced thin armor "protective" decks and "splinter" bulkheads of pre-WWI capital ships, including HOOD, were designed to protect against. While the fragments of this type cannot usually be stopped until they have gone very deep into the ship, making their use against small ships preferred, which is why CPC shells were adopted, the decks are thicker than most of the vertical bulkheads in their way and, due to the shallow angle of fall and somewhat reduced speed after going through the side belt armor, they will hit those decks at a very highly oblique angle, making it highly probable that most of the fragments will glance off upward even when hitting such thin decks (though possibly tearing long slots in the deck plates) and remain above the tops of the magazines and

other important below-the-waterline spaces, even if sometimes still hitting the top portions of engines and boilers in those regions of the Citadel projecting above the waterline (most ships have more than one boiler or engine, so they can allow some damage here), so the decks will have performed their duty of keeping the magazines intact and preventing the ship from blowing up.

(3) The many tiny, very-fast-moving sideways-thrown fragments from the blast of a properly-functioning detonated HE filler of any such shell, here being AP shells that made it intact through the armor and exploded as designed due to their non-delay base fuze just after exiting the back of the CA side belt plate (or, with Lyddite, going off due to impact shock at the same time). These fragments are going so fast that the forward motion due to the shell's remaining velocity after penetrating the CA armor has almost no effect and can be ignored almost completely, with ricocheting fragments off surrounding structures having more forward and backward damage-causing effect than this projectile-velocity component in such a case (other than the few heavy nose tip fragments, such a detonation simply stops the effects of the forward motion of most of the projectile's fragments completely). While very damaging to nearby ship equipment, on top of the powerful blast and concussion effects of an HE detonation, such fragments, due to their rather small size, light weight, and brittle consistency (due to the high shock of the blast that tore them apart forming many internal cracks in each fragment), have a very limited "carry-through" capability. Air resistance also slows them down rapidly, so only the heaviest will reach very far from the blast point. Due to the blast wave behind them during their initial motion, I assume that the air resistance slowing will only begin after the fragments are about 5 calibers (projectile diameters) from the projectile centerline. The ability of these fragments to penetrate steel armor is also rather limited. A typical HE filler (TNT assumed here; while this varies of course, there are so many other variables that this widely-used explosive can be used as is with little error, since we are only talking about typical, average effects) in an AP shell is under 3.51% of the projectile's weight (US Navy large-caliber WWII AP projectiles only had 1.4-1.5% filler, the least of all nations with that had AP shells using an HE-type explosive filler, but again I am not going to try to use anything but an average between the 1.4% and 3.5% filler of all "AP" shells). Assuming US Navy WWII Special Treatment Steel (STS) homogeneous, ductile full-strength armor (similar to British NCA, German Wh, Japanese NVNC or MNC, and so forth), with other plates multiplied by a relative quality factor to get a roughly equal thickness that would have the same resistance, such a small HE filler in a thick hardened-steel AP shell body would accelerate a rather large number of such fragments formed by shattering the thick sides of the shell surrounding the filler, though to a somewhat lower average velocity than with a large-cavity HE shell that has less steel and thus fewer, though faster, fragments. We are ignoring the small number of much larger, slower-moving chunks of the thick nose still moving forward, as described in (2), above, and also the very thick base plug and bottom of the shell, designed to withstand the blast of the gun propellant, that may remain almost intact or be broken into only a couple of pieces, but the blast is pushing those backwards and they essentially stop moving altogether and simply fall downward with no real speed or damage-causing effects. This acceleration, due to the AP shell's small amount of explosive and large number of such mid-body fragments, would be rather less than for a usual nose-fuzed, thin-walled, high-filler-weight HE shell, as noted above, and thus have less plate penetration ability at any given distance, though I assume that the decrease in penetration ability of these tiny fragments due to gravity and air resistance with increasing distance from the blast point is the same for all fragments from all HE-filled shells of any kind.

For the typical HE-filled shell, from studying fragmentation tests by Krupp and the US Army and Navy, I came to the following average values for the penetration of STS by such fragments at and within the 5-caliber "near-field" about the explosion point (this changes very abruptly in my approximation above 5-calibers due to the fragments no longer having the blast pressure behind them assisting them during their entire push through the plate and due to the spread of the fragments now being wide enough apart to no longer assist one-another by tearing adjacent and even overlapping holes) and in a ring of 90-degree arc-width at right-angles to the projectile centerline:

HE shell with a filler of 6-8% (very light-case bombardment and mortar shells or general-purpose aircraft bombs with larger HE fillers are not covered here, but would also be proportional, I would think, though blast effects are so much larger as to make the close-by fragment penetration of such thin plates kind of irrelevant) has a 0.156-caliber of STS penetration at right-angles, with the effect of angling of the impact the same as the COSINE of the obliquity angle -- for example, a 12" HE shell within the 5-caliber distance could punch through a 1.87" STS plate -- two-decimal places will always be the maximum used in all actual calculations, rounding off as needed -- if the fragments hit at right-angles and, if, say, the fragment hit the plate at 60-degrees from right angles (an "Obliquity Angle" of 60 degrees), the plate it could penetrate would be 1.87 x COSINE(60) = 1.87 x 0.5 = 0.94". The use of the simple COSINE approximation is due to the fragments being highly irregular in shape, so actual penetration for each fragment will vary markedly, with the COSINE being roughly in the middle of the spread of values, on the average, which is the best that can be expected in my analysis -- the occasional penetration of a slightly thicker plate at low remaining velocity is hardly ever going to accomplish anything, so I am ignoring such things.

For a Common shell -- nose or base-fuzed, it doesn't matter -- a full high-order detonation of its 3.51-5.99% HE filler will penetrate 0.135-caliber of STS at right angles, so the 12" Common shell would decrease the plate penetrated to 1.62" (less filler and more shell weight to accelerate).

An AP shell would decrease this, on the average, to just 0.113-caliber of STS or, for the typical 12" AP shell, to 1.36".

Just outside of the 5-caliber region I abruptly drop the penetration values to 0.11-, 0.095-, and 0.08-caliber for the HE, Common, and AP shells, respectively; there is no way to know how such things "ramp" between the inside and outside of the 5-caliber zone, so I just consider the 5-caliber edge a sharp cutoff point. I gradually drop the penetration versus range using as an example a US Army test of an 8" HE shell after WWII, which I smoothed between test results. Some fragments are still dangerous at a very long distance away, but they are spread over such a large area that the chance of them hitting anything is kind of small. (NOTE: I have a chart of penetration versus distance including the expected number of fragments still moving for that 8" US Army HE shell test, which I assume can be scaled linearly to other shell sizes and types by simple multiplication of shell size/8" shell size and/or by shell type multiplier given above divided by the HE shell type multiplier to adjust the values in the table to your particular shell. While only one case, this will give some idea of the expected results. This chart is found in Part 6.D of my article MISCELLANEOUS NAVAL-ARMOR- RELATED FORMULAE at the World Wide Web Site NAVWEAPS.COM.)

One further point about the penetration of steel plates by such HE-created small fragments: They are brittle and very irregular in shape (usually termed "splinters" for good reason) and when they punch through even a very thin plate, they act like a cookie-cutter and punch out a chunk of plate about the same area as the fragment surface area that hit the plate, as well as in many cases being broken into even smaller pieces by the impact. What this means is that after penetrating a single thin plate, most of these tiny sideways-thrown shell pieces will no longer have enough energy to be able to penetrate a second spaced plate, even if much thinner than the first one that they hit, with essentially none able to ever go through a third such plate, no matter how thin (but that is still of useful thickness for some purpose to the ship, of course) that this third plate is and what penetration ability they had on hitting the first plate. This greatly intensifies the damage within, but greatly reduces, the volume of space inside the target surrounding the blast point that such a shell will damage; it will do little damage due to fragmentation outside the space it explodes in and, if the surrounding plates are thin enough to allow penetration, a ring of spaces one bulkhead/deck outward to all sides. Again, I am not covering extra-large-filler bombs or bombardment/mortar shells. This is the reason that a properly designed and reliable delay-action fuze was needed to cause major deep damage by more than by a few heavier projectile nose pieces and armor fragments moving in a narrow line forward along the shell path, even in ships, such as destroyers, with nil armor. Of course, if the delay is too long, the shell would have to hit heavy armor that slows it down considerably -- or hit the ship hull lengthwise and fly down its centerline -- if it is not to simply fly through the ship like in (1), above, and explode after it exits the far side, with no filler damage effects.

Analysis of the Original Hull Protection Design of HOOD

First, that 2" roughly-30-degrees backward and downward sloped HT steel turtleback portion of the main deck armor inserted behind the 12-degrees-forward-tilted 12" waterline CA belt. This plating was roughly 45 degrees sloped if from the rear surface of the forward-tilted belt plate, which more-or-less matches the design of many earlier British battleships with vertical belts as to such a design detail. It is too thin to stop the large chunks of armor moving at high speed punched out of the belt plate if a large hole is punched completely through the belt by the impacting projectile, though it would slow down such chunks somewhat. I think that it is there for impacts that do not make such a hole ("incomplete penetrations" in US Navy terminology), where it would (1) stop such things as the armor bolts and nuts and any reinforcing plates holding the armor to the tilted 1" HT hull plate that might be broken or torn off and thrown back into the ship by the impact; and (2) impede any leakage of sea water into the ship caused by the impact deforming the supports and allowing adjacent armor plates to move apart and leak in the now-open crack between those adjacent plates. I do not know if the CA armor in HOOD corrected this, but earlier British battleship face-hardened vertical armor (and, I assume, smaller-ship armor, too) was not interconnected by armor-steel (or even merely nickel-steel) keying strips pressed into grooves on the plate edges and locking the adjacent plates together at their edges, as US Navy and German Navy plates were. In British warships, the edges were clamped tightly together solely by the hull plate, reinforced steel support straps, and the rows of bolts drilled into the soft back layer of the plates near their edges. This was found in the Battle of Jutland to be an error, since a few German shells hit the lower portion of the waterline belts of some British battleships underwater and, though they could not penetrate, they exploded due to fuze action while still next to the hull and acted like small torpedo hits, with the water behind the shell focusing the blast pressure onto the plate faces of any adjacent plates and pushing the them inward, opening up rather large cracks in the belt that caused significant flooding in that area of the ship, where a properly-keyed set of plates would have remained locked together and the crack opened would have been very much reduced in width, limiting the leakage considerably. The sloped 2" HT plate in HOOD was there to correct such things, I believe, though I would hope that by then the use of keys to lock belt armor plates together had been adopted, too.

A second effect of that sloped turtleback plate, as mentioned above, was that it replaced completely the continuation of the horizontal 3" laminated main deck out to the 12'/7" armor joint, leaving a gap in the deck armor just behind the joint and for several feet inboard. This was not true for any other deck, including the top edge of the 5"/7" joint at the upper deck level for most of the ship length and at the bottom edge of the 12" belt at the lower deck level where the lower deck provided the reinforced support for both this belt plate and the top edges of all of the vertical or sloped internal bulkheads of the anti-torpedo side-hull bulge system outboard of the main magazines and amidships propulsion plant spaces. Thus, a projectile that hit and penetrated near the lower edge of the 7" upper belt plate would hit no horizontal armor at all until after it punched through the 2" turtleback plate at nearly right-angles and then hit one or two thin internal bulkheads and finally the 1" HT lower deck forming the roof of the magazines. This decreased the protection of the magazines markedly for such a hit, compared to a hit only slightly higher on the same 7" plate that would then hit the laminated three-plate-- 0.75" over 1.25" over 1" -- 3" HT steel main deck (the closest thing to an "armored deck" in HOOD) before being able to continue downward at the same angle into the magazine; an empty slot in the ship's protection stretching along the entire Citadel length on both sides. When non-delay-fuzed and sensitive-explosive-filled shells were the threat, this really did not matter, since only chunks of 7" plate armor and of the projectile nose would hit that 2" turtleback plate and they would be slowed down enough for most of them to be stopped after hitting the various thin vertical bulkheads and the 1" lower deck -- any that got through that final 1" plate of the magazine roof would be going very slowly and would not be on fire, so the chance of those very few possible pieces setting off a magazine explosion was very remote. When delay-action-fuzed shells became the prime threat, this gap was now a critical failure, as was noted by those few German AP shells where their delays worked properly in various WWI battles -- such as against the British battleship WARSPITE when one of those many delay-action-fuzed German AP shells that hit her during the Battle of Jutland actually got a chunk of itself into one of the deep internal hull areas, which was one of the major "red flags" from the analysis of the battle that clued-in the British Navy that they were no longer fighting the same kind of naval battle envisioned prior to WWI.

HOOD's deck protection of its Citadel was designed to resist only non-delay-fuzed shells hitting the side armor, with any shallow-angle weather deck hits, even if they penetrated, never coming anywhere close to the lower hull spaces. By adding those large tilt angles to the side hull armor, especially to the 5" uppermost strake of the upper belt and upper portion of the 7" lower strake of the upper belt at about 20 degrees outward tilt (the 7" plate was bent into a curve in the vertical plane at right-angles to its face), the armor became much stronger against downward-falling AP shells even at rather close range where the shell would not be falling at much of an angle. (Soft AP caps used by the British and US Navies during most of WWI -- even after WWI for the US Navy -- failed completely at above 20 degrees impact angle from right-angles and had many failures in the 15.1-20-degree "Zone of Mixed Results", so shatter, which greatly reduced a soft-capped AP shell's penetration ability through face-hardened plate, was highly probable against even the thinnest of HOOD's upper hull armor.) The general design weaknesses of such pre-WWI AP shells to oblique impacts against face-hardened plate, even rather thin face-hardened plate and even when they did not shatter, made this design even more effective in reducing the chance of damage deep inside HOOD's Citadel region. Against an enemy using 1910 ammunition and fire-control systems, HOOD's hull armor was therefore the strongest ever used in a warship up to that time; quite a success for a "mere" battlecruiser supposedly not supposed to fight the "big-boy" battleships (and usually being destroyed when they did, as happened to four British battlecruisers and the only modern major warship, also note a battlecruiser, lost by the Germans during the Battle of Jutland to gunfire). HOOD, except for its poor deck armor, was a full-strength fast battleship when it was launched.

But HOOD or any other new warship was not going to be fighting against 1910-era warships, but post-WWI battleships with fire-control systems capable of tracking, ranging, and hitting targets up to 25,000 yards away or more so that the shells would be dropping down on the deck as "plunging fire", as well as against new hard-capped AP ammunition that would be designed to penetrate thick face- hardened armor in intact condition at angles of up to 30-40 degrees from right-angles using insensitive high explosives (British Shellite and its very similar French "Mn.f.Dn.", US Explosive "D", and desensitize or cushioned TNT mixtures by Britain, France, and Germany being the most widely-used types) that would not be set off by such impacts so that they could and would be using base fuzes with delays of 0.025-second or longer -- for example, 0.033-0.035 second delay was used by the US and German Navies for their AP shells during WWII -- so that the shell could reach virtually any internal space in the target's Citadel before exploding after penetrating the outermost armor. While the inclined side hull armor of HOOD was about as adequate at that time as most such armor could be against such threats, the horizontal protection was now lacking and some idea as to how much added deck protection would be needed and, more to the point, how much such improved protection could be added to HOOD prior to construction starting to at least partially correct this, needed to be ascertained immediately if this ship and any sisters were to be considered worth building in the 1919-1925 time-frame after the delays that had occurred in its development during WWI due to other priorities requiring attention first.

Projectiles to Be Used in Testing HOOD Armor Designs

The test projectiles used in these trials were newly-introduced British "Greenboy" (for their paint job to make sure that they were not confused with the older, inferior AP designs) post-Jutland hard-capped, 2.5%-Shellite-filled 1910-lb 15" Mark IIIA APC ("Armor-Piercing, Capped" in US Army and British Army and Navy terminology -- the US Navy just called all such "AP" with the "C" assumed in post-1900 maximum-strength anti-armor shells) or perhaps the later Mark VA APC shell of the final standardized design, both being roughly the same weight and penetrating power, with only minor changes. The document describing the tests does not give the Mark Number of the shells, unfortunately, though it probably would mean nothing in these tests, anyway.

The "A" designation indicated a new British Navy ballistic streamlining nose shape standard for all newly-designed shells, since before WWI due to the very short ranges assumed, the nose shapes of APC and Common shells made by various companies for the same guns were allowed to differ markedly, which made those older shells difficult to aim properly at longer ranges where the different drag effects became a major problem. During the 1920s and 1930s a long-nosed, more-streamlined, longer-ranged "B" shape was specified, replacing the "A" shells in many guns, though HOOD never had its shell handling systems modified to handle them, so it had to use blunter-capped "A" versions of newly-issued APC shells of otherwise similar design to the longer, slightly heavier "B" shells of those ships that were built to use them or were overhauled to do so later.

The shell used a newly-created high explosive mixture called "Shellite" that was 70% the older too-sensitive APC shell filler Lyddite thoroughly mixed with 30% of the much less sensitive and much weaker high explosive dinitrophenol (a chemical made much the same way as picric acid, but not charged with as much nitrogen in its molecules, so it had less energy available for its explosions). This mixture would not explode or otherwise degrade on impact with a face-hardened plate as long as the projectile cavity was not crushed or broken apart. It was about as powerful as US Explosive "D", that is, about 90% as powerful as TNT, whereas the old Lyddite filler had been 10% more powerful than TNT. Shellite could be set off by a black-powder booster at the tip of the shell just like Lyddite (allowing the older base fuze, the Number 16, to be modified with a circa-0.025-second delay element as the new Number 16D base fuze with no other change), but tests I have seen showed that this was not reliable in giving a maximum-power detonation or even sometimes more like a violent explosion such as black powder gave and during WWII a tetryl (British terminology "Composition Exploder" or "CE") booster was finally employed with large-caliber Shellite-filled APC shells just like it had been used with the post-WWI TNT/beeswax fillers of the 6" and 8" British cruiser anti-armor shells for many years . This seems to have finally made Shellite as reliable in its explosive power as the TNT mixtures were. Note that the two fuzed and Shellite-filled APC shells that exploded during these tests had rather widely different effects, one seemingly a full-power detonation and the other a mere burst not much different from a black-powder-filled shell; the use of black powder as a booster did not really work well with Shellite.

These shells had hardened AP caps that functioned at any obliquity where they hit the CA plate first and that in these tests completely protected the nose of these 15" APC projectiles even when punching through 7" CA armor at 40 degrees obliquity, which is extremely high quality as to projectile design for this time-frame. German tests at 30 degrees were the previous best shell tests, but this was only for half-caliber armor (for example, 7.5" for a 15" shell) and the British shells exceeded that by 10 degrees. Also, a US test at about the same time of a new British 14" APC shell made to the same design spec was found to be able to penetrate a 13.5" US Class "A" face-hardened plate at 30 degrees and also remain intact, which far exceeded the ability of any other AP-type shell that I know of at that time. These new British APC shells were about the best there were during the 1920s and early 1930s, to my knowledge.

These shells in the following tests were either full-up Shellite-filled and delay-action-fuzed Service shells or inert-filled shells used solely to test penetration of the projectile when not interfered by a filler explosion. The two filled/fuzed APC shells that both exploded more-or-less as designed here, though the distances moved into the mock-up target show a very long delay, much longer than specified by any non-WWII-Japanese AP shell. These are only two tests, so it does not prove that the British shells used a longer delay, especially due to the atypical extra-long delays that occurred -- that would need more test results.

Testing of Mock-Ups of HOOD Armor Protection for Determining Possible Improvements

These tests are described in detail in the British Navy DIRECTOR OF NAVAL ORDNANCE document SUMMARY OF "HOOD" TRIALS FOR INFORMATION OF POST WAR QUESTIONS COMMITTEE dated 26 September 1919.

It was determined that the main 12" inclined CA belt was adequate for protection of the waterline from the side, even from the latest British 15" APC shells, at most expected battles ranges, so the test mock-ups were limited to:

(1) for deck protection only, where the shell came down above the upper side belt armor, here ignoring the 5" uppermost strake and forecastle deck since the aft magazines did not have this extra protection, hitting the upper deck just inboard of the upper edge of the 7" CA plate, then hitting the main deck as designed, and finally hitting the lower deck roof of the magazine, which was thickened to a 2" solid HT steel plate in all of these tests, then repeating this test twice more with the main deck reinforced two different ways; and

(2) for penetrations of the 7" lower strake of the upper side belt (again, the 5" upper strake did not exist over the aft magazine so it was left out here too) and then through the main deck level, hitting the current 2" turtleback plate in one test before hitting the original 1" HT steel magazine roof portion of the lower deck armor, then repeating the test using a thickened solid 2" HT steel magazine roof plate (the lower deck over the anti-torpedo side protection system one each beam remained 1"), and then again attempting to hit the magazine roof in a third test, but here with an added 3" solid (not laminated, as in the main deck inboard of the 2" sloped region) HT steel extension of the main deck armor to cover the gap between the back of the main waterline belt and the top edge of the 2" turtleback plate, which now had to be penetrated before going through the 2" turtleback plate and into the 2" HT lower deck over the magazines again.

A. Deck-Only Tests

Study of a diagram of the amidships region over the forward magazine, where the 5" upper strake and forecastle deck covered the forward magazine, showed that for an enemy ship shooting at HOOD from directly broadside to HOOD (at a relative bearing of +/-90 degrees from HOOD's bow) and HOOD not rolling or listing, the minimum angle of fall had to be 25 degrees to miss the upper edge of the near-side 5" upper belt plate and penetrate the forecastle deck just inboard of it, then proceed in a straight line through all of the other decks and hit the lower deck magazine roof on the far side of the ship just where it ended and the far-side anti-torpedo system began. Thus, tests for deck-only penetrations to hit the magazine space should be at a steeper angle of fall. As mentioned, it was also decided to leave out the 1" HT forecastle deck altogether, since it did not exist over the aft magazine.

The as-designed HOOD main deck Citadel protection is a built-up 3" HT steel deck made up of laminating 0.75" over 1.25" over 1", as mentioned above. Such a plate is significantly weaker than a solid 3" plate of the same steel against AP shell penetration, though stronger as a construction deck if the joints are spaced in a staggered manner so that no single-plate failure during a heavy storm, say, can crack the entire deck through. The two mods tested were (1) adding a top plate of 2.5" homogeneous, ductile NCA steel (the same plate type used for British turret roofs) laminated to the 0.75" top-most HT plate layer (though bolted entirely through all three of the HT plates), and (2) replacing the NCA plate with a solid 3" mild construction steel plate (somewhat softer and weaker than HT steel and used for non- critical internal hull and superstructure plates in HOOD and most plates in non-military ships).

For reasons not given, it was decided that the deck-armor-only tests would be simulating the 15" guns on, say, WARSPITE or on HOOD itself at a range of 25,500 yards, near the maximum range that a hit was considered to be possible (this turned out to be true even in WWII with much better fire-control and even radar assistance). The simulated angle of fall was 32 degrees, giving an impact obliquity if not deflected of 58 degrees from right-angles to the flat deck plate face, and the striking velocity was 1350 ft/sec. All projectiles in these tests were inert-filled.

For the above impact conditions, the 2" solid HT steel simulated upper deck was spaced 17.5-18.5', depending on the test, from the simulated main deck and then another 13' from the main deck to the 2" solid HT steel simulated magazine roof (they assumed that the thicker, improved magazine roof used in the final 7" upper belt magazine protection tests would replace the original 1" HT steel magazine roof, which actually occurred in the final HOOD design as completed). This arrangement seems to indicate that the between-deck gap is significantly wider, 9.25', above the main deck than below it, 6.9'. The diagram of HOOD's decks does seem to indicate that there is a difference, though the sizes of the various gaps is not easily measured from that diagram.

The results of the tests were that the projectiles completely penetrated all of the spaced plates and buried themselves deep in the ground. Only one shell was recovered and it was completely intact, minus its windscreen and AP cap. The other two shells made neat round holes in the ground and were assumed to also be intact. The HOOD deck protection, even when beefed up to double-thickness by added thick laminated plates (one being the strongest homogeneous armor made by Britain at the time), was completely ineffective in stopping these shells. The only possible hope would be that the forward magazine, with its added 17.5' or so from the forecastle deck to the upper deck would be enough to cause the fuze of the projectile to go off prior to reaching the magazine roof, assuming that a 1" HT steel deck hit at 58 degrees obliquity would be enough to set off the base fuze of a 15" shell with a British Navy Number 16D base fuze set to its delay configuration, which is highly probable, though I am not sure of the forces needed to set off WWI-era British base fuzes.

A point noted in these tests were that in two of the tests, the projectile was only slightly deflected as it penetrated, even by the thick main deck plates, but in the case of the 6"-thick built-up plate using the 3" mild steel plate top layer, the projectile was deflected about 15 degrees toward the normal and thus hit the last plate at a steeper, less-oblique angle than in the other two tests, so it actually went a somewhat shorter distance to the last plate than those other tests did and hit that last plate near its edge instead of near the center. They noted no such deflection with the 2.5" NCA plate test, though my calculations give an appreciable deflection here also.

My deck armor penetration calculations using my latest corrected HCWCALC Revision 6 computer program dated June 11 2019 are as follows, for comparison to the actual results:

Assumed:

> 2" HT had a quality factor of about 0.8 compared to US WWII average STS armor and, as a rough guess, a Percent Elongation of about 22%, better than armor at that time, but not as stretchable as mild steel. It was a mild steel that had a small percentage of nickel added for increased toughness and thus could be hardened to a higher strength level than regular mild construction steel of the time; there were no other changes to its alloy, to my knowledge, and thus it was not as strong as the highest-grade High Tensile Steels in use in some other nations, such as the US with its HTS, which was never allowed in areas needing armor protection, or Krupp with its Low-% Nickel Steel, also used as a light armor, both with about 0.85 quality. In 1920, British Colville Company "D" or "D1" -- "DuCol" was the manufacturer's trade name for it -- extra-high-strength steel for construction and light armor with a quality assumed to be 0.9, replaced HT steel through WWII, though not used in HOOD (it was also adopted by Japan).
>
> 2.5" NCA had a quality factor of about 0.95 compared to STS and had a Percent Elongation of only 19%, the same as US WWI-era STS or Class "B" armor (Krupp homogeneous armor spec required 18% minimum, as a further comparison) -- this compares to the better WWII homogeneous, ductile armors, most with 25%.
>
> 3" mild steel had a quality factor of about 0.7 compared to STS and a Percent Elongation of roughly 25%, due to lower hardness requirement (not sure about this, but assuming this effect is nil).

Only the top-most layer in a laminated array needs a Percent Elongation given in the calculations using my approximations in HCWCALC, with the later plates only being reached after the top plate is torn through, with less effect from this variable. This value, if under 25% (the minimum allowed is 15%), has an added scaling effect against larger and larger projectiles that degrades the armor's resistance against such projectiles, with the lower this value, the greater the drop, and with a floor value reached with the largest shells of 18" and up. It is based on tests by Krupp of its WWII Wh homogeneous, ductile armor, with its 18% spec, compared to otherwise very similar US and British armor with 25% for this variable. (Trying to include it for the underlying support plates of different materials, here HT steel, would greatly complicate the calculations, which are only a rough approximation anyway.)

Effective thickness per plate:

> 0.75" Solid HT steel = 0.6" STS
> 1" solid HT steel = 0.8" STS
> 1.25" solid HT steel = 1.0" STS
> 2" solid HT steel = 1.6" STS
> 3" solid HT steel = 2.4" STS
>
> 0.75"/1.25"/1" laminated HT steel original main deck plate:

$$T1 = (0.75 + 1.25 + 1) \times 0.8 = 3 \times 0.8 = 2.4$$
$$T2 = [(0.6)^{1.4} + (1)^{1.4} + (0.8)^{1.4}]^{(1/1.4 = 0.71429)} =$$
$$[0.4891 + 1 + 0.7317]^{0.71429} = [2.2208]^{0.71429} = 1.768$$
$$Tlam = [T1 + T2]/2 = [2.4 + 1.768]/2 = 4.168/2 = 2.08\text{" STS}$$

2.5" solid NCA = 2.375" STS
3" solid mild steel = 2.1" STS

2.5" NCA/(0.75"/1.25"/1" HT) modified main deck plate:

$T1 = 2.375 + 2.4 = 4.775$
$T2 = [(2.375)^{1.4} + 2.2208]^{0.71429} = [3.3568 + 2.2208]^{0.71429} = [5.578]^{0.71429} = 3.413$
$Tlam = [T1 + T2]/2 = [4.775 + 3.413]/2 = 8.188/2 = 4.09$" STS

3" mild steel/(0.75"/1.25"/1" HT) modified main deck plate:

$T1 = 2.1 + 2.4 = 4.5$
$T2 = [(2.1)^{1.4} + 2.2208]^{0.71429} = [2.8256 + 2.2208]^{0.71429} = [5.046]^{0.71429} = 3.178$
$Tlam = [T1 + T2]/2 = [4.5 + 3.178]/2 = 7.678/2 = 3.84$" STS

T1 is thickness as though a single solid plate. T2 is as though the plates were spaced slightly apart so that they did not support each other and the projectile was not deflected during the penetration of all of them. Here, the De Marre Nickel-Steel Penetration Formula approximation is used, since it is not too far off the real quality-adjusted penetration curve for most thicknesses of plate used in laminated structures. The "split-the-difference" approximation was verified as pretty good for undamaged, bare-nosed, pointed AP projectiles in a series of WWII tests of various laminated US Army Rolled Homogeneous Armor (RHA) plates up to 1" thick per plate fired at by 0.5"-caliber M2 AP bullets at several different obliquities -- the results gave an average that matched my De Marre approximation rather well (luckily!). It does not work for very blunt bare-nosed projectiles, such as flat-nosed or tapered-flat nosed designs. A blunt AP cap will possibly give incorrect results, but if the cap is knocked off and/or broken/shattered as it goes through the plate, this error is reduced. My results are at least as good as the approximations used by the US Navy for two-ply laminated deck armor in the WWII document BuOrd Ordnance Pamphlet ORD.-653, "ARMOR: Armor Penetration Curves".

The first two 2" HT steel upper deck plate impacts were at 58 degrees and 1350 feet/second; the mild steel modified impact was at a slightly higher 1373 ft/sec. This plate will strip off both the ~3% weight windscreen and the ~7% weight hardened AP cap (these weights will vary somewhat depending on the projectile type and the manufacturer, neither of which we know; this is close enough) from the 1910-lb 15" APC shell, leaving a 1719-lb bare-nosed, medium-point projectile. Later "A" shells had a thicker, heavier AP cap and blunter pointed nose, though the windscreen was about the same weight.

First unmodified test impact:

2" HT (1.6"-equivalent STS) upper deck, then the original laminated 3" HT (2.08"-equivalent STS) main deck, then the 2" HT (1.6"-equivalent STS) lower deck/magazine roof.

1910-lb 15" AP shell with AP cap and windscreen; 1719-lb without them. Angle of obliquity on upper deck 58 degrees at 1350 ft/sec (25,500 yard range).

UPPER DECK RESULT: COMPLETE PENETRATION. 1719-lb bare-nosed AP shell moving at 1236 ft/sec at a new angle of fall of 33.8 degrees that gives an obliquity of 56.2 degrees against the main deck plate.

MAIN DECK RESULT: COMPLETE PENETRATION. AP shell moving at 1093 ft/sec at a new angle of fall of 41.3 degrees that gives an obliquity of 53.2 degrees against the lower deck plate.

LOWER DECK RESULT: COMPLETE PENETRATION. AP shell moving at 972 ft/sec at a new angle of fall of 43.9 degrees.

Matches test result. No deflection values given in document. The final calculated deflection was 11.9 degrees.

Second 2.5" NCA-modified test impact:

2" HT (1.6"-equivalent STS) upper deck, then the NCA/HT laminated 5.5"plate (4.09"-equivalent STS) main deck, then the 2" HT (1.6"-equivalent STS) lower deck/magazine roof.

1910-lb 15" AP shell with AP cap and windscreen; 1719-lb without them. Angle of obliquity on upper deck 58 degrees at 1350 ft/sec (25,500 yard range).

UPPER DECK RESULT: COMPLETE PENETRATION. 1719-lb bare-nosed AP shell moving at 1236 ft/sec at a new angle of fall of 33.8 degrees that gives an obliquity of 56.2 degrees against the main deck plate.

MAIN DECK RESULT: COMPLETE PENETRATION. AP shell moving at 714 ft/sec at a new angle of fall of 45 degrees that gives an obliquity of 45 degrees against the lower deck plate.

LOWER DECK RESULT: COMPLETE PENETRATION. AP shell moving at 643 ft/sec at a new angle of fall of 47.8 degrees.

Matches test result. No deflection values given in document. The final calculated deflection was 15.8 degrees from its original angle of fall in three steps, with the main deck having an 11.2-degree refraction. A deflection similar to this must have happened in the actual test, but perhaps a circa-10-degrees deflection at one time was considered nothing special (as it should be).

Third 3" mild-steel-modified test impact:

2" HT (1.6"-equivalent STS) upper deck, then the mild steel/HT laminated 6" plate (3.84"-equivalent STS) main deck, then the 2" HT (1.6"-equivalent STS) lower deck/magazine roof.

1910-lb 15" AP shell with AP cap and windscreen; 1719-lb without them. Angle of obliquity on upper deck 58 degrees at a slightly higher 1373 ft/sec striking velocity (either at a slightly lower range than the 25,500 yards used in the prior tests or just a known variation in muzzle velocity being simulated).

UPPER DECK RESULT: COMPLETE PENETRATION. 1719-lb bare-nosed AP shell moving at 1260 ft/sec at a new angle of fall of 33.7 degrees that gives an obliquity of 56.3 degrees against the main deck plate.

MAIN DECK RESULT: COMPLETE PENETRATION. AP shell moving at 657 ft/sec at a new angle of fall of 46.4 degrees that gives an obliquity of 43.6 degrees against the lower deck plate.

LOWER DECK RESULT: COMPLETE PENETRATION. AP shell moving at 604 ft/sec at a new angle of fall of 49.4 degrees.

Matches test result. The final deflection was 17.4 degrees from its original path in three steps, with the main deck having a 12.7-degree refraction. The deflection noted in the actual test was about 15 degrees at the main deck, where I got a slightly lower value. If they were measuring the main deck exit angle from 90 degrees minus the original simulated angle of fall, then if you add my 1.7 degrees at the upper deck, the total is 14.4 degrees, almost exactly their measure after exiting the main deck. "Good enough for government work..."

B. 7" Upper Belt and Main Deck Tests

These tests were against the 7" CA lower strake of the upper belt, plus its 1" of cement and 1" HT hull mounting bulkhead it was laminated to, between the upper and main decks at 40 degrees, simulating a hit at a 20 degrees angle of fall and 1430 ft/sec for a 19,500 yards range against that plate where it was tilted 20 degrees outward, matching the tilt of the 5" CA top strake of the upper belt (lower hits would reduce the obliquity more and more down to the 12 degrees of the waterline 12" CA belt). The hit simulated a shell going through that plate from a ship located at right-angles to the near side of HOOD, then passing through the level of the main deck -- initially with the empty gap between the 2" HT sloped "turtleback" plate and the back of the 12" CA main belt and then with an added 3" solid HT steel horizontal deck plate closing the top of that gap, extending the main deck to the back of the joint between the 12" and 7" CA side plates, retaining the turtleback plate, too -- then passing through a 0.75" HT vertical bulkhead parallel to the hull side, and finally hitting the 1" HT original plan and then, later, the 2" upgraded HT roof of the magazine.

The first two of these tests were with live Service rounds with active Number 16D base fuzes and Shellite fillers. The last test was the one with the 3" HT main deck extension, as well as the 2" HT magazine roof improvement; it used an inert-filled projectile, like the deck tests.

The first test, with the original 1" magazine roof, went directly through all of the plates in roughly a straight line and detonated at a point several feet behind the magazine roof, indicating a catastrophic hit in a real battle (similar to what happened to HOOD in real life, regardless of the actual path of BISMARCK's shell into HOOD). The shell went 40 feet inside the simulated ship.

The second test, with the upgraded 2" HT magazine roof, only went 34 feet after penetrating the back of the 7" upper belt plate, also going through the simulated 2" HT turtleback plate, the 0.75" HT vertical bulkhead plate, and then blowing up as it hit the magazine roof plate, blowing that plate to pieces. The explosion of the shell was rather low-power compared to the first shell's detonation (called merely a "burst") , but quite enough to blow up the magazine since it punched through the magazine roof plate on the lower deck in the process of exploding.

With these two rather negative tests on HOOD's protection, the 3" HT main deck extension upgrade was made and a third test, just like the last two failures, was performed. Again the projectile punched through the middle of the simulated 7" CA upper belt plate at 40 degrees with no damage (it lost its AP cap and windscreen, of course) and then slammed into the 3" solid HT plate simulating the improved horizontal main deck, above and in front of the sloped turtleback plate, which was also retained in the final design. The impact obliquity on the deck extension would have been at least 70 degrees, plus whatever upward deflection the simulated down-facing 7" CA plate caused. The shell bounced off of the 3" plate, denting it considerably, and ricocheted away from the test setup. The first success in these trials! This change was added to the final plans, in addition to the 2" solid HT lower deck over the magazines, with some secondary guns, torpedo tubes, and a few other things removed to compensate for the added weight.

HMS HOOD: British 1919 Tests on Upper Belt and Deck Armor

by Nathan Okun

NOTE: THIS HIGHLY-EFFECTIVE MAIN DECK EXTENSION WAS **ONLY** ADDED ABREAST THE MAIN MAGAZINES, **NOT** ABREAST THE LENGTH OF THE AMIDSHIPS PROPULSION PLANT, WHICH RETAINED THAT GAP IN THE MAIN DECK BEHIND THE BELT ARMOR IN FRONT OF THE 2" TURTLEBACK PLATE. As mentioned elsewhere, the large propulsion plant was not considered worthy of the great weight of deck armor needed to protect it like the magazines, due to its high degree of redundancy if partially damaged.

Using my FACEHARD Version 8.0 program, the impact on the WWI-type 7" CA armor with a standard 1910-lb GREENBOY 15" Mk 3A or regular (not improved "blue band") Mk 5A APC shell at 40 degrees and 1430 ft/sec striking velocity, resulted in the shell being undamaged, though being reduced to a 1719-lb bare-nosed projectile, and exiting the plate back at 634 ft/sec (along with a lot of plate chunks moving at a similar velocity) deflected upward by 9.22 degrees, so that it now has an effective angle of fall of 10.78 degrees, which would also be the impact obliquity on a vertical side hull plate. Against a horizontal deck plate, the impact obliquity would be 79.22 degrees, barely within the allowed penetration obliquity angle in HCWCALC. This is the impact obliquity and striking velocity that it hit the 3" HT extended deck plate in the third test.

Against the 30-degree back-tilted 2" HT turtleback plate, without that 3" deck extension, the impact obliquity is 19.22 degrees below the normal line projecting out the plate face, thus any deflection during penetration is going to be downward and increase the simulated angle of fall against the next plate in line, the 0.75" HT vertical bulkhead. The projectile punches through the 2" turtleback plate with a 1.5-degree angle of fall increase to 12.28 degrees at 581 ft/sec. This is the impact obliquity that it hits the 0.75" bulkhead at.

After penetrating the 0.75" HT vertical bulkhead, the projectile is moving very slightly slower at 569 ft/sec and with a slightly lower angle of fall of 11.98 degrees. This is the velocity that it hits the magazine roof plate at an obliquity of 78.02 degrees, again barely within the automatic ricochet maximum of 80 degrees. The shell cannot penetrate even a 1" HT steel plate at this high obliquity and at that striking velocity, which is not reflected in the actual test, where the shell did so penetrate.

Something is not correct in my analysis of these side hit tests using the default plate data.

The straight-line distance (no deflections during penetration of any plate) from the back of the 7" CA plate to the detonation point inside the simulated magazine in the first test using the original armor design, was given as about 40'. If the 7" CA plate (0.76' thick at 40 degrees obliquity) was of somewhat low quality (an old scrap plate from the proving ground salvaged for this test, perhaps), and the Remaining Velocity after penetrating was 800 ft/sec, then the delay, if the other plates subtracted no velocity (impossible, of course), would have to be 40.76/800 = 0.051 second. Since the projectile, even with minimal deflection, is going to be moving somewhat less than this due to the 2" HT slope + 0.75" HT bulkhead + 1" HT lower deck, especially after penetrating the lower deck at 70 degrees obliquity angle, it is obvious that the delay of this shell was much longer than the average used of 0.025-0.035 second for almost all nations after WWI (except Japan with their long-underwater-path diving AP shells having a 0.2-0.4 second delay from 1928 on). Thus, the long distance moved before detonating behind the 7" CA plate in the first test is not going to be typical of most British APC shells used during the last couple of years of and after WWI. The second test, where the shell reached 34' and blew up on the lower deck magazine roof plate, would have had a 0.042-second delay with this 800 ft/sec velocity; again well over the usual design average for such a base fuze. The reason that you did not want such long delays inside your target after being set off on the nearest plate to your gun on the enemy ship is that the shell if it hits thinner armor or just a construction plate thick enough to set the fuze off, then the shell will be moving at a quite high velocity after penetrating such thin plating and could easily pass out the far side of the target before exploding, with much reduced effect (this is why shooting AP shells at destroyers is not the best use of your ammunition in cruisers or battleships, if you have any other choice). This being the case, I am going to ignore the fuze delay in this analysis from now on.

For an average 1" HT steel plate hit at 70 degrees (no deflection from prior plate hits), the minimum striking velocity to completely penetrate nose-first with the 15" AP shell being used here is 575 ft/sec. There is a slightly lower velocity for such thin plates at this high obliquity angle where the nose begins to be deflected away from the plate, but in the process the cylindrical base region of the shell slams down on the plate into the long torn-open slot made by the nose and upper body and punches through, riding like a surfboard in the slot until it hits the end and either flips out upward or tumbles downward through the plate at a very low velocity and random direction (the fuze will never be set off by such a base-first penetration, so to work it must have been set off by a prior impact). The first test did not indicate any such base-first penetration, however.

To get the results of the first test (again, ignoring the extra-long fuze delay), you will need a projectile hitting the lower deck plate at close to 70 degrees obliquity and at above 650 ft/sec. If the obliquity gets much higher, the US Navy Ballistic Limit (NBL), which is the estimated minimum striking velocity for a complete penetration of the shell or most of its pieces entirely through the plate, for the plate goes up rapidly to over 900 ft/sec at about 80 degrees, which is not possible for this scenario. This means keeping the upward deflection at as close to zero as possible, at most about 5 degrees, due to the 20-degree-sloped 7" CA plate hit at a simulated 20 degrees angle of fall, giving a 40-degree obliquity, since a higher upward deflection (almost 10 degrees in my prior unsuccessful analysis above) makes the impact obliquity and hence NBL of the lower deck plate too high. If the striking velocity gets much lower, noticeable deflection occurs when tearing through the lower deck plate, making a long, canoe-shaped dent with a torn-open slot at its bottom. This deflection was not noted, though some deflection may have occurred and been ignored as not significant.

For a 5-degree deflection at the 7" CA plate, if unchanged by the 2" sloped plate, the impact obliquity on the 1" lower deck plate goes up to 75 degrees and the nose-first NBL (I am ignoring the base-first NBL since that did not happen in the test) becomes 745 ft/sec, a considerable increase.

What does it take to keep the 7" CA plate deflection to near 5 degrees? Let us do some calculations. We already know that the average WWI British 7" CA plate hit at 40 degrees with a 1" HT back and a 1" cement layer hit at 1430 ft/sec by the 15" AP shell will give a deflection of 9.22 degrees. to get that down to 5 degrees, with the 2" sloped plate causing a small downward change to this, needs the plate quality dropped significantly. Here goes. If we drop the plate quality to that of a 6" plate, with a 0.857 quality, we drop the deflection to 5.98 degrees and the Remaining Velocity to 825 ft/sec.

If the same 5.98-degree deflection and 825 ft/sec striking velocity is used against the 30-degree sloped 2" turtleback plate, that plate is hit at 15.98 degrees obliquity rather than 10 degrees. Using these numbers, the Exit Angle Deflection is 0.7 degrees, causing the obliquity angle on the lower deck plate to become 75.28 degrees and the Remaining Velocity is 786 ft/sec.

We can ignore the 0.75" HT vertical bulkhead hit at about 15 degrees obliquity as having no real effect on the result (at most about a 0.2 degrees deflection and 5 ft/sec reduction in striking velocity on the lower deck plate). We will simply change the impact obliquity on the lower deck plate to 75.5 degrees and the striking velocity to 780 ft/sec.

Using the 75.5 degree obliquity and 780 ft/sec striking velocity the projectile penetrates the 1" HT plate with only a 3-degree downward deflection and a Remaining Velocity of 610 ft/sec. This matches the test result perfectly.

We can tweak the value of the plate quality upward slightly and still match the test result, but not by much, since the effect of increasing the impact obliquity at such a high obliquity is huge. At most, maybe we can increase the plate quality up to 0.88 or so; acting like a 6.16" average-quality WWI CA plate.

Such a face-hardened plate is within, though near the edge of, the typical plate-to-plate quality variations of most such armors at that time. Indeed, British acceptance tests had TWO minimum striking velocity values where no through crack must be made in the plate: The regular one for the desirable standard plates (the one I use in FACEHARD) and a lower one where the plate would still be accepted, but at a lower cost to the Admiralty (the US Navy had no such double standard). This does make it more difficult to analyze British warship protection, since there is no way to tell what quality plate is mounted on any given part of any given ship. If the plate is one of the low-cost plates that they had at the proving ground and decided to use up in these tests, which is reasonable, as this is not a test of the latest 7" CA armor, then it can very easily be at 0.88 quality without any need to fall back on older, inferior armor types. Note also that the quality of the HT plates can vary somewhat and thus this can soak up some of the needed variation otherwise being applied to the 7" CA plate. Almost all of our above computations have been in trying to match the penetration results on that 1" lower deck plate hit at above 70 degrees, where even small obliquity changes have large effects on the NBL. We do not know how accurate the mock-up was made or if the plates could shift a little when hit. At low obliquity, this is not a big deal, but here the effect on the simulated 1" lower belt can be huge, negating all of my computations.

In the second test, with the 2" HT magazine roof, the required striking velocity would go up and perhaps the plate could not be directly penetrated, but the actual test had the shell explode while tearing a long slot in the plate, destroying the plate, so this test did not show this either way.

In both tests one and two, a standard fuze delay would have precluded either shell from reaching the magazine roof after punching through the 7" CA upper belt plate, though the 1" magazine roof was inadequate to stop the high-speed fragments created if the shell detonated correctly nearby. The 2" plate upgrade was definitely needed for this reason.

To try to penetrate that 3" solid HT steel main deck gap-closing extension plate at about 70 degrees with the decapped 15" AP shell, assuming a worst-case 0.88-inferior-quality 7" CA upper belt plate, equal to a 6.16" CA plate, to minimize the deflection angle over 70 degrees, we get a striking velocity of 805 ft/sec and an obliquity of 76.26 degrees. To penetrate this plate at that obliquity requires a striking velocity of 1476 ft/sec for a base-first penetration and 1568 ft/sec for a nose-first penetration. Both are well above the Remaining Velocity of the 0.88 CA plate, so penetration is impossible, as shown in the actual test result. The 7" CA plate quality is of no consequence in this test.

Testing of Selected Mock-Ups of HOOD Armor Protection using BISMARCK Shells

BISMARCK projectiles were 38cm Psgr.m.K. L/4,4 (14.96 in Armor Piercing High Explosive Shell with AP Cap Length/4.4 calibers). It weighed 1764 lb and had a 13.5% AP cap and a 1.5% aluminum windscreen, so the shell weighed 1737 lb with no windscreen and only 1500 lb with a bare nose.

Only these late-model Krupp AP shells had non-steel windscreens, nobody else used them. They were designed to shatter on impact with virtually anything to make sure that an oblique impact against steel plate too thin to usually knock off the AP cap of the shell would not use the leverage of a long steel windscreen as a "crowbar" on highly oblique impact to crack the solder holding the AP cap on.

The closest approximation by any other nation was the especially-weakened threads of Japanese WWII Type 91 and later Type 1 AP shell windscreens. This made the windscreen be knocked off on impact with water and allow the now-blunt-nosed shell to dive underwater at lower angles of fall than a more pointed shell with an intact windscreen could, hitting an enemy battleship, for example, below its armor belt. Since two such hits occurred during the BISMARCK's fight with HOOD and PRINCE OF WALES, one by BISMARCK on PoW that was a dud and one by PoW on BISMARCK that blew up against the inner holding bulkhead of BISMARCK's anti-torpedo side system and caused a slow leak, this kind of design, if not compromising anything else, would have been a good idea. Unfortunately, it was combined with an enormously-long fuze delay to allow a long underwater travel distance and this meant that a number of hits on US ships that might have caused serious damage only made cannon-ball-like holes of minimum damage and, to make things worse, it only worked properly once during WWII, to my knowledge, but the large hole in the lower portion of the magazine of the US ship so hit -- USS BOISE hit by a Japanese 8" Type 91 AP shell -- sprayed high-pressure water into the magazine and, though the magazine and surrounding ship area burned up eventually, the self-dousing shell hit failed to do what the designers had expressly made it for, which was to blow up the ship.

Krupp AP caps used a unique, extremely-high-strength solder to attach its AP caps to its AP projectiles (from the C/11 designs introduced in 1911 that could remain attached up to 30 degrees obliquity, when previous Krupp AP caps and all other nations' naval projectile AP caps would not remain attached at over 20 degrees obliquity and were torn off about half the time in the 15.1-20-degree Zone of Mixed Results). It took hitting a steel plate (any kind at any angle of impact) 0.2-caliber or more (3" for the BISMARCK AP shells) to decap a Krupp naval AP or capped Common shell from 1911 through the end of WWII (except some late-WWII Krupp 40,6cm (16") Psgr.m.K. L/4,4 coast defense gun shells that, due to wartime metal shortages, used a strong rubber cement to hold on the AP caps about as well as non-Krupp AP shell caps). Most other capped shells in WWI and WWII could be decapped by a hit against a 0.0805-caliber steel plate at any obliquity angle (1.2" for a BISMARCK-size shell), from many US Navy tests of its own and US Army capped AP sells. The one known non-Krupp exception to this rule was some WWII US Army capped AP shells that used a higher-strength high-temperature solder that doubled the needed thickness to decap them, depending on the manufacturer of the given shell batch tested -- it seems that various WWII shell manufacturers just continued to use whatever kind of solder that had been used on their civilian products that met the minimum spec. Why Krupp worried about this so much compared to anyone else is unknown to me.

Krupp used a version of the British-introduced late-WWI Firth Company "Knob-and-Ring" AP cap, with a dome-shaped bulge in the center and a wide, almost flat "brim" ring with the windscreen screwed into its close-to-right-angles edge. Most other AP caps had a cone or shallow dome shape as their forward face, with the US WWII designs sometimes having a raised flat-faced "meplat" in the center where the dome of the Krupp cap was. This made the Krupp AP cap much blunter than most others. Again, the Japanese Type 91 and Type 1 AP shells were even flatter, since when the windscreen was knocked off, the tip of the nose or, in the larger capped versions, AP cap also was knocked off, leaving a flat forward face 0.68-0.69-calibers wide, with half the flat area of the entire projectile cross-section; enough to keep the nose moving forward nose-first by reducing sideways turbulent drag forces, but small enough to minimize that drag to allow a long underwater trajectory before the base fuze exploded the shell (the fuze was set off on water impact). Due to this very wide and very flat AP cap side region, on armor impact at high obliquity the late-model Krupp AP cap will dig deeper into a homogeneous, ductile armor or construction steel plate before it shatters or breaks up, so that these caps have an enhanced ability to penetrate thinner plates -- this is not as good as the US Navy WWII AP projectiles, which were extremely blunt-pointed or even oval-nosed, so they had this increased effect even after the cap was removed during the impact, but should give them an enhanced value in the HCWCALC logic. I would estimate that when HCWCALC asks for the AP cap Edge Effect that has -12% enhancement by decreasing the NBL, with this kind of Krupp AP cap you should choose -15%.

These late-model Krupp caps are also very hard on their face and for a short depth into them, at up to 627 Brinell Hardness Number (BHN), but this was replaced by a thick layer of soft steel surrounding the nose itself under the cap, with only the late-WWII US Navy 6" Mk 35 MOD 9 & 10 or 8" Mk 21 MOD 5 AP shells with their Triple-Alloy caps of 650-680 BHN having much higher hardness that extended through the entire cap from the face to where it contacted the projectile nose surface at all points, for increased effect against face-hardened plate, but this also resulted in these US AP shells having inferior effects at under 45 degrees against homogeneous, ductile armor due to the caps shattering more quickly on impact with any thickness plate.

The Krupp AP shells used by BISMARCK are at least as strong as the British shells used in these trials, so they would usually remain intact under the impact conditions of these HOOD tests. The shells used a base fuze with a "graze" design to increase the impact of obliquity where reliable fuze action on armor impact would be expected, here maybe up to 70 degrees. The fuze delay was a nominal 0.035 second, though it would probably have about 10% or so duds (hit on PoW, for example), and maybe only 60% of the rest of the shells would have a delay between 0.03 and 0.04 second, with the other 30% being outside this range in a bell-shaped curve decreasing in probability from 0.03 to 0.003 second (this last is no delay) or from 0.04 to 0.06 second, extra-long delay. The number of duds might be larger since there was a lot of sabotage by slave labor in WWII German factories, but that would only matter for newer shells, not those already made before WWII.

The BISMARCK's 38cm/52 C/34 guns had a muzzle velocity of 2690 ft/sec.

The HOOD protection trials given here were for 20 degrees angle of fall and 32 degrees angle of fall, which the information I have ion when HOOD was sunk was when it was 14,000 m or so from BISMARCK, which is about 15,300 yards, though this may be as high as 15,700 yards or as low as 14,900 yards.

Here is the ballistic data fior these three ranges from BISMARCK's own range table in the German Navy Document G.Kdos. 100 (Secret Command Document #100):

Muzzle Velocity: 2690 ft/sec

32-degree angle of fall: 33,140 yards, 1503 ft/sec
20-degree angle of fall: 25,000 yards, 1591 ft/sec
9.8-degree angle of fall: 15,300 yards, 1913 ft/sec (gun elevation 7.5 degrees)

Note how flatter the German gun's trajectories are compared to the British 15"/42 guns with their 2475 ft/sec muzzle velocities.

There is no reason to even do the 32-degree tests, since they are way beyond the maximum ranges used in this battle. The chance of such a hit is virtually nil.

The 20-degree test could have happened near the initial portions of the battle, where the range was about 26,000 yards, so it might be meaningful here.

A 9.8-degree evaluation is very much of interest here and should be done with some degree of reality. HOOD was hit when it was in the middle of a turn to allow its aft guns to fire, though what the Target Angle HOOD presented to BISMARCK (90 degrees being broadside-on) is not known to me. I will assume 45 degrees for want of anything else.

The very shallow angle of fall of BISMARCK's shells means that a pure deck hit on the forecastle deck or aft upper deck would not get anywhere near the aft magazine. There would be at least the main deck between the shell's sideways-thrown fragments and the magazine and even at within 5-calibers of the shell. the penetration of solid HT steel by an AP shell's fragments at right-angles is only about 2.11" HT and the main deck is equal to about 2.08" STS = 1.66" HT steel, leaving only, at best some fragments with 2.11" - 1.66" = 0.45" HT steel remaining penetration at right-angles impact. Fragments could penetrate the main deck, but they would not be able to penetrate 2" HT = 1.6" STS afterwards.

SCENARIO #1: THROUGH THE UPPER BELT DIRECTLY INTO THE AFT MAGAZINE

A side hit above the main deck against the 7" CA lower strake of the upper belt where it was only 12 degrees at its joint with the top of the 12" waterline belt would of course penetrate, but it would be deflected somewhat upward so that its angle of fall is now less than 10 degrees. Let us see what FACEHARD predicts about this (standard quality British late WWI CA assumed for ARMOR SELECTION #12 versus GERMAN PROJECTILE SELECTION #15):

14.96" 1764/1500 lb shell (Total/Body Wt) hitting a 12-degree-forward-tilted 7" CA plate at 1913 ft/sec and 9.8 degrees angle of fall, giving an Impact Obliquity of 21.8 degrees on the plate even ignoring the 45-degree rotation angle compared to the line-of-fire..

RESULTS:
Shell undamaged, but AP cap and windscreen destroyed
Remaining Weight: 1500 lb
Remaining Velocity: 1503 ft/sec (not a big deceleration here)
New Angle of Fall: 21.07 - 12 degrees = 9.07 degrees
Impact Obliquity on a Horizontal Deck Plate: 80.93 degrees (rotation angle does not change this)

With that impact obliquity, the shell will ricochet off even a rather thin plate. The 3" solid HT steel main deck extension or even the weaker laminated portion inboard of the 2" sloped turtleback armor would easily deflect such a shell, just like the British 15" shell was deflected. As mentioned above, the small, sideways-thrown fragments that the shell could blow through the main deck would be easily stopped by the 2" lower deck over the magazines.

CONCLUSION:
There is no direct path into the aft magazine for the shell or its fragments after it explodes through the upper belt.

SCENARIO #2: THROUGH THE MAIN BELT DIRECTLY INTO THE AFT MAGAZINE

This time we will take the rotation angle into account:
COS(Ob) = COS (45) x COS (12+9.8)
COS(Ob) = 0.656538624
Ob = 49 degrees

12" WWI CA (ARMOR SELECTION #12) tilted forward at 12 degrees hit at 49 degrees (9.8 degrees from the horizontal) by the same shell as in SCENARIO #1 when HOOD is midway in its turn away from BISMARCK (45 degree Target Angle as seen from BISMARCK assumed). We assume a hit just above the edge of the anti-torpedo bulge so it is directly onto the 12" plate face. Striking velocity is 1913 ft/sec.

RESULTS:
Plate not holed (Incomplete Penetration) (2107 ft/sec = Holing Limit)
Shell completely broken up.
Remaining Weight: 0
Remaining Velocity: 0
Turtleback plate will stop anything knocked from bulkhead supporting armor.
Local fragmentation and perhaps some blast damage (low-order explosion only) to upper part of anti-torpedo bulge near impact. Perhaps some slow leakage due to armor plate being dislodged.

CONCLUSION:
There is no direct path into the aft magazine for the shell or any part of it through the main belt during this turn.

SCENARIO #3: HIT BELOW THE WATERLINE BELT DIRECTLY INTO THE AFT MAGAZINE

Same as Scenario #2 except that the shell hits the water so that it dives below the lower edge of the main belt, as it did with PoW. Note that there was a 4" thick, 3-feet-long CA plate extending of the main belt below the lower edge of the 12" portion over the entire length of the Citadel, designed, most probably, to protect not against direct hits by diving AP projectiles, but against the chunks of an exploding AP or Common shell, large or small, that hit the sea close-enough to the hull to act like a small torpedo hit, though will many more fragments due to the much thicker steel used in such shells compared to a lightly-constructed torpedo warhead. This adds to the depth that a diving 38cm shell would have to go to clear the belt armor, if not to be slowed down appreciably at that point after the great deceleration it would experience going through sea water for any significant distance.

RESULTS:
If the shell, due to its flat-faced cap and shattered windscreen, continues straight ahead at an angle of fall of 9.8 degrees, it has to go deeper than about 8.5' to clear the bottom edge of the belt, including that 4" lower extension. This means it has to hit at about 50' short of the HOOD armor bulkhead plate, pass through the water (assuming that the flat cap keeps the projectile stable) until it is about 40' from its impact point for the propulsion plant length, where the bulge is much wider or 35' abreast the magazines where the hull narrows appreciably so there is more slanted travel distance inside the ship, where it now runs into ~1" HT hull plating of the outer bulge (thickness varies somewhat) and immediately a few feet thick of the packed steel tubes in the anti-torpedo system, which may add up to maybe another 1" of solid armor.

Let us say that the delay is 0.04 second (being generous about the tolerances) and it is moving straight ahead. First, how much is it being slowed down by water drag? It has a much wider face than the Japanese Type 91 AP shell when it has lost the AP cap tip (called a "Cap Head"), so it will have much greater drag with all that extra surface area near the edge of the shell diameter. I will be conservative and assume double the drag of a Type 91 AP shell (this is probably well below the real value, which I do not know). That Japanese shell can go 200 calibers in 0.4 second before detonating, so a 15" Type 91 AP shell would have an average underwater speed of 625 ft/sec, where the hit is at 17 degrees angle of fall at about 1500 ft/sec striking velocity (best case). Double the drag and you would halve the speed down to only 313 ft/sec. For a 0.04 delay, this gives a distance of 12.5 feet. Assuming the higher striking velocity of the German shell here, this may be increased somewhat, but it is unlikely to be much more than the 35'-40' that the shell has to move underwater to get to the outer hull abreast the aft magazine or propulsion plant below the belt lower edge, to say nothing of the internal distance to get past the 1" HT tilted belt support bulkhead with any kind of significant remaining forward speed. It might be able to if a dud, as probably the BISMARCK hit on PoW did, but never if the shell fuze is working.

The 45-degree rotation angle would allow the shell to get closer to the hull, but then it would be moving longer underwater unless it hit the water too close to get deep enough to get under the belt. This also makes the distance the shell has to move through the anti-torpedo system considerably longer before it reaches where the belt is above it, so that does not really help as long as the base fuze is working properly.

CONCLUSION:
An underwater hit by a live, properly-functioning Krupp 38cm AP shell below the main belt at this extremely shallow angle of fall, even if the shell does not move back upward as most such shells do at that flat impact, here only due to the AP cap shape, is extremely unlikely. A dud might reach the magazine, but would most likely flood the part it hit with sea water, not blow it up. A steeper angle of fall allows a closer impact to the ship and a somewhat better chance of an underwater hit, but that is only up to 30 degrees or so, above which the shell will never get out of the anti-torpedo system before exiting the bottom of the ship.

SCENARIO #4: A HIT IN THE AFT ENGINE ROOM AND INDIRECTLY INTO THE AFT MAGAZINE

The aft engine room abuts the aft magazine and is only separated by a 0.75-1" (not sure which) HT steel bulkhead, which the blast fragmentation of the German 38cm AP shell, if close enough can penetrate easily. The aft engine room also has no lower deck inside it (other than a mild steel plate 0.35" thick being the floor of a raised passageway about 10' wide just behind the turtleback plate that overhangs the edge of the huge internal propulsion plant volume) due to the large engines sticking up into the upper hull, so it is a much larger target than the aft magazine and easier to get at. The flat main deck has also been thinned to only 1.5-2" thick HT plating, laminated from two plates, either both 0.75" HT or one 0.75" and one 1.25" thickness, equaling only about 1-1.25" STS.

Scenario #1 but with the lower deck removed at 45 degrees Target Angle and 12-degree minimum tilt to the 7" CA plate.

RESULTS:
Projectile completely penetrates the rotated and inclined 7" CA plate where the 12" plated rejected it. It then penetrates the upper portion of the 2" turtleback plate and, even if slightly deflected by that plate, punches through the very thin vertical bulkhead of the inner side of that raised passageway (can be ignored here) and into the upper portion of the aft engine room.
Shell completely intact with functioning fuze, with only AP cap and windscreen destroyed.
Remaining Weight: 1500 lb
<u>After Penetrating 7" plate:</u>
Deflection Angle: 6.57 degrees (slightly upward, but mostly toward right-angles to side)
New Angle of Fall: ~9.5 degrees
New Horizontal Angle: ~41 degrees (slightly closer to sideways to ship centerline)
Remaining Velocity: 1178 ft/sec
Distance Moved before Hitting 2" HE Turtleback Plate: 10' (0.0085 sec)
<u>After Penetrating 2" HT Turtleback Plate @ ~45 degrees Obliquity & 1178 ft/sec Striking Velocity:</u>
Deflection Angle: 1.1 degrees (slightly downward, but mostly toward right-angles to side)
New Angle of Fall: ~9.6 degrees
New Horizontal Angle: ~40.8 degrees (slightly closer to sideways to ship centerline)
Remaining Velocity: 1131 ft/sec (hardly any effect on projectile speed)
Distance Shell Moves after Exiting 2" Plate: 24.3' (0.03 sec delay); 30' (0.035 sec); 35.6' (0.04 sec)
Distance Shell Moves Aft: ~15' (0.03 sec delay); ~18.5' (0.035 sec); ~22' (0.04 sec)

Total Distance Shell Moves Downward @~9.6 degrees from Original Impact on 7" Plate:
~5.7' (0.03 sec delay); ~6.7' (0.035 sec); ~7.6' (0.04 sec)

CONCLUSION:
A hit in the 7" CA plate above the aft engine room can penetrate completely with a lot of remaining velocity that can punch through any remaining sloped or vertical plating to move the shell along the near-to-45-degree aft impact angle and downward at near the original angle of fall to about 6-7' lower (directly behind the main belt) close to or at the aft magazine area so that when it explodes, it can throw a lot of blast and fragments through that thin separating bulkhead into the aft magazine or, if far enough aft, penetrate itself into the aft magazine, and KABOOM!!! No more HOOD. From this analysis, this is the most likely thing to have killed HOOD, with no fluke hits, just a very, very poor timing for it to happen to HOOD.

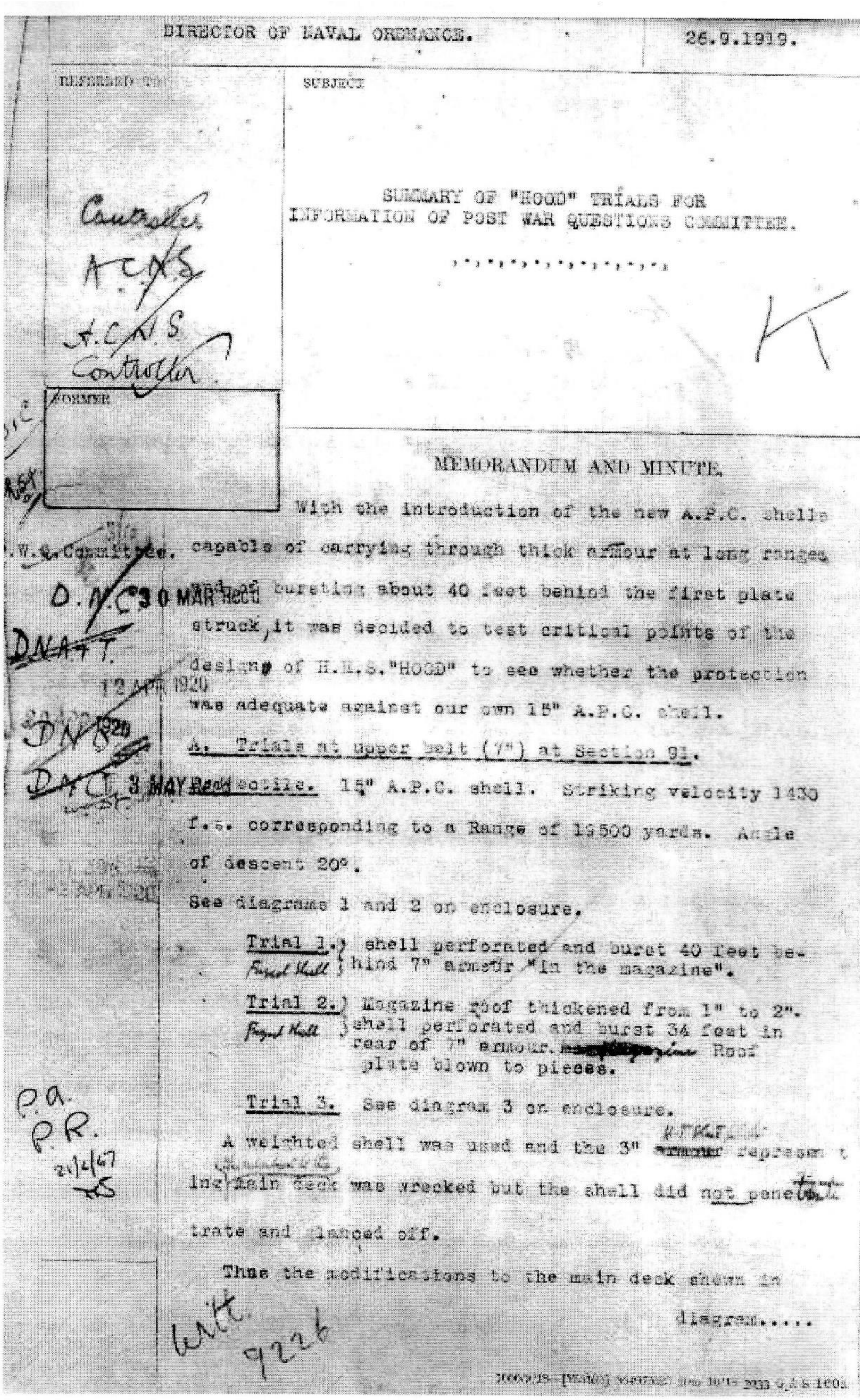
NOTE: If shell hit 7" upper belt higher up -- at most at about 5' above the main deck level if the shell is to be able to hit and penetrate the main deck before exploding due to fuze action -- the large, sharp- cornered, and high-hardness chunks of the 7" armor face and softer back pieces, thrown at high speed in front of the projectile would tear up the flat main deck along an oval region stretching most of the width of the ship. All of this thin laminated deck plating is merely fastened together by rivets and standard bolts, not the heavily reinforced supports and nickel-steel bolts used for armor plate. When the projectile itself hits the main deck very shortly thereafter, much of the main deck bolts and rivets in front of it will have been broken and the plating deeply dented, folded, or even torn up in places, significantly weakening the deck against the projectile hit.

As with the overlapping turret roof plates of USS WEST VIRGINIA and TENNESSEE at Pearl Harbor that were torn open at the joints of two plates by Japanese large 16.1" AP bombs (re-manufactured obsolete AP projectiles) of similar size and weight to the 38cm shell here, even when held together by thick armor bolts and by a slower-speed projectile hitting them at a much lower obliquity, if the laminated plate connections fail at this very-highly-oblique main deck impact point from this high-speed and intact projectile, the plates will bend away downward and to the side or even fold upward in front of the shell, be ripped apart at the seams, snapping the remaining rivets and bolts, and an opening made to let the shell pass through the plate, even when a solid plate of significantly lesser thickness would have caused the shell to glance off. The shell may glance off here too, but it has a very good chance of penetrating such a deck even at this otherwise impossibly-high obliquity. If so, even if the shell explodes while still going through the deck, if the penetration is close-enough to the bulkhead between the aft engine room and aft magazine, the blast and fragments will easily penetrate and again, KABOOM HOOD.

In addition, note that the shell is passing through the engine room, which has a large portion of its volume made up of heavy, solid-steel -cased objects of many different shapes. The shell can ricochet around and end up in a wide region to the side or up and down from its original path before the fuze sets it off. The original shallow angle of fall is thus of little use in determining where the shell will end up at during its movement through this space.

THE END

Appendix – Summary of “HOOD” Trials for Information of Post War Questions Committee



DIRECTOR OF NAVAL ORDNANCE. 26.9.1919.

REFERRED TO

Controller

~~A.C.N.S.~~

A.C.N.S.

Controller

FORMER

SUBJECT

SUMMARY OF "HOOD" TRIALS FOR
INFORMATION OF POST WAR QUESTIONS COMMITTEE.

K

MEMORANDUM AND MINUTE.

P.W.Q. Committee.

~~D.N.C.~~ 30 MAR 1920

~~DNA & T.~~ 12 APR 1920

~~DN 1920~~

~~DA & T~~ 3 MAY 1920

With the introduction of the new A.P.C. shells capable of carrying through thick armour at long ranges and of bursting about 40 feet behind the first plate struck, it was decided to test critical points of the design of H.M.S."HOOD" to see whether the protection was adequate against our own 15" A.P.C. shell.

A. Trials at upper belt (7") at Section 91.

Projectile. 15" A.P.C. shell. Striking velocity 1430 f.s. corresponding to a Range of 19500 yards. Angle of descent 20°.

See diagrams 1 and 2 on enclosure.

Trial 1. Forged Shell } shell perforated and burst 40 feet behind 7" armour "in the magazine".

Trial 2. Forged Shell } Magazine roof thickened from 1" to 2". shell perforated and burst 34 feet in rear of 7" armour. ~~[illegible]~~ magazine Roof plate blown to pieces.

Trial 3. See diagram 3 on enclosure.

A weighted shell was used and the 3" ~~armour~~ [illegible] representing [illegible] main deck was wrecked but the shell did not penetrate and glanced off.

Thus the modifications to the main deck shown in diagram.....

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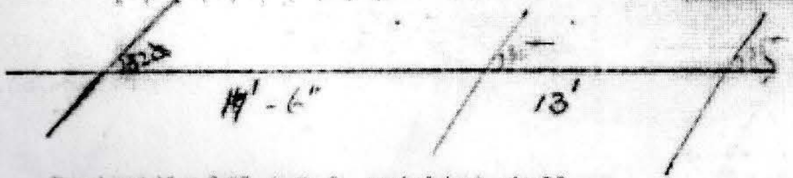
1000918—[W.1103] 100000 10/18 2033 G.& S. 1003 diagram 1 may be considered to give fairly good protection to the magazines from shells which hit the side armour. This addition of 3" plating & of the proposed 2" extra plating on the crown of the magazines were approved & fitted in Hood.

B. Trials at "HOOD'S" decks.

See Line B on diagram 1.

Target. 2" H.T. Plate   3" H.T. Plate.   2" H.T. Plate (Magazine Roof.)



Projectile 15" A.P.C. weighted shell.

Angle of descent [illegible]°3½' } corresponding to 25300yds. range.
Striking velocity 1350. }

Trial 1. Shell perforated all three plates and buried itself 8 ft. deep in the ground and was recovered intact.

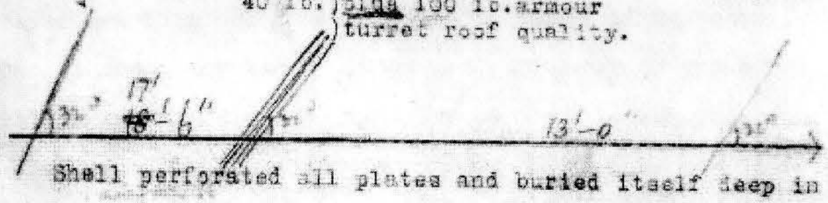
Proposals were then made to surrender smaller weight in "HOOD" by removing certain of the 5.5" guns and their ammunition and by removing above water torpedo tubes etc, the weight thus saved to go in thickening the main deck as follows:-

Trial 2. Same as above only different target.

2" H.T.

30 lb. } H.T. plates
50 lb. } (existing deck)
40 lb. } plus 100 lb. armour
} turret roof quality.

2" H.T. plate (magazine roof)



Shell perforated all plates and buried itself deep in the ground - probably it will be recovered whole.

Trial 3. Not yet done Same as trial 2 but with 3" (120 lb.) mild steel plate instead of the 100 lb. armour plate.

* It is probable therefore that the weight available cannot protect "HOOD'S" magazines from plunging fire at extreme ranges unless the ship were re-built with a deck of = thick homogeneous armour plate.

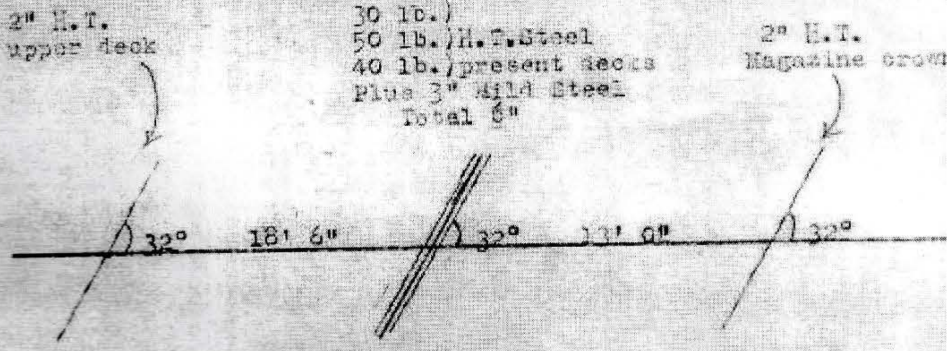
MB/
26.9.19.

HR Crooke
DNO

Register No. G.0965/19 Minute Sheet No. 1

1. Series B. Trial 3.

"Hood's" decks "reinforced" with 3" mild steel same as trials 1 & 2 (B. series) hit target as shown:-



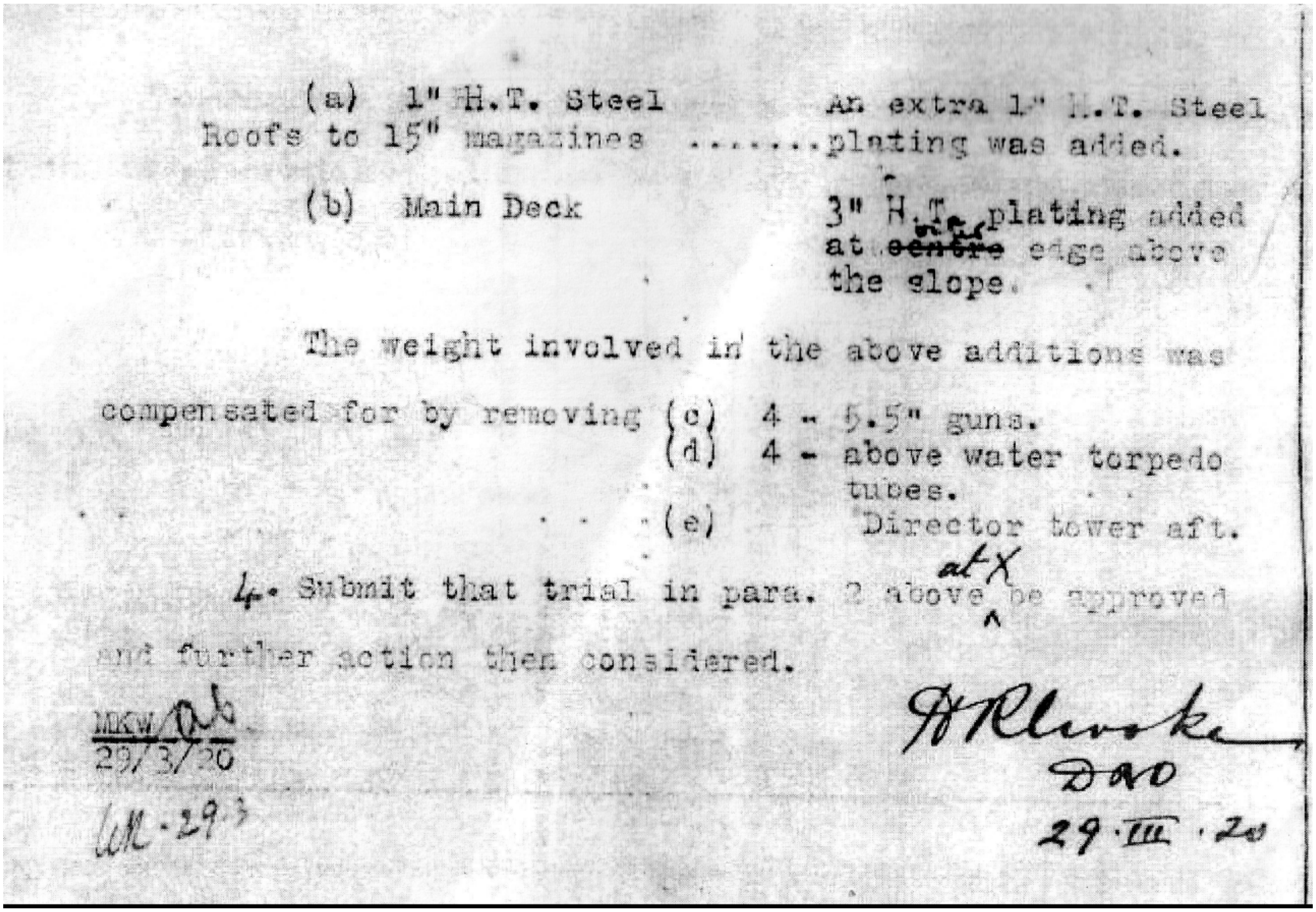
S.V. 1373 f.s.

<u>Result.</u> 15" A.P.C. shell perforated ~~with~~ all plates, presumed "whole", shell being buried in ground and not recovered. The shell <u>turned down</u> about 15° while perforating the "armour" deck (i.e. centre plate of target).

2. These trials showed that neither 3" mild steel nor 2½" armour quality steel added to the main deck are sufficient to keep out the 15" A.P.C. shell at this angle of impact. It was therefore proposed (C.Sec C.1527/18 attached) to complete H.M.S. "HOOD" without any further additional deck armour and to press on with D.N.C's trials of improved "special treatment steel" plates etc. in hopes of producing plating which would meet the case without adding undue weight, and at a cost less than that of "armour quality" plating. This policy was carried out. [illegible]

X It was further proposed to carry out a further trial at "HOOD"deck" target, the main deck being reinforced with 4½" roof plate quality armour. No approval for this proposed further trial was given (C.Sec.01527/18).

3. H.M.S. "HOOD" was completed with following additions and alterations to original designs as regards protective decks:-



(a) 1" H.T. Steel Roofs to 15" magazines	An extra 1" H.T. Steel plating was added.
(b) Main Deck	3" H.T. plating added at ~~centre~~ outer edge above the slope.

The weight involved in the above additions was compensated for by removing

(c) 4 - 5.5" guns.
(d) 4 - above water torpedo tubes.
(e) Director tower aft.

4. Submit that trial in para. 2 above at X be approved and further action then considered.

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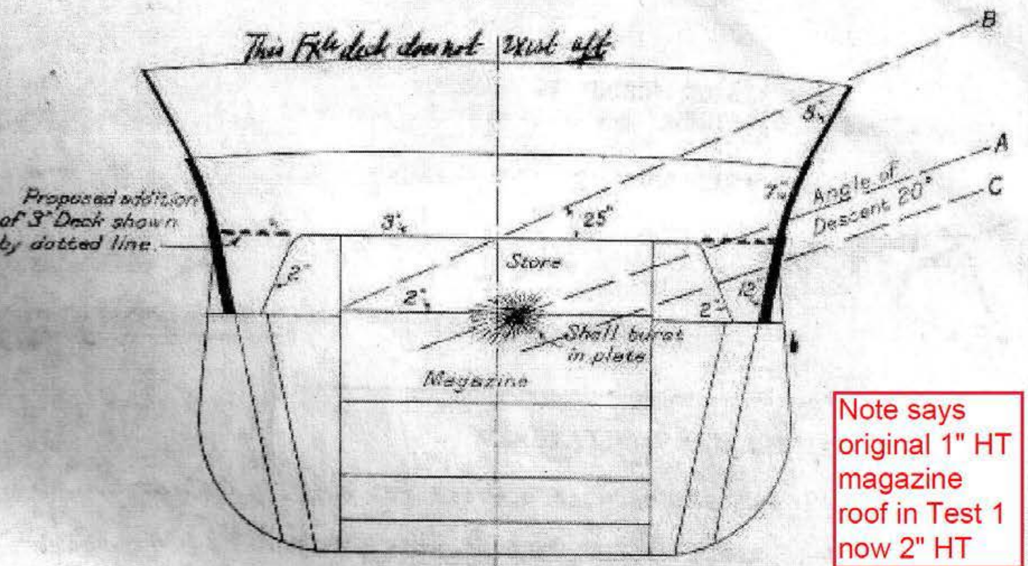
"HOOD."

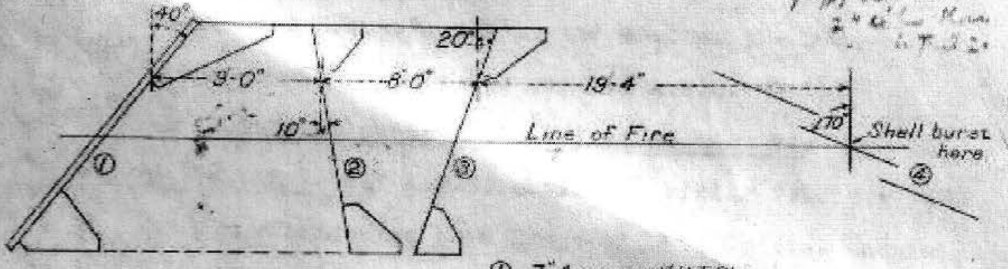
This Fx^le deck does not exist aft



Note says original 1" HT magazine roof in Test 1 now 2" HT

Diagram 1.

2" in Trial I the magazine 'roof' plate was 1" HT [illegible] 2" [illegible] in T. 3 [illegible]

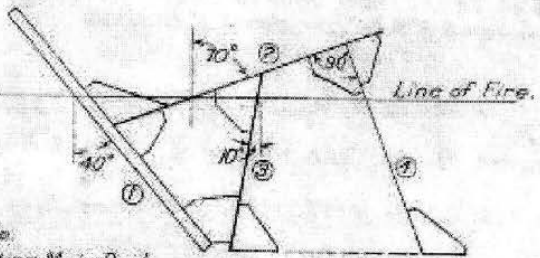


① 7" Armour + 1" H.T. Plate.
② 2" H.T. Plate representing Main Deck Slope.
③ ¾" H.T. Plate " Bulkhead.
④ 2" H.T. Plates " Crown of Magazine
(These plates are in the Horizontal plane.

SKETCH OF ACTUAL TARGET.
Scale ⅛" = 1 foot.

Diagram 2.

Diagram 3 is the actual Test 3 plan used to upgrade original main deck by added a solid 3" HT extension to connect with back of 7"/12" armor joint point



① 7" Armour + 1" H.T. Plate.
② 3" H.T. Plate representing Main Deck.
③ 2" H.T. Plate " Main Deck Slope.
④ ¾" H.T. Plate " Bulkhead.

SKETCH OF TARGET FOR NEXT TRIAL.
To represent strengthened Armour Deck indicated in Diagram 1.
Scale ⅛" = 1 foot.

Diagram 3.