An Attempt to Model Japanese Air Dropped Torpedo P(hit)

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Motivation:

The reason for this exercise is to try to extrapolate the impact of a Japanese attack on the US Pacific Fleet on December 7, 1941 had the fleet been at sea rather than in port. There are several basic issues here. First, what sort of attack would the Japanese have mounted, and with what degree of coordination? A case can be made for several different scenarios ranging from the historical attack but applied to the fleet at sea, to an attack optimized for attacking the fleet with no attacks on airfields. The latter could have as many as 134 torpedo bombers attacking the Pacific Fleet, split between two waves. A second question is how the fleet would be disposed and the degree to which an effective anti aircraft screen could be established. But, the most basic question of all is what the likelihood is of scoring a torpedo hit. Until some rational number for this is established, it is difficult to evaluate the various possible scenarios. This exercise, then, is an analytic attempt to find a probability of hit for Japanese air dropped torpedoes from examining the historical record. Any modification of that number to apply to the different circumstance of attacking Pacific Fleet battleships rather than the historical targets is set aside for now.

Approach:

Various sources have been explored to find data on various circumstances of the torpedo attacks made by Japanese aircraft on capital ships in 1941 to 1942. There are not that many such attacks. In order find even a dozen cases, some assumptions have had to be accepted.

1. Attacks on both battleships and aircraft carriers are included. Because the battleships had speeds and lengths comparable to those of aircraft carriers, it is not unreasonable to assume that the probability of hitting either varies much. Individual ships would have more variation. For example, USS Lexington has about double the radius of the USS Yorktown, an important characteristic in trying to dodge torpedoes.
2. Attacks by both land based (Nell, Betty) and sea based (Kate) aircraft have been included. The two engine land based aircraft are larger targets but also faster. So at least to a first approximation, perhaps they are roughly comparable in their ability to launch torpedoes. Both sorts of aircraft were piloted by navy crews well trained for the torpedo attack mission, so there is no reason to expect different effects on p(hit) based on the pilots as there might be in other theaters. The quality of torpedoes is assumed to be comparable as well.

Ultimately, the intent is to develop data that can be examined using statistical techniques. The data for each engagement needs to include the most important aspects of the attack. The granularity is a discrete attack by several aircraft simultaneously on a given target. Attacks separated in time are considered a different attack. The different data used to characterize the attacks are described in the next section. See the table (from an Excel spreadsheet) – Appendix A following the report body.

The Data:

This section describes the different data collected for the engagements:

1. Engagement identification: The date, time, and target ship. (Probably should add the attacker too.)
2. Top speed: The nominal top speed for the ship, or if damaged, the speed of the ship could achieve when attacked.
3. Maneuverable: 1 means the ship was maneuverable. 0 indicates steering control or motive power was lost.
4. Heavy AA battery (of the target): The number of AA capable guns of 4 to 5.25 in caliber. (An argument might be made that the 5.25 in guns were not as capable, or likewise for the 4 in, but this study lacks the resolution to address that. Most heavy AA guns are 5 in 38 or 5 in 25, the exceptions being the British ships.
5. Fire Control: The US had several AA fire control systems at the time, ranging from the early Mk 19 in older BB's and cruisers to Mk37 in Hornet and the newer DD's and Atlanta class cruisers. The Prince of Wales is credited as having effectiveness equivalent to Mk 28, and the Repulse effectiveness equivalent to Mk 19. These are guesses.
6. Light AA (of the target): Torpedo drops were typically between 1000 and 2000 yards from the target, and this is within effective range of light AA, but the chances of inflicting fatal damage before the drop is small. Nevertheless, the effect of such fire may well make the drop less accurate. The number given is based on the number of 40mm guns. 1.1 in guns are less effective, and are credited with ½ the number, and 20mm guns are credited at ¼. The rationale for these ratios is discussed later.
7. Attacking aircraft type: Nell, Betty, or Kate.
8. Escort AA, counting only heavy (5 in) AA capable weapons: These are broken down by the fire control system of the various ships.
9. CAP interceptions: The number of attacking aircraft shot down by CAP prior to or during the attack. Some of the aircraft may be able to drop, others not, but the thought here is that CAP activity will strongly affect the effectiveness of the drops.
10. AA loss: As with CAP, the number of losses to AA fire prior to or during the attack. Some losses may be before and others after the drop.
11. Drops: The number of torpedoes actually dropped at the target in the attack.
12. Anvil attack: A coordinated attack with two or more groups of aircraft approaching from both sides of the target gives a better chance to hit. The target maneuvers to avoid one set of torpedoes but finds itself exposed to others. One would expect that this means half miss, but the other half have much more of a chance to hit compared to an attack against a maneuvering target from only one side. Against a target that can't maneuver, an anvil attack is probably counterproductive, or at least no worse than an attack from one side. In the data, any attack with attackers coming from multiple directions is credited as an "anvil" attack.
13. Hits: The number of torpedoes that hit the target and explode, causing damage. There is no differentiation of the degree of damage.

The Attacks:

Cases 1-6: The various attacks by the Japanese 22nd Air Flotilla on British "Force Z" off Malaya, December 10, 1941. In this attack both British capital ships were sunk after a succession of attacks. Only the torpedo attacks are addressed here.

Both the 5.25 inch AA of Prince of Wales and the 4 inch AA of Repulse are credited as equivalent to 5 inch for purposes of this study for lack of specific data to give

a different value. Both weapons managed to bring down and damage Japanese aircraft, so they were effective. British AA fire control was inferior to the US contemporary equipment, and certainly not up to Mk37 standards. The assignment of Mk28 and Mk 19 equivalencies is a guess.

The four British DDs are not credited with having effective AA for purposes of this study. The 4.7 in Mk IX gun in single mounting had elevations only up to 30 to 40 degrees, training and elevation rates of 10 deg/sec. This compares to 85 degrees elevation and 20 and 30 degrees per second training and elevation for the US 5in/25. No account I've seen credits these DD's as making a significant contribution to the protection of the capital ships.

While earlier sources give 2 hits and 4 hits for the attacks on Prince of Wales, examination of the wreck has shown show that the correct numbers are 1 and 3. The wreck of Repulse shows no torpedo hit where contemporary accounts placed one, so the number of hits for the final attack has been reduced from 4 to 3. It is likely that the mistaken hits were from premature sympathetic detonations triggered by the actual hits. That's one possible reason cited. (Information from Garzke, Durkin and Webb book on Axis battleships supplemented by "Death of a Battleship", Garzke Dulin and Denlay, report at < http://www.pacificwrecks.com/ships/hms/prince_of_wales/death-of-a-battleship-2012-update.pdf. A report on the Repulse wreck, showing the visible torpedo damage and comparing it to wartime reports, has been seen. But it could not be found again; it may no longer be accessible. A mention of the hit discrepancy - the hit abreast after turret was missing - can be found at <http://www.enotes.com/topic/HMS_Repulse_(1916)>.

a. Case 1: Attack on Prince of Wales -The first attack was by 9 aircraft on Prince of Wales. The aircraft attacked from the port side only. Apparently the aircraft were low on fuel and did not have time to set up a more elaborate attack. The ship turned to comb the wakes. One aircraft was shot down and apparently did not drop its weapon. The one hit struck at the shaft exit from the hull and was amazingly destructive, badly crippling the ship. Because the engine was restarted after the hit, the shaft opened every space along its length to flooding. (Similar damage to a US modern BB would have sunk it.) The BB was left unmaneuverable but able to steam in wide circles at 16 knots. This seems to be the only case of a torpedo hit against a maneuverable target that scored without being a coordinated attack.

b. Cases 2 and 5: Unlike any other case here, the two British ships were quite close together (900 yards) when the 1219 attack developed. Prince of Wales had just one heavy AA mount working. The circumstances played an important role in increasing the effectiveness of the attack, since the Repulse did not expect to be attacked by three aircraft that were thought to be attacking Prince of Wales. Nevertheless, this single attack is treated as two separate cases, one for each ship. The one hit on Repulse was disabling. The three hits on Prince of Wales, together with some additional flooding from bombing near misses and a bomb hit, sunk the ship. Two of the torpedo hits really did not contribute much to the sinking, but another at the stern also hit in way of the propeller shafts. Detailed information that indicates why the one hit on Repulse disabled the ship have not yet been found.

c. Cases 3, 4: Repulse managed to dodge torpedoes from two attacks which were apparently not delivered from multiple directions.

d. Case 6: The demise of Repulse came from a coordinated attack from multiple directions after the ship was disabled. Originally four torpedoes were thought to have hit, but one of those is missing on the wreck. It is remarkable that AA (relatively primitive 4 in) brought down 2 aircraft, when the ship brought down no torpedo planes earlier. It is possible that the steadier platform may have helped. (If so, this may also be an effect seen in Japanese AA gunnery, since the Japanese also relied primarily on maneuver to avoid taking hits for both bomb and torpedo attacks.)

Cases 7 and 8: Attacks by Zuikaku and Shokaku air groups on Lexington and Yorktown at the Battle of Coral Sea, May 8, 1942. While the two U.S. aircraft carriers were operating together in one formation, they maneuvered independently during the attack, and so are considered two separate cases. The AA screen formation more or less dissolved with some ships following each carrier, so half of the AA total screen values are assigned to each case. As with most other cases, attacks by dive bombers about the same time has not been identified in the matrix. Perhaps it should since that would be a diversion of much of the AA

a. Case 7, attack on Lexington by 14 Kates from Zuikaku and Shokaku. Dive bombers also attacked. One torpedo bomber was shot down by CAP before dropping its torpedo, and three additional were shot down by SDB's flying CAP later but still prior to drop. The attack was an "anvil" with 5 torpedoes launched on one side and six from the other (though only 4 of these at Lexington). One aircraft was lost to AA after drop. Two aircraft dropped against CA Minneapolis rather than Lexington and missed. Of the 10 reported launches (8 against Lexington) two hit. The reason two aircraft in seemingly favorable position attacked the CA is unknown, but in many other attacks similar diversions happened, usually because the aircraft in question had poor position due to target maneuvers and chose better chances against a different target. None of those attacks hit, unless the diversion of a few aircraft from an attack on Prince of Wales which delivered the first hit on Repulse is counted. It is noteworthy that both hits were from the same shotai of three aircraft. The Lexington remained maneuverable and capable of high speed until secondary explosions from gasoline vapors caused damage that ultimately led to the loss of the ship.

b. Case 8, attack on Yorktown by 4 Kates from Zuikaku. This attack was simultaneous with the attack on Lexington above, and with dive bombers attacking about the same time. With so few aircraft, the attack was launched from only one side. Yorktown maneuvered to avoid the torpedoes. Two aircraft were shot down by AA and one by CAP (an SDB).

[Lundstrom "First Team" for information and numbers]

Case 9: Attack by the Hiryu air group on USS Yorktown at Midway, June 4, 1942. This attack seems to be the most remarkably successful of all the cases seen, in that the attackers scored 2 hits for 9 aircraft and 7 drops despite CAP involvement and considerable AA against a still maneuvering (but slowed) target. This is credited as an "anvil" attack since the attackers came from two directions, and indeed the effect was to place 5 attackers almost ideally with beam drops.

Note that the escorting DD Balch (Porter class) is not credited with effective heavy AA (the class had dual 5 in mounts and 8 guns, at the cost of not being effective for AA). The scoring attackers came over this ship.

(Has examination of the wreck confirmed 2 hits in this attack? In the pictures I have seen from the Ballard expedition, it looked like only one midships port side torpedo hit. The hits were close together (frames 92, 80) but thought to be at the same depth, and far enough apart that you'd think two distinct holes would be visible. Still, the crew reported two distinct hit, so the probability that there was only one hit is small, though such cases of reporting torpedo hits where none occurred did happen for other ships.)

Both hits were from the same chutai of 5 aircraft, grouped close together. One failed to drop its torpedo. The damage from the attack, added to that from bomb hits earlier, left Yorktown dead in the water and close to sinking condition.

Cases 10 to 13: Attacks by aircraft from Shokaku, Zuikaku, and Junyo on Hornet and Enterprise at Santa Cruz, October 27, 1942.

These cases differ from most earlier ones by the presence of more effective AA. Most of the escorts had Mk37 fire control systems, and the escorts included three Atlanta class CLs and USS South Dakota. Japanese aircraft losses overall were extremely high.

a. Case 10: Attack by Shokaku torpedo bombers (and simultaneously Zuikaku dive bombers) on Hornet. The 20 torpedo bombers and 21 dive bombers were escorted by 12 fighters. CAP destroyed 5 dive bombers and 1 torpedo bombers and damaged several additional torpedo bombers before the aircraft could attack. AA shot down 4 dive bombers and 8 torpedo bombers. After bombing 2 additional dive bombers and one additional torpedo bombers were shot down.

The torpedo attack was mounted by two groups (chutai) of aircraft, one from the south that had the advantage of escorts. The attack from the South by 11 aircraft scored 2 hits of 8 torpedoes launched against Hornet and launched 2 against Pensacola as Hornet turned making the last attack angles very poor. The two hits were from the same chutai of three aircraft which seemingly had poor position, but nevertheless better than other aircraft in that same group. Two of the drops that missed were early at 1500 and 2000 yards, with both of those aircraft among the five lost to AA. The two successful launches were the first ones at ranges of 1000 yards or less. Of 11 attackers in this group, 8 launched torpedoes at Hornet, of which 2 hit. Two launches against Pensacola missed. 5 aircraft out of these 11 were lost to AA, and none to CAP until one was shot down (by an SDB) after the attack. It would seem that many of the AA losses occurred as aircraft tried to gain an advantageous position against a target that was turning away, requiring them to fly further within the AA envelope. It was the last group of aircraft that finally attacked the heavy cruiser instead.

Of note, neither CLAA was on this side of the formation. This may not be significant since some of the AA had to be employed against the dive bombers. On the other hand, the side of the formation having the CA's (with older fire control) did remarkably well, although the hits did come from this side.

The other nine torpedo bombers attacked from the north with no fighter escort. (The escort engaged the US strike from Hornet.) CAP shot down one and damaged several others, two of which departed without launching attacks. AA accounted for two (one of which had been fatally damaged by CAP). The remaining four launched from 300-800 yards off both of Hornet's bows, but all missed. These aircraft escaped. One AA loss was to a CLAA. The other was in the vicinity of a DD.

So, the coordinated torpedo attack by 20 aircraft had 2 CAP losses, 8 AA losses, resulted in 12 launched torpedoes vs Hornet and 2 vs Pensacola, of which 2 hit Hornet. (source Lundstom seems to describe one aircraft as thought to be lost to CAP in one place but the totals credit it to AA.)

At the time of the attack, 36 CAP fighters protected both task forces, and 32 of these (plus an SDB) fired their guns in the engagement. [Source, Lundstrom Guadalcanal pp393-404]

There were also two additional torpedo bombers with this strike launch that did not attack; they were unarmed scouts.

For statistical purposes, the two launches against Pensacola are counted as these were intended as attacks to be made against Hornet. The reason for the alternate targeting was due to Hornet's maneuvering.

b. Case 11: Attack on Enterprise – Attack by Zuikaku torpedo bombers and (a bit earlier) Shokaku dive bombers. The torpedo bombers attacked in two groups of 8, with one group escorted by fighters. The first group to attack (unescorted) lost an aircraft to 20mm AA which was being hit by CAP at the same time, credited to AA. Three torpedoes launched from ahead and one from behind missed. Two torpedo bombers with hopeless attack angles attacked BB South Dakota. One was destroyed by AA and the other launched and missed.

The second group to attack (escorted) lost one to CAP, one was damaged and aborted, and another crippled, with several others damaged. The one crippled by CAP was also hit by AA, and crashed into a DD causing considerable damage. Five launched against Enterprise from bad angles, one of which was lost to AA after launch. CAP got two more after exit.

In summary, 4 were lost to CAP, and three to AA. Twelve torpedoes were launched (including one against the BB) and all missed. It seems that the two attacks lost synchronization, and thus Enterprise was able to maneuver to comb the wakes in both cases. The launch against BB South Dakota is counted since it was meant originally for the CV, and the successful maneuver of that target made any shot at it a very likely miss.

Note that one additional Kate was launched with this strike unarmed to maintain contact with the US Task force. (Information from Lundstrom)

Damage sustained in this attack reduced Hornet to an immobile status. (This has been blamed in part on the arrangement of the engineering spaces in this class of ships.)

c. Case 12: Attack on Hornet, DIW – Junyo had attacked with 17 dive bombers in her first strike against Enterprise, and followed with 7 torpedo bombers that hit Hornet (escorted by eight fighters, but there was no CAP). Two were shot down, one after launching the torpedo that got the one hit. Six planes attacked of seven launched, the other apparently hit by AA before launch (Lundstrom p447, Hammel).

Subsequently there were additional bomb hits from a Zuikaku 3rd strike by Kates dropping 800 Kg bombs, and a hit from a Junyo 3rd strike by dive bombers before US forces tried to sink Hornet with 5 inch gunfire and left the ship burning.

It is surprising that the last attack on an immobile Hornet by Zuikaku planes (3rd strike) used bombs instead of torpedoes. Perhaps some had presumably had made an earlier attack (into heavy AA) and thus those planes may not have been available. The likely explanation is that these were the search planes that had carried bombs earlier.

Given the urgency of the situation, time would perhaps not have been taken to convert from bomb to torpedo configuration, not simple for the Kates.

Sources: The data in the matrix is drawn from a variety of sources. Data on weapons and fire control equipment is from John Campbell, *Naval Weapons of World War Two*, Naval Institute Press, 2002 edition. Information on the Prince of Wales and Repulse attacks come primarily from Garzke, Durkin and Webb, *Allied Battleships in World War II*, Naval Institute press. This was supplemented by information available online about the wrecks of those ships. A detailed and thorough account of the Coral Sea action was found in Lundstrom, *The First Team*, Naval Institute Press, 1984. The Midway attack information was from the detailed description in Parshall and Tully, *Shattered Sword*, Potomac Books, 2007. (Lundstom also has information on that action.) A detailed description of the Santa Cruz action was found in Lundstrom, *The First team and the Guadalcanal Campaign*, Naval Institute Press, 1994 supplemented by Hammel, *Carrier Clash*, Zeneth press, 1999 & 2004. Some useful data on AA relative effectiveness is given in Zimm, *Attack on Pearl Harbor*, Casemate, 2011.

AA Aggregation:

One important issue is how to aggregate the various AA data into a number that represents the intensity and danger posed by the defensive fire of the attacked ship and its escorts. There are two parts of this: How to account for the differing effectiveness of the various fire control systems, and how to account for the different types of light AA weapons.

The Mk 37 fire control system is taken as a baseline. This was the best AA fire control system in the war, and appears in all engagements involving US ships. It is the dominant system at Midway and especially Santa Cruz. Lacking any analytic measure of effectiveness, a guess will be made rather than ignore the differing effectiveness of the various systems.

So, other systems are given effectiveness multipliers relative to Mk 37: Mk 33 at .6, Mk 28 at .5, and the earliest effective AA fire control system, Mk 19, at .3. I have no quantitative basis for these guesses. However, I am expecting that the overall effect of more AA and more effective AA in the later battles will be significant, and how much that depends on the fire control systems as opposed to the sheer number of guns is relatively unimportant. Also, the difference between the effectiveness of the earlier 5in / 25 and the later 5in / 38 is assumed to be rolled up into the fire control numbers (Mk 19 or 28 vs more modern types).

Light AA weapons can be compared given a table of rounds fired per aircraft destroyed:. Zimm provides a set on numbers for 1942 (from USN sources, 1945). Campbell provides numbers for Oct 1944 – Jan 45 non Kamikaze attacks. Note that the 5in numbers do not include VT rounds, which were a bit less than twice as effective (624 rounds per plane). The dramatic differences between the early and late data may have a lot to do with differing tactics being used late in the war: more individual aircraft attacks rather than coordinated mass attacks, so more weapons would be used against each individual aircraft, especially at longer ranges, and the aircraft were not coming as close giving the 20mm fewer short range shots. From this data it seems odd that the 40mm

numbers (alone) stay about the same from 42 to 45, and for ’42 are less effective than 20mm in kills per round.

Weapon	1942	1944-5	round weight
5in/38 AA	252	960	
40mm Bofors	2788	3361	2 lb
1.1/75	1503		.9 lb
20mm	1809	7152	.27 lb
50 cal	9496	15139	

So, how to equate the effects on torpedo aircraft of these different weapons? For the 40mm, a comparison of the 44-45 kill data suggests a factor of 3.5. The seemingly abberant ’42 data for 40mm is ignored. The 40mm does have the range to reach a torpedo bomber during its approach, but for a much lesser distance (but at a higher rate) than the 5 inch, so an aggregate AA score will include the light AA score divided by 3.5, and a further factor of 2 for distance over which the effect is felt, added to the heavy AA score. This is admittedly a guess not based on a solid analytic model.

For the lighter 20mm gun, kill rates per round are about half that for 40mm (44-45) and the effect is probably not going to be felt until just before release, so the 20mm numbers have been divided by a factor of 4 relative to 40mm. The 1.1 inch have arbitrarily been assigned a factor of 2 relative to 40mm, half way. So, ultimately, an AA score for the target ship is calculated as follows:

Hy AA guns * FC effectiveness + Lt AA (40mm equivalent) / 7
Lt AA = Number of 40mm + .5 * number of 1.1 in + .25 * number of 20mm

For escorts, typically some guns will not bear, and others ships may be on the disengaged side. However, in most cases attacks came from more than one direction. As a guess at the overall effect on TF supporting heavy AA fire a factor of .5 is used. Light AA from escorts is not counted, but may have been present. However, the coarse resolution of any such guess on heavy AA swamps the value any such accounting.

This is all acknowledged to be so much rather arbitrary guesswork. These AA scores do gradually increase over the course of time, ranging from 2.7 for the damaged Prince of Wales to 44 for Hornet under attack at Santa Cruz. No manner for aggregating CAP into this has been attempted.

In reading the accounts of the 1942 carrier battles, some observations were made that may not be quantifiable or accounted for with statistics, but are of interest. First, in cases where two hits were achieved, those hits came from the same shotai of 3 aircraft in two cases (Lexington and Hornet) and the same group of five aircraft for Yorktown. The implication is that the probability of a flight of aircraft having a “good shot” (high probability of hit) is smaller than the average single aircraft probability of hit, while those with “good shots” seem to score very well. The probability of hit for a “good shot” is close to the Pearl Harbor average against sitting targets of about 50%. There was only one case of a single hit against a CV, and that was against an unmaneuverable target. There was only one case of a hit on a maneuvering target without a coordinated attack.

Analysis:

The analytic approach is to find the correlation coefficients, and thus the relative contributions of various factors, affecting these engagements. These will then be used to construct a relatively simple model for torpedo hits against capital ships, understanding that with the small numbers available for analysis there will remain considerable uncertainty.

However, a few simple statistical data can be found more directly. One of those is the average P(hit) across all of these attacks, which is 13%. Against targets that are maneuverable the number falls to 9.4%, and rises to 24% against targets that are not maneuverable. The largest percentage against an unmaneuverable target is 50% (Prince of Wales, which was still moving but couldn't steer), and the largest against a maneuverable target is 29% (Yorktown at Midway). These are percentages of dropped weapons. The most successful attacks on maneuverable targets (18%+ hits) share one thing in common: a target with somewhat limited maneuverability. Lexington had a wide turning circle and Yorktown at Midway had damage reducing speed to 20 knots. No maneuverable ship except Prince of Wales (case 1) was successfully attacked from only one direction ("non-Anvil").

Some of the more interesting correlations:
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For dropped weapons (P(hit)|drop: 13.2%), correlation coefficients between percent hits (weighted by number of attackers) and:

AA intensity (calculated score) : -.35
Whether target is maneuverable : -.53

For maneuverable targets only (P(hit)|drop: .094): correlation coefficients between percent hits (weighted by number of attackers) and:

AA intensity (calculated score) : .02
Whether it is an "anvil" attack : .50

A negative AA correlation was expected – if the drops have to be made in the presence of intense AA fire, the pilot may be inclined to drop early or not as accurately. The "all cases" variability due to AA is about 2/3 of that attributable to being able to maneuver, which is to say it's pretty important. What was unexpected was a falloff to nearly zero for maneuvering targets. Could this mean that an unmaneuverable target has more effective AA (or, the flip: aircraft attacking an unmaneuverable target are more vulnerable)? It's interesting that Repulse shot down two attacking torpedo planes only in the final attack after the ship had been immobilized. Her early AA fire control may have been more effective with a motionless ship and aircraft following straight trajectories. There are other similar cases (e.g. Chikuma). Note that aircraft shot down before dropping due to AA are not accounted for here, so there is still an AA effect beyond the correlation coefficient given here which only accounts for dropped weapons.

The low AA correlation for maneuverable targets in large part is driven by Repulse being so adept at dodging torpedoes, and the fact that the Japanese best percentages were against Lexington and Yorktown in the middle of the AA spectrum. Maybe a ship/fleet that depends on maneuver to dodge torpedoes has both better chances

of avoidance and less success with AA (less consistent courses messing up solutions). The British behaved more like Japanese under attack perhaps. If this issue could be accounted for, the AA contribution would be even greater over all cases, perhaps as large as the importance of being maneuverable.

Anvil attacks are considered to be coordinated attacks from multiple directions for our purposes, even if not a classic anvil from both bows. Such attacks vs. nonmaneuverable targets are pretty much meaningless; they have no additional benefit, and are not counted as 'anvil" for statistical purposes. Against maneuvering targets, the effect is a correlation coefficient of .5, similar to the difference between being maneuverable or not. It seems to have been pretty much Japanese doctrine to do anvil attacks. The exception in the case of the first attack on HMS Prince of Wales was due to the hasty/low fuel situation. In the two cases where attackers had two simultaneous targets, only one got an anvil attack. Such more complex cases may be where lack of good /many radios had its effect.

CAP mostly was reflected in drop rate, although some CAP did follow torpedo planes into the flak. Those cases correlated pretty much with heavy AA, so think of the AA correlations as including that effect. In many cases aircraft were damaged by CAP and subsequently engaged by AA, and some attacking aircraft shot down by CAP were splashed after dropping their weapons (fewer of these for AA).

One question that comes to mind is whether being a "new ship" (less practice) might be showing up as an effect. Prince of Wales really was still "new". It's half a year since the Bismarck fight, and she was having operations problems then (and did well, considering). She really hasn't had that much practice in various things like maneuvering under combat conditions. Similarly, Hornet is still very much a new ship. Her air group had atrocious performance at Midway (can't blame Torpedo-8!) and she got torpedoed at Santa Cruz despite having comparable AA support to Enterprise (2CLAA vs CLAA+BB, with Enterprise having less capable DDs). Lexington can be excused as having a long turning radius, as well as the misfortune of receiving an anvil attack, and Yorktown could only make 20 knots at Midway when attacked and also got attacked from multiple directions. (So, in our wargames should brand new (perhaps inadequately worked up) ships, or air groups, have a combat modifier?)

Application to the Fleet at Sea at Pearl Harbor case:

Any attempt to extrapolate from the data above to the case of the fleet being at sea to receive the Pearl Harbor attack is at best highly speculative. There are two separate components to the issue. First, how many aircraft, and discrete attacks, would be made by torpedo bombers, and second what would the probability of hit be for those bombers which did attack? The statistical exercise can only address the second point.

An initial question is what kind of formation might the Pacific Fleet have adopted upon getting to sea? The one example of a BB formation expecting air attack that was found is from Morison showing TF 58.7 in a circular formation with one BB in the center and 5 BB's, 4 CA's and 12 DD's in a circular screen about 5 miles in diameter. In 1941 the BB's might instead have been clustered in a smaller circle inside the outer ring, as for the carrier TF's in TF58 at the Marianas. Ships available to be in the formation included seven BB's (assumed to be the targets), 2 modern CL's (the ones not in the Navy Yard), 2 old CL's, and about 20 modern DD's. A formation including all but the BB's, 24 ships,

at 1000 yard intervals round the circumference of the formation, would give a screen about 4 nautical miles in diameter, which seems fairly consistent with formations used later in the war. So, it does not seem unreasonable that all of these ships might be in one formation. That is what will be assumed.

If the formation AA is summed using the methods earlier, assuming two BBs are the target and the other ships divided in half, each counting as "escort" to one of the attacked BB's, as was done for the Lexington – Yorktown formation at Coral Sea, the defending AA score is:

	Guns	score
Attacked ship:	8 5 in guns (old BB) x .3 (early Mk 19 FC system)	2.4
	8 .50 cal = 1/8 40mm each	.14
DD's x 10:	4 5 in guns x .6 (Mk 33 FC) x ½ (escorting)	12.
CL x 1	8 5 in gins x .6 (Mk 33 FC) x ½ (escorting)	2.4
BB's x 2	8 5 in guns x .3 (Mk 19 FC) x ½ (escorting)	1.2
Total:		18.14

This score is comparable to that for Lexington and Yorktown at Coral Sea, and significantly below that for later carrier battles. The mean for all of the cases studied was 17.3, so the effect of AA can be taken as "typical" and no further adjustment made.

In all of the cases above, the discrete attacks considered were by the torpedo aircraft of a land based squadron or CV division, typically several to as many as 20 aircraft attacking together. In the larger attacks, aircraft separated to effect a coordinated attack in groups of three (shotai) or more (chutai). It seems reasonable to consider attacks on the fleet at sea coming in waves of similar size. Even in the Pearl Harbor attacks against stationary targets, which were supposed to be simultaneous, some loss of synchronization occurred. Even a few minutes between attacks provides maneuver opportunities. Furthermore, training would have been on this basis rather than a massed simultaneous attack by the entire torpedo bomber force on one formation. In effect, we are assuming that the circumstances are not terribly different than the historical attacks described.

One very significant difference between the formations attacked historically and the Pacific Fleet being at sea is that there would be a very large concentration of capital ships in one formation. This gives the defenders advantages and disadvantages. The formation would be relatively large, making coordinated attacks more difficult. Attacks from different sides would likely target different ships. On the other hand, aircraft would have opportunities to shift targets, similar to what happened to repulse (a critical hit) and as was attempted in late 1942 attacks (all missed the alternate targets).

The battleships of the Pacific Fleet were slower than the targets of the historical attacks. However, they were also much shorter, hence presenting a smaller target. The old BBs were about 600 ft in length, compared to 850 and 751 for Lexington and Yorktown and 745 ft for Prince of Wales. They also had relatively small turning radii (except Nevada). Arizona's tactical diameter was 525 yards at 16 knots, for example. Yorktown was relatively handy at 790 yard tactical diameter at 30 knots, but Lexington was 1950 yards at 33 knots. All in all, a guess is that these factors are a wash.

The historical cases include about 50% each maneuverable targets and those that are not. In an initial attack on the fleet all targets would be maneuverable, but subsequent

attacks may well pick out ships that have suffered disabling hits. What percentage of hits would be disabling is difficult to guess. In other attacks, every single attack that achieved a hit on a target disabled it or, in the case of Lexington, resulted in the loss of the ship by other means. The Pacific Fleet BB's as reconstructed had some of the best torpedo protection in the business – that had been a point of emphasis in lieu of speed. Likely they would have fared better, but would still be vulnerable to hits in the stern, though such a hit on average should not be as catastrophic as the single extraordinary initial hit on Prince of Wales. For purposes of simplicity and lacking authoritative information that would allow refinement, the same mix as for the historical cases is assumed.

The Pacific Fleet is assumed have had some CAP provided from Army airfields. The fleet sortie early on Dec 7th would still have been close to Pearl Harbor, and if there was enough time for the fleet to get to sea, there would have been enough time for fighters to get airborne. Many of the fighters were not competitive with the Japanese zero, but they still would have been an asset against torpedo bombers, as were SDB's at Coral Sea. However, the fighter cover would not have been of the quality seen in the later 1942 battles. Again, we assume a mean from the mix of circumstances including the attacks on the undefended British BBs to the attacks on the carriers as a compromise for lack of a better assumption.

The mean hit rate per drop from the historical cases was 15.5%. With 86% drops per attacking aircraft, the hit rate per attacking aircraft overall was 13.3%.

The above look at circumstances suggests that the historical averages seem like a reasonable first guess as the probabilities of hit against the Pacific Fleet. The nature of the attack itself also requires guesswork, but there are a discrete number of cases. One is the historical attack. Given preparations for a surprise attack, at some point it would be too late to change from AP bombs to torpedoes in time for the attack, and the attack would proceed with the historic aircraft loadouts and targets. Sufficient notice that the fleet would sortie would allow 50 Kates which carried AP bombs to carry torpedoes instead, and the usual tactic of mixing dive bombers with torpedo attacks would have been used. One might suppose also that aircraft from Shokaku and Zuikaku could have been used against the fleet instead of airfields, but that requires assuming that the green pilots from these carries were sufficiently prepared to make torpedo attacks, and that the Japanese would neglect to attack American airpower, the primary threat to the attacking force.

Suppose this torpedo hit rate was achieved by the historical attack, which included 40 Kates carrying torpedoes and 50 with AP bombs. That yields 5.3 torpedo hits on average, and probably less since the chances against crippled targets would be reduced by the small number of hits. AP bombs against ships free to maneuver would have probably been a waste. There might have been a few hits and a small chance of a catastrophe as happened to Arizona.

With knowledge that the fleet would sortie in time to arm the aircraft differently, the attack could have included 90 Kates from the carriers which historically attacked ships, Akagi, Kaga, Hiryu and Soryu. The expected number of hits would be 12. Some might have been directed against ships other than those targeted, as happened in Pearl Harbor and in the historical cases. These would presumably be spread in two waves, with dive bombers (which were unable to inflict lethal damage) included in each, rather

than all Kates first and Vals later as at Pearl Harbor historically. The second wave would have the opportunity to attack crippled ships, if any. So, there would be a reasonable chance that one or perhaps two BB's would be sunk as well as some others damaged. (It has been estimated that four torpedo hits would typically be needed to sink one of these ships. If that is accepted, the chance of sinking more than two is very small, and most likely one ship disabled early attracts disproportionate attention and a large proportion of the hits, as did West Virginia at Pearl Harbor and Musashi at Sibuyan Sea.)

If the additional Kates on Shokaku and Zuikaku could be used against the Pacific Fleet, then 50 or so additional torpedo capable aircraft could be counted. If the same probability of hit applies, this would yield 6 or 7 additional hits and likely an additional sinking. Two factors argue against this possibility. One is the very green new pilots on these just commissioned ships. The other is that weakening the offensive counter-air mission would both make the attack on the fleet more vulnerable to interception and would do nothing to suppress American searches and air attacks on the Japanese carrier force. If US aircraft carriers were about, and many aircraft damaged in attacking the Pacific Fleet, the Japanese force would be even more vulnerable. It was not understood at the time that land based air often was ineffective against a carrier task force; that would become more apparent at Midway, but that island had a much smaller air contingent than Pearl Harbor did.

Conclusions:

There are too many uncertainties to reach strong conclusions. Achieving 5 hits with the historical attack (and likely no BB losses) or 12 torpedo hits (with 1 or 2 BB losses) with AP bombs replaced by torpedoes at cost of many more aircraft and pilot losses by the Japanese (perhaps two carriers' worth) may be a victory for the Americans. Even with BB losses at sea, personnel casualties would probably have been lower unless a ship suffered an unlikely magazine explosion or sudden capsize (e.g. like Barham).

The circumstances of the hypothetical attack simply differ enough from the historical record that extrapolation of this sort can't be done with confidence. Much depends on one's assumptions concerning the attack. My own guess is that the Japanese would not have shown much flexibility and would have gone ahead with the historic attack even with warning as late as midnight before the attack.

Even though firm conclusions can't be reached, still, it has been an interesting exercise. The most interesting discovery made in the course of the investigation was the fact that most of the attacks against maneuvering targets that scored achieved two hits, both from the same shotai or chutai of three or four aircraft. In addition, the hits were achieved by the first such group to attack except in the case of the Yorktown. This suggests that not reacting quickly enough under attack, perhaps failure to take into account the delay in a ship answering the helm, was the prime cause of ships failig to evade. This would also perhaps explain the first hit on Prince of Wales, the only maneuverable ship to be hit without a coordinated attack. It would be interesting to pursue this hypothesis by examining World War II torpedo attacks more widely.

The failure of later attacking air flights to achieve hits is perhaps explained by the fact that a maneuverable ship can change heading faster than aircraft can achieve favorable relative position, requiring the attackers to either fly to better position within

the AA envelope, accept a low odds stern or bow shot, or give up and attack an alternate target. In other words, a well coordinated attack was very, very difficult to achieve in practice, the failure to hit Enterprise at Santa Cruz being an excellent example.

The one case of a later aircraft flight (a chutai of 5 aircraft, of which 4 dropped torpedoes) achieving hits was USS Yorktown at Midway. But this attack had the benefit of special circumstances. Yorktown was down to 20 knots, the attackers came through a cloud and happened to be in perfect position, and the attack came over the least capable AA ship in the screen. This was the best (highest hit proportion) attack of all those considered.

These observations about the attacks in general are probably of more interest than speculations about the Pearl Harbor situation.

Appendix A The Data and Analysis (from Spreadsheet)

The data:

Atk	Date	Time	Target	Attkrs	Spd	Mvrbl	AAsc	Drops	Anvil	Hits
1	12/10/41	1142	PrinceOfWales	9	28	1	10.7	8	0	1
2	12/10/41	1219	PrinceOfWales	6	16	0	2.7	6	0	3
3	12/10/41	1142	Repulse	7	31	1	5.0	7	0	0
4	12/10/41	1156	Repulse	7	31	1	5.0	7	0	0
5	12/10/41	1219	Repulse	8	31	1	5.0	7	1	1
6	12/10/41	1225	Repulse	9	0	0	5.0	9	1	3
7	5/8/42	1120	Lexington	11	34	1	15.7	10	1	2
8	5/8/42	1118	Yorktown	4	34	1	18.9	4	0	0
9	6/4/42	1440	Yorktown	9	20	1	26.3	7	1	2
10	10/27/42	900	Hornet	20	34	1	43.7	14	1	2
11	10/27/42	1028	Enterprise	16	34	1	39.9	12	1	0
12	10/27/42	1520	Hornet	7	0	0	29.7	6	0	1
			Mean	9.4	24.4	0.75	17.3	8.1	0.5	1.25
			Sigma	4.46	12.8	0.45	14.5	2.8	0.5	1.14

Correlation coefficients

	Attackers	Speed	Maneuverable	AAscore	Drops	Anvil
Top speed	0.27					
Maneuverable	0.26	0.83				
AA score	0.67	0.13	0.18			
Drops	0.89	0.24	0.22	0.54		
Anvil	0.59	0.08	0.18	0.35	0.60	
Hits	0.13	-0.48	-0.53	-0.099	0.18	0.35

Note that these are correlated weighting all attacks equally, regardless of attackers. The analysis below is similar but weights the attacks by number of attacking aircraft.

Correlation coefficients, weighted

Attack

# Attkrs	Spd	Mvrbl	Aasc	Drps	Anv	Hits	Pcthits	%drops	CAP loss
1	9	28	1	10.7	8	0	1	0.125	0.89	0
2	6	16	0	2.7	6	0	3	0.5	1	0
3	7	31	1	5.0	7	0	0	0	1	0
4	7	31	1	5.0	7	0	0	0	1	0
5	8	31	1	5.0	7	1	1	0.143	0.88	0
6	9	0	0	5.0	9	1	3	0.333	1	0
7	11	34	1	15.7	10	1	2	0.2	0.91	4
8	4	34	1	18.9	4	0	0	0	1	1
9	9	20	1	26.3	7	1	2	0.286	0.78	2
10	20	34	1	43.7	14	1	2	0.143	0.7	2
11	16	34	1	39.9	12	1	0	0	0.75	4
12	7	0	0	29.7	6	0	1	0.167	0.86	0
Sum	113				97		15			13

Weighted Averages (by numbers of attackers)

	26.1	0.81	21.9		0.65	1.32	0.155	1.08

Weighted averages by drops:

		0.78	20.0		0.61			
stdev		0.41	15.4		0.49	0.14	0.11	1.56

For dropped weapons:

Correlation: Pct drops, AA	-0.79
Correlation: Pct hits vs AA, weighted	-0.43
Correlation: percent Drops vs AA	-0.94
Correlation: Pct drops, CAP	-0.52
Correlation, Pct hits vs anvil attack	0.13
Correlation: percent Drops vs CAP	-0.50
Correlation, Pct hits vs Maneuverable	-0.74

For maneuverable only cases:

# Attkrs	Spd	Mvrbl	Aasc	Drps	An	Hits	Pcthits
#1	9	28	1	10.7	8	0	1	0.13
#3	7	31	1	5.0	7	0	0	0
#4	7	31	1	5.0	7	0	0	0
#5	8	31	1	5.0	7	1	1	0.14
#7	11	34	1	15.7	9	1	2	0.22
#8	4	34	1	18.9	4	0	0	0
#9	9	20	1	26.3	7	1	2	0.29
#10	20	34	1	43.7	14	1	2	0.14
#11	16	34	1	39.9	12	1	0	0
Sum	91				75		8	

Wtd avg by drops

31.2		22.4	0.65	1.0	0.11

Stddev by drops

4.1		15.5	0.48	0.89	0.098

Correlation, Pct hits vs AA, weighted	0.07
Correlation, Pct hits vs anvil attack	0.51