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Calculating Scenarios in the Loss of CV *Shōkaku*

Anthony P. Tully, Technical Careers

Introduction

In the Battle of the Philippine Sea (called the Battle for the Marianas by the Japanese), the Imperial Japanese Navy lost three aircraft carriers within a period of thirty-six hours. These were the Taihō, Shōkaku, and Hiyo. All three were victims of the same fateful combination of torpedo damage that set up massive vapor-induced explosions. Adequate reports exist for the Taihō and, to a lesser degree, for the Hiyo's loss. This analysis concerns itself with the third carrier mentioned, the veteran and famous Shōkaku, torpedoed and sunk by U.S.S. Cavalla (SS-244) on 19 June 1944.

The Shōkaku was indeed a famous ship, and battle-scarred as well. Her illustrious record included such battles as the attack on Pearl Harbor, the Indian Ocean sorties, the Battle of Coral Sea, and the naval battles around Guadalcanal. With sister-ship Zuikaku as part of CarDiv 5, the Shōkaku had participated in nearly every carrier battle except Midway. Indeed, some historians cite the absence of the Shōkaku and Zuikaku as the deciding factor in the Japanese defeat at Midway. Whether that is true or not, there was no denying that Shōkaku's record and crew were both of the highest standing. It was natural, then, that she and her sister should be teamed with the grand new carrier Taihō when Admiral Ozawa set forth to challenge the U.S. invasion of Saipan in June 1944.

It was hoped by the Japanese that the combination of sea and land-based air forces would turn the tide at the Battle of the Philippine Sea, but it was not to be. Taihō would perish from complications arising from a single torpedo hit, and Shōkaku herself would be sunk this selfsame day by the same agent—U.S. submarines. Yet Shōkaku's sinking is largely undocumented, which forms an unsatisfactory end to such a brilliant career. One of the missing pieces of data concerns the number of torpedoes that actually struck Shōkaku. Although this point might seem insignificant, in that the ship sank in any case, it is nevertheless a continuing point of controversy that might be solvable.[1] [2] [3] [4] [5] [6]

This paper describes the computer-based analysis that was used to help resolve this basic question. Our approach was to use a spreadsheet model Cavalla's attack, based on well-established data such as the firing interval and "flight" times of her salvo, the typical trajectory physics of a Mk. 23 torpedo, and the range, bearing and speed values for the Cavalla and her target. By doing so, we were able to create scenarios based on several different combinations of torpedo hits, and thereby derive a sense for the damage that would have resulted from each. In

the end, our calculations suggested a damage scenario for Shōkaku that was later confirmed by newly translated Japanese documents.

A Frustrating Lack of Details

The reason that Shōkaku's sinking is wrapped in mystery is that her Detailed Action Report (DAR) for the battle has apparently been lost or destroyed. Shōkaku's DAR would have given details of her damage, the damage control measures taken, and a chronology of the crew's battle to save the ship. In its absence, however, and with no detailed accounts from modern Japanese authors being available at the beginning of this study, we were left with only three brief accounts of her loss.

The first, located in Naval Technical Mission to Japan (NavTech) Report S-06-3, dated January 1946, states the following:

"Shōkaku (CV-6) - Shōkaku Class. Sunk 19 June 1944 during the Battle of the Philippine Sea. 1100 (approx.) She was west of the Marianas when struck by not more than three submarine torpedoes. One was close to the forward bomb magazines. Gasoline tanks were ruptured, and there was a fire of undetermined proportions. The fire was extinguished promptly, according to survivors, by closing all access to the spaces surrounding the gasoline tanks. Gasoline fumes, however, began to seep throughout the ship. Several hours later an enormous explosion caused her to disintegrate. It may have been her bomb magazines." [7]

The second source, "The Campaigns of the Pacific War," contained little more. Indeed, except for some internally conflicting track position coordinates, the only added information found in this source is a repeated assertion that Shōkaku was hit by four torpedoes. This presents a discrepancy between the two American accounts regarding the number of hits. [8]

Then, in 1952, less than ten years after these reports were written, Fukaya Hajime wrote an article on the Shōkaku-class vessels for U.S. Naval Institute Proceedings. Though his account of the sinking is brief, it adds a remarkable additional detail as given from the Japanese side. Fukaya writes that after the torpedoes hit Shōkaku, "damage to the carrier, already severe, was compounded by the outbreak of fires which soon enveloped the entire ship. The situation soon became hopeless as the ship settled rapidly by the bow. Water quickly reached the flight deck and spilled through the open Number 1 elevator into the hanger. Thus stricken the Shōkaku lost stability, turned over, and sank". [9]

With the exception of a few other scant notes, these three sources form the core of nearly every English account of Shōkaku's sinking. Though modern Japanese sources or memoirs were hoped to exist, the primary source quotes above represented the sum total discovered by the authors prior to our analysis of Shōkaku's loss. Such sparseness of detail, for so great a ship, seemed a

gap in the historical record.

However, these reports did give a vital clue—the fact that one of the torpedoes had hit in Shōkaku's forward aviation fuel stores. Given this, the authors were challenged to reconstruct the sinking mathematically, as has been done with such noted success recently with RMS Titanic. Though such a reconstruction could only be speculation, the temptation to try was spurred by the fact that (in contrast to the IJN records) the U.S. side of the account was amply covered. Cavalla's full attack report includes the firing angles and sequences of the torpedoes launched at her target. Armed with this, we resolved to match the Cavalla's attack figures to the one fixed point - the hit near the forward bomb magazines - and proceed from there, bearing in mind the historical conditions that had to be satisfied. What began as an analytical exercise later evolved into a feature web article when a modern Japanese source account was found, and contributed important and unique details to our analysis. It was found that our original analysis, while speculative, did in fact exhibit striking correlations to the new information discovered.[10]

Modeling the Attack on Shōkaku

Circumstances of the Attack

At 1100 19 June 1944 the three carriers Taiho, Zuikaku, and Shōkaku were steaming in formation, having launched air strikes against the U.S. carrier fleet covering the invasion of the Marianas. The trio formed a spearhead, with Zuikaku in the lead, and the Taiho and Shōkaku on the port and starboard quarters of the formation respectively. The demise of the Japanese formation began at 0810, when the USS Albacore slammed a fateful single torpedo hit into Ozawa's flagship Taiho. The Taiho shrugged off the damage, but fumes were gathering below decks that would eventually reach a fatal concentration.

Cavalla's attack occurred nearly three hours after the strike on Taihō. She had approached the southern flank of the Japanese fleet and at 1048 had sighted the Shōkaku in the process of landing a recon patrol. Excitedly, the Cavalla's skipper, Lt. Comdr. Herman Kossler, had watched as the big Japanese carrier steamed a steady course into the southeast wind, raising large bow waves. The destroyer Urakaze steamed alongside to starboard, seemingly oblivious to the submarine's presence, while two cruisers (identified by Cavalla at the time as Atago-class) were ahead off the carrier's port bow. (Actually these were the light cruiser Yahagi and probably heavy cruiser Haguro.) It was nearly a perfect setup. At 1118, after raising his periscope a scant three times, the Cavalla unleashed a salvo of six torpedoes at Shōkaku's starboard side at a range of 1,200 yards.

Cavalla's log gives us three crucial pieces of data with which to reconstruct the attack:

- First, it details exactly the bearings of all six torpedoes fired, and their firing

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sequence.
- Second, it details Cavalla's and Shōkaku's course and speed.
- Third, it provides fairly exact timings of torpedo impacts against Shōkaku.

Modeling the Engagement

Given these clues, we went about filling in the details of the torpedo attack and the likely impact points of the torpedoes against Shōkaku. The geometry of Cavalla's torpedo spread was known, and could be reconstructed fairly exactly. To do so, a mathematical model of the engagement was built which accounted for:

- A rather complex torpedo launch sequence, wherein the torpedo is being launched at a slower speed, accelerating, and turning to the correct bearing, all within the first six to eight seconds after launch.
- Cavalla's motion through the water
- Target motion

Thirty years ago, one might have approached this problem by writing a FORTRAN program to calculate the relative positions of the submarine and her 6 torpedoes on a second-by-second basis. If the scope of this study had included a larger number of ships or scenarios to be evaluated, a programmatic approach would have been warranted. But for six torpedo trajectories, it was simpler to calculate the positions as the sum of lines and arcs which mathematically represented the events. The equations were entered into a spreadsheet to facilitate the calculations as the “model” evolved. These equations were based on the various firing, course, and target angles described in the diagram below.

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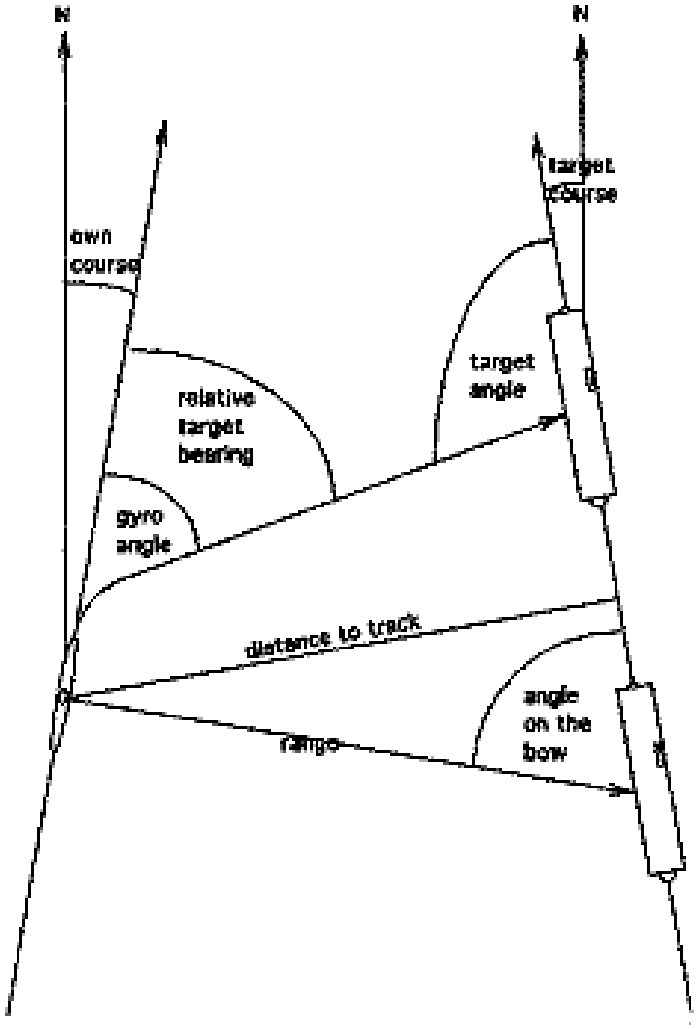

Figure 1. General Submarine attack parameters

The following assumptions were used to reconstruct the engagement:

1) Cavalla was traveling at 3 knots (5 feet/sec.) on course 025 True.[11]

2) Torpedoes are fired at 8-second intervals (per Cavalla's log), leading to a 40-second firing sequence, with torpedo launches at T=0, 8, 16, 24, 32, and 40 seconds. Cavalla will move roughly 200 feet forward during this time interval.

3) Mk 23 torpedo will leave the tube at 30 knots (50.66 feet/sec.)

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4) Upon leaving the tube, the torpedo will move forward on a straight line for 120 feet to avoid making a turn into Cavalla's bow.

5) Thereafter, the torpedo will continue accelerating and begin turning to its final heading. It will accelerate to 90% of full speed within 6 seconds, and up to full speed within 8.4 seconds (per conversation with Mr. Fred Milford, a noted authority on WWII torpedoes).

6) Cavalla's torpedoes are fired on the following bearings:

#1 fired with 107 track angle, gyro 017 (042 True)
#2 fired with 110 track angle, gyro 020 (045 True)
#3 fired with 120 track angle, gyro 030 (055 True)
#4 fired with 112 track angle, gyro 022 (047 True)
#5 fired with 134 track angle, gyro 044 (069 True)
#6 fired with 122 track angle, gyro 032 (057 True)

7) U.S. Mk 23 torpedoes run at 46 knots (77.68 feet/sec.)

8) Shōkaku is moving on course 115 True, at a speed of 25 knots (42.22 feet/sec.)

9) Estimated "wander" (the amount a torpedo will vary from its initial course track) for a Mk 23 torpedo over a range of 1,200 to 1,500 yards is assumed to be negligible (per conversation with F. Milford), and will be a matter of a few feet.

10) Shōkaku will not slow appreciably during the course of this engagement, even though her power may be knocked out. Shōkaku is a large ship, and her momentum is assumed to carry her through the engagement at nearly constant speed.

11) Shōkaku is assumed to not take any evasive action during the attack, and will therefore not make any course changes. It is unlikely in any case that a course change would have had any effect during at least the first sixteen seconds of the engagement, which is when the critical torpedoes strike home. One source in the Japanese record does mention beginning a turn to comb the wakes, but makes it clear that this action was too late to work.

Cavalla's Attack

The diagram below illustrates Cavalla's attack, with the submarine moving at 3 knots on course 025 True, firing a torpedo every 8 seconds. For sake of simplicity, torpedo run-outs and turning arcs are not represented.

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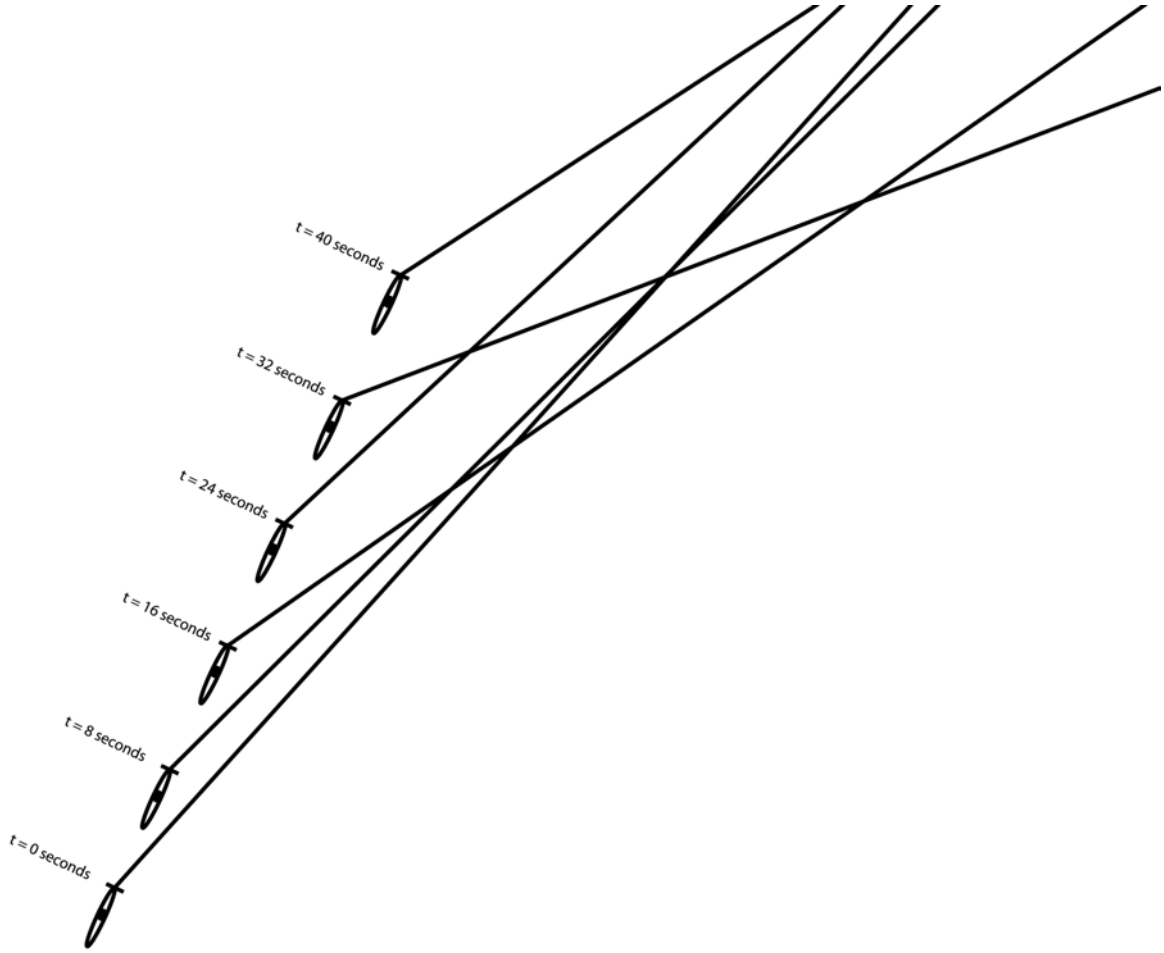

Figure 2. Simplified submarine/torpedo trajectories

The next illustration takes the simplified diagram presented above and amplifies the detailed trajectory for a single torpedo. This helps illustrate the calculations developed in the spreadsheet model. In this case, torpedo #2 (fired at T=8 seconds) is shown.

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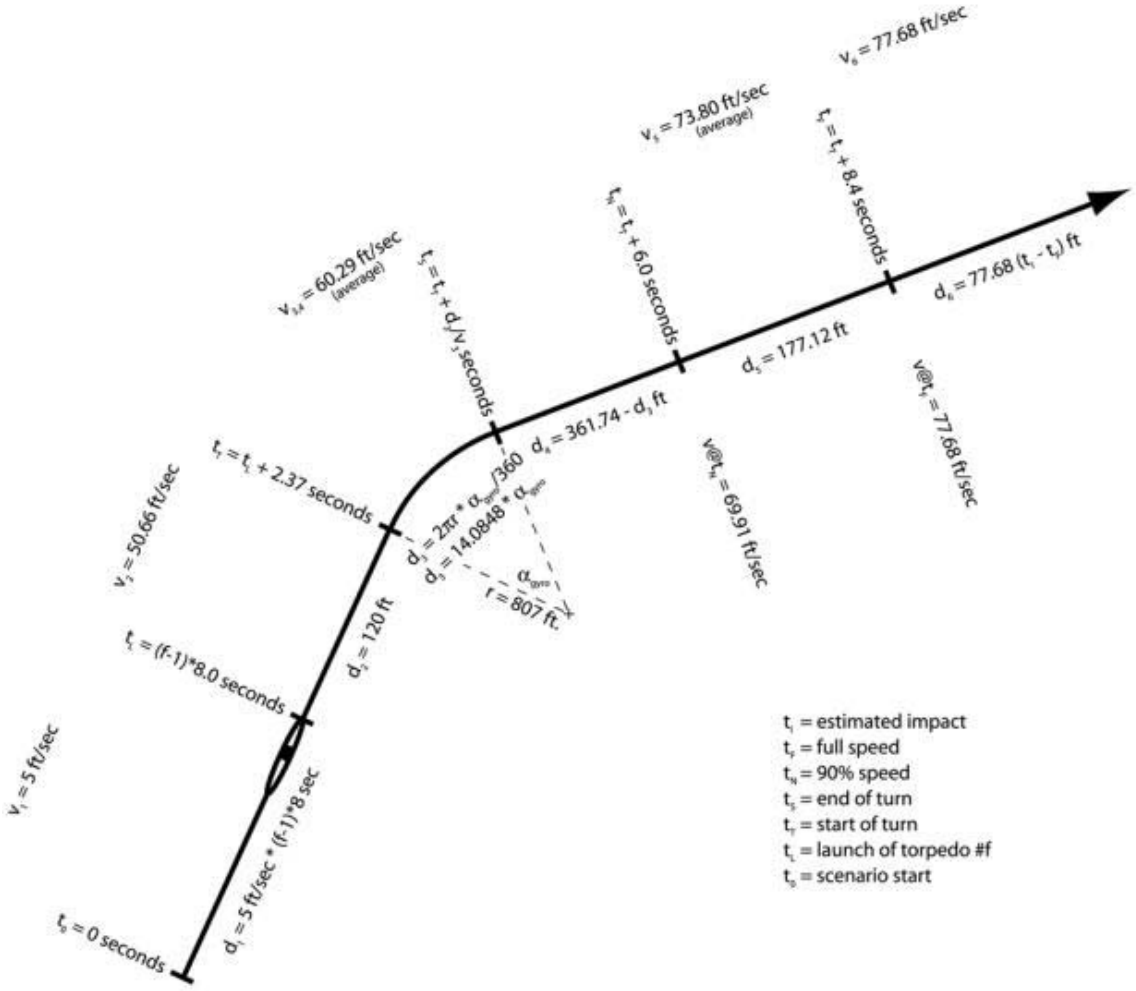

Figure 3. Detailed torpedo trajectory

Modeling Shōkaku's Motion

Once the geometry of the torpedo spread was created, the next step was to reconstruct the motion of Shōkaku. This was trickier to do, since we knew very little about her relative position and movements other than her course and speed. From Cavalla's records, we know she was hit by torpedo #1 at T=50 seconds. Furthermore, Cavalla's log claims that probably the first three torpedoes hit Shōkaku, with hits occurring at 8 second intervals. Lastly, Japanese accounts indicate that at least one torpedo struck in the forward aviation gasoline storage tanks.

Damage Scenarios

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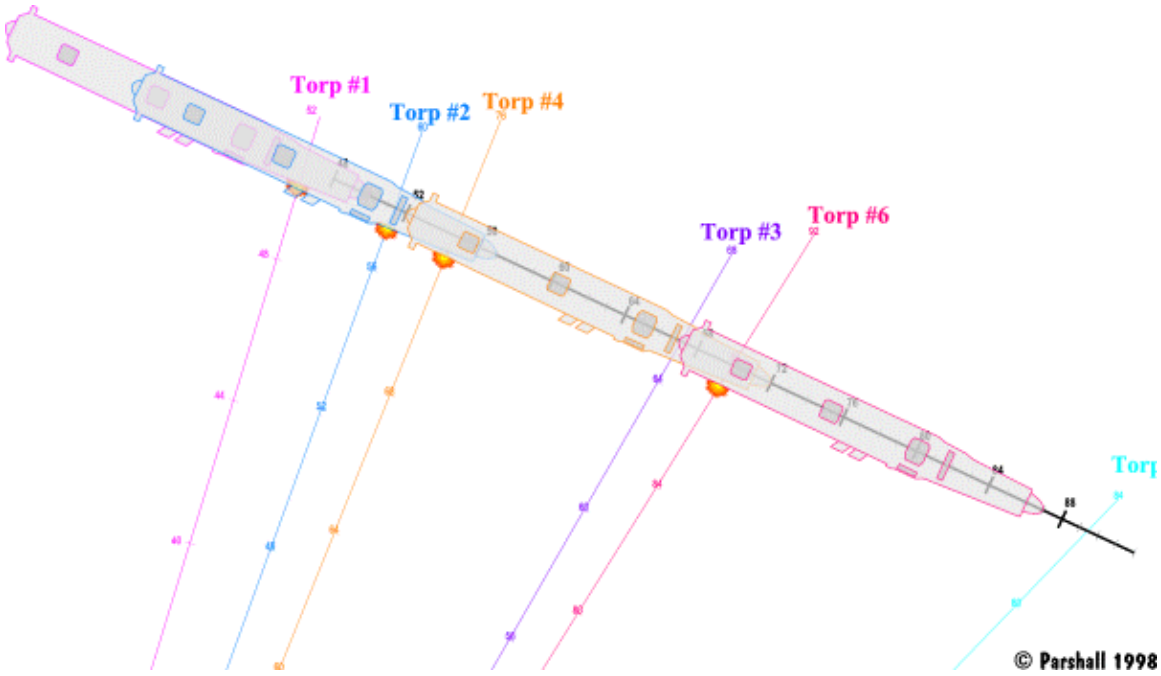
Armed with this knowledge, we set about creating three separate scenarios in which the Shōkaku's aviation gas storage was hit by either torpedo #1, #2, or #3. By placing Shōkaku relative to a torpedo striking the forward avgas and then "moving" the ship mathematically backwards and forwards along her course track at the proper speed and bearing, it was possible to determine where the other torpedoes hit (or missed) for each specific scenario. A graphical example of the outcome of this method is shown below:



The results of this approach were intriguing, to say the least, and we discuss each of the three resulting hit scenarios below.

Scenario #1

In scenario #1, it is assumed that it is torpedo #1 that strikes Shōkaku's avgas, at T=50 seconds. This scenario also produces a hit by torpedo #2 at T=57 seconds which impacts Shōkaku almost directly on the bulkhead dividing Boiler Rooms #3 and #5. Torpedo #3 then hits at the forward end of the bridge. Torpedo #4 misses astern by about 130 feet. Torpedo #5 hits some 60 feet behind the bow. Torpedo #6 misses astern by nearly 300 feet.

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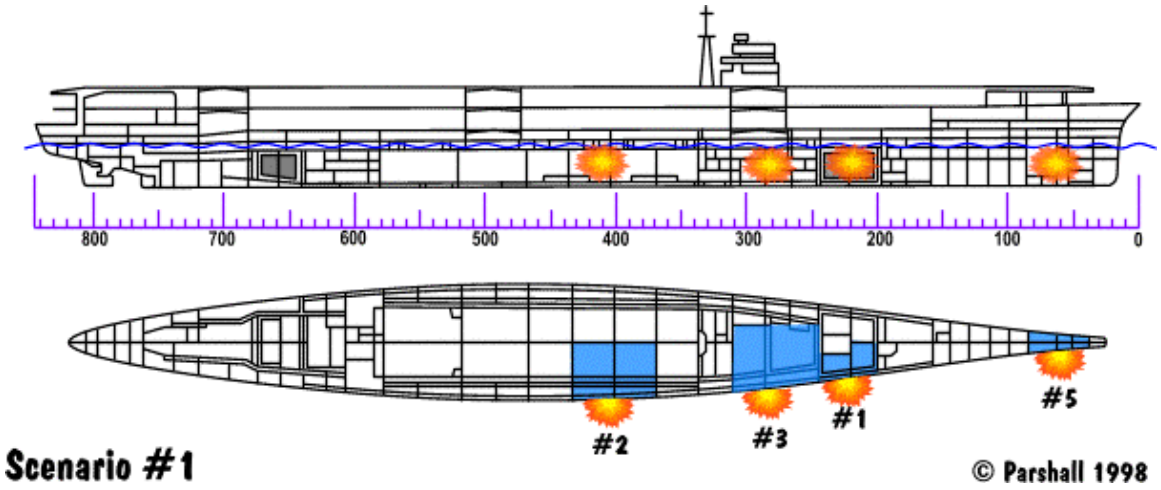

Analysis: This scenario produces four hits in the forward half of the ship, and causes heavy flooding. Torpedo #1 causes the requisite damage to the avgas storage and starts fires. Torpedo #2 would most likely flood two of Shōkaku's eight boiler rooms, and might stop Shōkaku's machinery as well (there are several instances of large Japanese warships having their propulsion systems incapacitated by a single torpedo hit). Torpedo #3 hits on or near the forward magazines and torpedo storage area, and likely contributes to the damage already sustained near the avgas storage. After this third hit, Shōkaku may have had as much as one hundred sixty feet of her starboard length flooded, including a number of large machinery spaces. This would have undoubtedly caused a starboard list. In the midst of this chaos, Torpedo #5 then hits home well forward, possibly blowing a hole through both sides of the bow (which is no more than 15-20 feet in breadth in this region. This hit would cause still more flooding and would contribute to the bow trim (mentioned in some Japanese sources) by virtue of the relatively larger flooding moment that such a hit in the extremities would produce. The overall damage profile is one of extensive flooding forward, serious fires, an imminent danger to the forward magazines themselves, and heavy damage to the boiler rooms.

Scenario #2

In scenario #2, torpedo #2 is presumed to strike the avgas at T=57 seconds. By backtracking to T=50, we find that torpedo #1 hits the extreme end of the bow. Torpedo #3 hits about 60 feet further aft of Torpedo #1. Torpedo #4 hits almost directly on the rudder. Torpedo #5 misses ahead by more than 130 feet. Torpedo #6 misses astern by about 90 feet.

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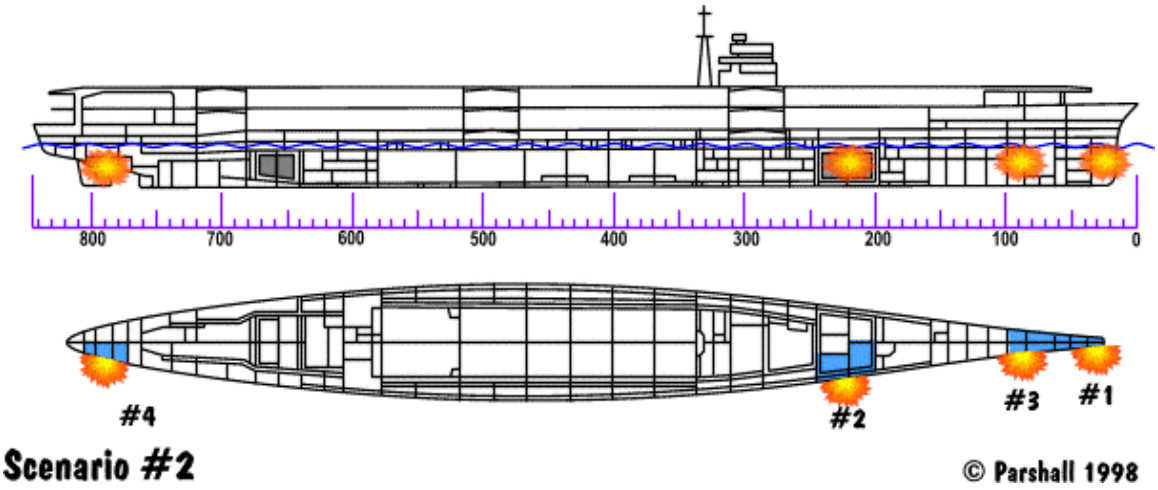

Analysis: Scenario #2 produces a damage profile which puts three hits in the bow of the ship, and one hit in the stern. The two bow hits at the extreme stem would likely produce the bow trim mentioned in the Japanese record. The hit in the avgas (by default) produces fires. However, the hit in the rudder area is not mentioned in any of the Japanese accounts. The failure to note a hit in this region is extremely unlikely, given both the critical nature of this space to the ship's operations, and the large separation between it and the hits forward (which would have made it even more noticeable).

Scenario #3

Scenario #3 produces three hits against the ship. Torpedo #1 strikes forward, near the rearmost bow trim tank. Torpedo #2 hits Boiler Room #1 directly. Torpedo #3 hits the avgas. Torpedo #4 misses astern by about 70 feet. Torpedo #5 just barely misses the bow by a matter of a few feet, (although the overhang of the stem makes this distance even larger and almost ensures a miss). Torpedo #6 misses astern by more than 200 feet.

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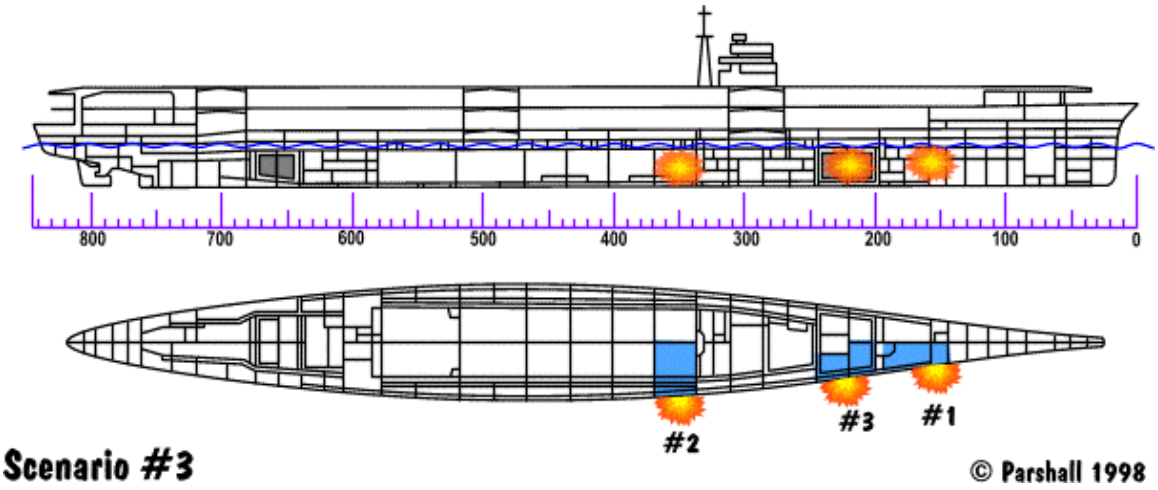

Analysis: This third scenario produces a damage profile similar, but not as severe, as Scenario #1. A bow trim is again likely as a result of the damage, and some machinery damage is in evidence as well, with Boiler Room #1 being flooded and damage to the forward generator (which was just forward of the forward pair of boiler rooms) likely. The hit in the extreme bow contributes to the bow trim.

Evaluating the Scenarios

We then examined the three scenarios for a best fit with the historical data. In order to satisfy the record, a good scenario should fulfill all of the following criteria:

1) Does it fracture the av-gas tank?
2) Does it likely cause a bow-heavy trim and steady settling to develop?
3) Does it inflict sufficient machinery damage to stop the carrier?
4) Does it seem to account for an immediate loss of electrical power?
5) Does it support a #1-#2-#3 torpedo hit pattern as reported by *Cavalla*?
6) Does it start fires?
7) Does it give four hits rather than just three, as the Japanese tend to believe?

The results matrix for the scenarios is presented below:

Scenarios/Criteria	One	Two	Three
Avgas Hit?	Yes (by default)	Yes (by default)	Yes (by default)
Causes Bow Trim?	Yes	Yes	Yes
Machinery Damage?	Yes	No	Maybe
Loss of Electrical Power?	Maybe	No	Probably
#1-#2-#3 Hits?	Yes	Yes	Yes

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#1-#2-#3 Hits?	Yes	Yes	Yes
Starts Fires?	Yes (by default)	Yes (by default)	Yes (by default)
4 Hits Total?	Yes	Yes	No

Scenario Analysis

Beyond the matrix presented above, each of the scenarios has its strengths and (in some cases) weaknesses. Scenario #2 is the weakest of the three. First, it is hampered by a rudder hit, which is at odds with the historical record by its omission. It also produces no direct damage to the machinery of the ship. The fact that Shōkaku ground to a halt relatively close by Cavalla is a clear indication that her machinery was rendered inoperable very quickly. The fastest way to accomplish this is through direct damage to either the boilers or the engine rooms, neither of which is supported by this scenario.

Scenario #3, while matching the letter of the base criteria, begins to look less promising on closer inspection. It produces only three hits, and an examination of the hits reveals that only #3 (the hit in the avgas) can really be considered serious, although the hit on the forward boiler room could be more serious if it also damaged the generator spaces immediately forward (which is a distinct possibility). However, the overall impression one gets is of a ship that is only moderately damaged. The Japanese record suggests a far more devastating set of circumstances had actually occurred.

Scenario #1 produces just such a situation. The four hits are spaced all along the bow and manage to hit just about everything of value there, including the avgas, magazines, and machinery spaces. Torpedo #3, in particular, strikes a particularly vital point in the carrier and acts as a damage multiplier for torpedoes #1 and #2 because it threatens both machinery (in this case the electrical generating equipment immediately forward of the boiler rooms) as well as the avgas and magazines. This hit would likely complicate damage control efforts in both of the earlier hit locales. Not only that, but many of the spaces hit under this scenario (boiler rooms and magazines) are relatively large (and tall), meaning that flooding would be more severe and produce larger lists. If this scenario was true, Shōkaku probably lost two boiler rooms instantly, and had further fires burning forward of the engine spaces. The final hit in the bow is well placed to destroy the navigability of the vessel and also exacerbate the bow trim by virtue of its placement on the extreme end of the ship. The net result is a damage profile of unusual severity.

An additional point in the historic record also supports this scenario. One Japanese source mentions specifically that the initial hit sent a combination of water and burning substances in a spray across the front of the bridge, killing several aviators gathered on the flight deck there. This description strongly indicates that it was the initial hit that impacted the aviation gasoline stores. All in all, in the authors' estimation, this scenario fits the historical record almost

perfectly.

Error Analysis

Our analysis was subject to a number of sources of potential error. We discuss these, and their likely impacts below.

The course tracks for Cavalla, Shōkaku, and the torpedoes may be in error. This is a possibility; however, Cavalla's logs seem fairly detailed with regards to obtaining an accurate course and speed for the target. In order to produce a valid target solution, Cavalla had to generate accurate course tracks for Shōkaku. The nature of this attack seems to be an orderly one - Cavalla was able to launch a well thought-out spread at the target, rather than simply loosing a volley in desperation as she dove deep.

The timing of the initial hit on Cavalla at T=50 seconds may be in error. At the speed the torpedo spread was traveling, and given the angles of the spread, any discrepancy here would necessarily introduce a large error in the impact points of the torpedoes. Our response to this mainly rests on the timing of the impacts produced by the mathematical model we built. In this model, when we fed course data of the two ships, as well as firing data, we got back impact times which match the 8-second separation of the historical record very closely (within a second).

The torpedoes may not run true, or may run faster or slower than rated. After discussing this possibility with Dr. Frederick Milford, a noted expert on WWII torpedo technology, we discounted this factor. By this point in the war, American torpedoes had generally worked out the teething problems that had plagued them earlier in the war. Dr. Milford's opinion was that the torpedoes would most likely "perform as advertised", and would therefore strike very close to their predicted impact points. The Mk 23 torpedo's "wander" (the amount of lateral inaccuracy over the range traveled) at a range of 1,200-1,500 yards would most likely be a matter of a few feet, not yards.

The forward aviation gasoline storage area itself is a fairly large target, leading to corresponding uncertainty as to the precise point of impact in this area. This, in turn, would affect the accuracy of the other hits as well. Shōkaku's forward aviation fuel tanks cover approximately 40 feet of her length. A hit anywhere in this region, or even fairly near it, would produce the fires mentioned in the historical record. As a result, an error of plus or minus 25 feet is probably not a bad margin of error to apply to the predicted hit locations of the other torpedoes as well. Obviously, this has potentially important implications. To try and make this potential source of inaccuracy more apparent, we have intentionally chosen to size our "torpedo hit" icons in our illustrations such that they take up an area roughly equal to this margin of error.

Shōkaku's starboard evasive maneuver, while insufficient to avoid the first three torpedoes, may

have caused later torpedoes to miss. Furthermore, if Shōkaku's machinery was damaged immediately by the initial hits, she may have slowed enough to cause later torpedoes to miss ahead. This applies mostly to Scenarios #1 and #2, which predict Shōkaku taking hits in the extreme bow. In the authors' opinions, the possibility that later hits may have been affected by Shōkaku's maneuvers cannot be discounted. However, it also cannot be modeled with any degree of accuracy. Given the relative 'cleanness' of the model we had managed to build, we decided not to tamper with it on the basis of the very speculative evidence at hand regarding Shōkaku's despairing efforts at evasion. The turning and/or slowing of the ship does potentially produce one fewer hits on the ship, if it actually occurred. Without better evidence that it did occur, we chose not to modify the fundamentals of the model.

Confirmation from New Sources

What has the record revealed since the time of our study? As it happens, since that time some interesting confirmation has come from Japanese sources.

In "Nihon Kubo Senshi" (History of Japanese Aircraft Carriers) by Kimata Jiro, the author quotes a Shōkaku engineering officer who knew the details of the impacts.[12] According to Chief Engineering Petty Officer Miyazaki Tomotsu, the first torpedo struck at the front of the main control panel room, which is below and forward of the ship's bridge. The second torpedo hit starboard amidships in the aft transformer room and immediately disabled half the electric lights of the ship. The third and last torpedo also hit forward. Unfortunately, some of the vagaries of translation obscure the third hit's location. Kimata seems to say that it hit between the spare aircraft workroom, the electrical machinery workshop, and the electrical generation room, although it is unclear exactly where these are. The plans of the Shōkaku show that the electrical generator was located on the hold deck (lowest other than bilges) just aft of the forward elevator well. The result of the third torpedo hit was to disable No.1 boiler either from vibration or explosion. Shōkaku was reduced to steaming on three shafts, though initially she was still capable of 25 knots.'

The new data in Kimata's book also potentially explains a question raised by our most likely scenario, namely, how did Shōkaku avoid a fourth hit by the No.5 torpedo if she had indeed lost power? The answer seems to be that she did not lose any speed, and was under full evasive action. Given power for a brief time, and a hard starboard turn, it is possible for the No.5 torpedo to miss ahead. The net result was a fascinating correlation with Scenario #1. Moving hit No.1 aft 30-40 feet, and making a similar adjustment of 40 feet for hit No.3, would almost precisely match Scenario # 1 with Kimata's description.

Towards a New Account

At the start of the analysis we were in suspense regarding whether four or three torpedoes had hit

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Shōkaku. USS Cavalla herself had claimed specifically only three, and more importantly, that all three of the first fired had hit. The most detailed Japanese source available immediately post-war said Shōkaku was hit by "no more than three" torpedoes, one of which cracked the av-gas tank forward. Upon learning from more recent accounts that Shōkaku sighted four torpedoes bearing 60 degrees to starboard, it appears likely that she evaded one successfully, and the certainty of this was used to imply "no more than three". This is however, speculation.

The new Japanese sources provide striking confirmation for the Cavalla's claim, as apparently all three of the first torpedoes hit. The first struck beneath and forward of the island. The second struck amidships, apparently disabling a transformer room, of which there were about three aboard. The third torpedo hit the forward generator room, or "center" generator room, as aft there were two generators, side by side on the outboard flanks.

Kimata's book also goes on to elaborate on the effects of the torpedo hits. The initial hits opened up the starboard side forward, and set raging fuel-fires in the hangars from just-landed and fueling aircraft. Initial flooding was so severe that damage control over-compensated, canting Shōkaku over into a port list. Despite this, the flooding at first appeared manageable. The best evidence suggests that none of the eight large boiler room spaces were actually flooded, and only No.1 boiler was knocked off line by the hits. If the engine rooms also remained dry, this put the bulk of Shōkaku's flooding forward.

Though much has been made of fuel vapor building up in the carrier and suddenly exploding to cause her loss, this may in fact be a lacuna in the text from the loss of the Taiho. None of the detailed evidence suggests a massive explosion on Shōkaku. At least, not until the very moment of the final plunge. Instead, Kimata's account indicates that her fires were never fully under control, and that progressive flooding worsened beyond recall till the forecastle was awash.

Shōkaku's Sinking

While still submerged, USS Cavalla felt four heavy detonations at 1408 to 1411. Though the precise facts remains unclear, it now appears that these were in fact underwater explosions, as Yahagi sent a signal at 1400 that Shōkaku had sunk. Many Japanese sources list 1401 as the sinking time, though some list 1410. In support of this interpretation is the fact that no primary Japanese source implies that Shōkaku blew apart and then sank. In fact, no detailed Japanese source even mentions her exploding as Taihō did, but simply say she was torpedoed and sunk. The three sources that describe the sinking in narration fashion all imply that Shōkaku was ablaze, and gradually settled by the bow until she upended and sank. They do not mention a terrific above surface explosion. The explosions would then have taken place just after the final plunge, or even under water, as in the case of the Soryu and the Kirishima. The one other primary source, USS Cavalla's war log, clearly states that breaking up noises and flooding was heard as early as 1330. This is consistent with Shōkaku commencing her final settling a bit prior

to 1400. Finally, it should be noted that the 1945 NavTech damage summary - which specifically warns much of its information is not correct -- is really the only source for Shōkaku being sunk by massive explosion.

Conclusion

While computer-aided simulation can never be a substitute for a good primary account, it should be apparent from this exercise that a quality simulation can be a useful tool in any naval historian's "kit bag." In Shōkaku's case, computer simulation allowed us to generate some fairly detailed conclusions regarding the number of torpedo hits, their sequence, and the rough damage profile suffered by Shōkaku as a result of each competing scenario. The simulation also allowed us to identify key questions that needed answering, such as why Torpedo #5 apparently missed, despite the model's indicating it ought to have hit. This gave us things to look for when newer conventional sources became available.

The other valuable lesson to be learned from this exercise is that sophisticated tools are not always required for creating a good simulation. In this case, a spreadsheet, access to an expert on torpedoes, the use of high-school trigonometry, and ample sweat and common sense were sufficient to produce a model that was relatively simple to implement and produced results that were sufficient for our needs. It is our belief that too much attention to detail in simulation development is generally unwise. Instead, the urge to develop detail for detail's sake must be curbed by the knowledge that the basic data in many cases does not warrant excessive treatment. Indeed, a simulation should be driven as much by a sense for the magnitude of the likely errors in the data as by the data itself. For instance, although we could have simulated the turn of the torpedoes out of the tube more "precisely", we were painfully aware that the running time of the torpedo out of the tube until it began its turn was largely a matter of educated guesswork anyway. Introducing needless complications to the simulation in this regard was therefore unwarranted. Knowing when to say "good enough" is often just as important as knowing how to use the tools at hand.

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[1] Japan Self-Defense Agency. "Boeicho Kenshujo Senshishitsu (BKS), Vol. 12 - Marianas Campaign".

"At 1120 Shokaku was torpedoed, caught fire, and sunk at 1410 in position 12°00' N, 137°46' E. Number of torpedo hits are not certain; survivors disagreed whether it was 3 or 4 hits."

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[2] Kojinsha. Maru Special Series "Imperial Japanese Navy, Vol. 3: Aircraft Carriers, Part I", 1994.

"On 19 June 1944 attacked by submarine. 4 torpedoes hit, inducing fire from gasoline tank. Big fire resulted. Bombs exploded, and ship sank. 887 crew members and 376 of Air Group 601 were lost, for a total of 1,263 sharing the fate of the ship."

[3] Samuel Eliot Morison. "History of United States Naval Operations in World War II, Volume VIII: New Guinea and the Marianas, March 1944 - August 1944", Little, Brown and Co., 1953.

Page 281:

"... the first three hit... The time was about 1220. Shokaku fell out of the formation, Urakaze standing by. Ruptured gasoline tanks started fires which damage control dealt with promptly, but deadly fumes continued to seep through the ship. ....Shortly after 1500 Kossler began to hear explosions and prolonged, monstrous rumblings. These were the death rattles of Shokaku. A bomb magazine had exploded, and the big carrier literally fell apart."

[4] William T. Y'blood, "Red Sun Setting", U. S. Naval Institute Press, 1981.

Page 128:

"Although Kossler had heard only three explosions, four torpedoes had actually slammed into the Shokaku at 1220. The big carrier slowed and fell out of formation. Flames raged through the ship and explosions tore her apart. The Shokaku's damage control personnel were better than the Taiho's and got many of the fires under control, but they could not contain them all. And all the while, the deadly fumes from ruptured gas tanks, and tanks carrying the Tarakan petroleum, were seeping throughout the ship."

"The Shokaku was doomed. Her bow settled lower and lower in the water. Finally the water began to pour into the ship through her open forward elevator. Shortly after 1500 the fires cooked off a magazine and this explosion, intensified by volatile fumes, ripped the carrier apart. What was left of her turned over and sank at 12°00' N, 137°46' E. The Shokaku took with her 1,263 officers and men (out of a complement of about 2,000) and nine aircraft."

[5] Norman Polmar. "Aircraft Carriers: A Graphic History of Carrier Aviation and its Influence on World Events", Doubleday, 1969.

Note: Since Polmar collaborated with Minoru Genda on this book, this account may be a reliable connection of the magazine explosion and the forward lift flooding being in that order, rather than just "guessed".

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"At about 1220 three of the torpedoes slammed into the Shokaku. The three torpedo hits caused the Shokaku to fall out of line. Her fuel tanks were ruptured and fires flared up. Although damage control parties made good progress against the fires, deadly fumes from the volatile, unrefined Borneo fuel oil spread through the ship.

"The fumes created an explosive atmosphere which, shortly after 3.pm, caused the 25,675 ton Shokaku to blow apart. Her shattered hulk, enveloped in flames, began to sink by the bow. As her head went down water poured into the hangar deck through the forward elevator well and the ship quickly rolled over and sank. There were few survivors; 1,263 officers and enlisted men were lost-nine planes - five Judy, two Jill, and two Val bombers - went down with Shokaku."

[6] Paul S. Dull, "A Battle History of the Imperial Japanese Navy (1941-1945), U. S. Naval Institute Press, 1978.

Page 308:

"...at 1222, the submarine Cavalla got four torpedoes into the heavy carrier Shokaku. The carrier lost power and was engulfed in flame; despite valiant efforts to save her, the flames reached her magazines, and at 1510 she blew apart and sank."

[7] U.S. Naval Technical Mission to Japan, "Reports of Damage to Japanese Warships - Article 3, Japanese Records of Major Warship Losses", Index No. S-06-3, January 1946.

This source describes damage and sinkings of Japanese warships in two different sections that are very similar, but differ in minor details.

The first section is a series of 'capsule reports' that were compiled from interviews of naval designers and constructors from the Japanese Naval Ministry, written reports from the Naval Ministry, and various USSBS interrogation reports. The personnel interviewed included Technical Rear Admiral Yagasaki [Masatsume] and Technical Captain Inagawa, ex-IJN, of the Design Branch, Fourth Section (Ship Construction), Technical Department, Japanese Naval Ministry. These men were especially knowledgeable of the design and construction details of the Japanese aircraft carriers and had participated in the panels that investigated sinkings of many Japanese carriers."

For SHOKAKU, it reads:

"6. SHOKAKU (CV-6) - SHOKAKU Class. Sunk 19 June 1944 during the Battle of the Philippine Sea. She was west of the Marianas when struck by not more than three submarine torpedoes. One was close to the forward bomb magazines. Gasoline tanks were ruptured, and there was a fire of undetermined proportions. Several hours later an enormous explosion caused her to disintegrate. It may have been her bomb magazines"

The second part of S-06-3 includes what is termed Enclosure (A), "Second Repatriation Department, Historical Survey Section, Japanese Government Report to NavTechJap, dated 15 December 1945. It is stated as being "based almost entirely on Japanese Naval Action Reports, submitted by the Commanding

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Officer or by the Senior Surviving Officer (as the case might be) for the various ships. It was submitted to NavTechJap in the Japanese language and translated by U.S. Naval Officers (Japanese Language Officers) assisted by civilian employees (Japanese Nationals) of NavTechJap." It can be considered as a brief of official Japanese naval action reports.

Note: Curiously enough, NavTechJap's review finds the enclosure untrustworthy and suspect. However, in the vast majority of cases where one of the authors (A. Tully) has been able to compare the original records, the summaries are faithful reproductions. A few have gross errors, like the KUMANO, but some of the more blatant errors are merely due to translation slips, as in KUMA vs. TAMA. In addition, historian S.E. Morison found it sufficiently accurate that he used it for his Marianas volume. The following quote is THE source for Morison's description of the fate of SHOKAKU, and hence most of the writers after him.

The Enclosure A entry for Shokaku reads:

"9. SHOKAKU

Sunk 19 June 1944 by submarine.

1100 (approx.) Struck by three torpedoes from a submarine, resulting in a gasoline fire of unreported proportions. The fire was extinguished promptly, according to survivors, by closing all access to the spaces surrounding the gasoline tanks. Gasoline fumes, however, began to seep throughout the ship. Several hours later an enormous explosion occurred and SHOKAKU disintegrated."

[8] United States Strategic Bombing Survey (Pacific), "The Campaigns of the Pacific War", United States Government Printing Office, 1946.

WDC 161517, "First Mobile Fleet Classified No. 1048 (5 September 1944), Detailed Battle Report of AGO Operations":

Page 243:

"On the same day [19 June], the Shokaku was attacked with torpedoes by an enemy submarine at 1120 (4 torpedoes hit). Caught fire and sank at 1401. (Position: 12°00' N, 137°46' E).

WDC 239992, "Impressions and Battle Lessons (Air) in the 'A' Operations":

Page 262:

"At 1120 the Shokaku was subjected to enemy submarine torpedo attacks (four hits) causing fire to break out and to sink at 1401."

Page 269:

"The Case of the Shokaku (carrier) -

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1. One cause of suffering an explosion on the ship in this battle seemed to have been leakage of gasoline from a damaged tank. It is necessary to consider a preventive measure to safeguard fuel tanks. One suggestion will be a need of cutting off the fuel load to one half. Any space obtained in reconditioning should be directed to safeguard fuel tanks.

2. The position of gasoline tanks should be located farther away from the hangar.

3. The gasoline tanks should be more strongly safeguarded and be so constructed that a slight damage will not cause leakage.

4. The part adjacent to to the gasoline tanks should be partitioned to small units. Each of such units should be equipped with a powerful ventilator. And it is also necessary to have proper equipment with which the hangar can be ventilated rapidly.

5. It is essential to install an outlet and its accessory with which gasoline can be drained rapidly when in need. This concerns with the fate of the carrier. This important item should be considered soon and acted upon."

[9] Hajime Fukaya, (edited by Martin E. Holbrook); "The Shokakus - Pearl Harbor to Leyte Gulf", U. S. Naval Institute Proceedings, June 1952, pp. 638-641.

Fukaya relates that "The first blow came from an unexpected source. At 2:01 P.M. on June 19, 1944, the Shokaku while 140 miles north of Yap Island was torpedoed three times by the U.S. submarine Cavalla. Damage to the carrier, already severe, was compounded by the outbreak of serious fires which soon enveloped the entire ship. The situation soon became hopeless as the ship settled rapidly by the bow. Water quickly reached the flight deck and spilled through the open No. 1 elevator into the hanger. Thus stricken the Shokaku lost stability, turned over, and sank".

[10] Edo, Yuusuke. Higeki "Mariana oki no shichimenchouchi" (The Tragic "Marianas Turkeyshoot"), Kojinsha, 1992. pp. 252-261

Translation paraphrased and abbreviated slightly:

Page 252:

"At 1120, because of the out-ranging tactics adopted by Ozawa, the Shokaku was cruising back and forth in the same general area at a slow speed. Since she was engaged in landing operations and attention was focused skyward for enemy planes, attention was lacking to the sea surface and the lookouts careless in regard to searching for submarines, words to that effect. Suddenly at this time the lookouts noticed 4 torpedo tracks bearing approaching from 60 degrees starboard, far too close to avoid. The helm was turned but it was too late. "3 to 4 torpedoes hit the ship. They struck on the starboard side forward, and also on the starboard side amidships. The first hit directly before the island, blasting fire and spray over the bridge and burning several aviators relaxing there. Since aircraft had just been landed, and were just then having been stored in the hangar, there was much fuel and materials about. Immediately a massive fire broke out, and an explosion blasted the hangar and raised all the elevators 90 centimeters.

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As a result of the flooding from the torpedo holes, the Shokaku began to list quickly to starboard; to correct this, spaces were counterflooded on the port side----but this was done *too well*---with the result that Shokaku canted back over with a *reverse* heel to port! [Important detail. Ed.] and became waterlogged.

Meanwhile the hangar had become an inferno, for all power failed immediately, electric circuits went out, and extinguishing gear could not be used, no could anyone reach the hangar's mains. Therefore the crew desperately resorted to portable extinguishers and *bucket bridgades*---but this could not of course prevail against the fire, which also "dropped down like rain upon their heads" [av-gas burning and leaking from pipes? Ed.].

Shokaku became unnavigable, with the bow dipping, and stopped dead in the water. Many crew had died when they fell into the flames of hangar when the lifts jumped from the hits, and others had bodies "torn apart and scattered" by the explosions. Captain Matsubara soon realized that hope was lost, and gave the order for all hands to assemble and abandon the ship. Men went around calling for comrades, and several hundreds of men gathered on the flight deck for roll call even though the ocean had "already begun to swallow the front, having started to wash over the forecastle deck and was rising nearly to the level of the flight deck forward". Still the roll call continued for many sections, while others threw rafts and debris overboard and then lept after them.

Fires and explosions continued to increase, and then suddenly the ship upended, causing "sevaral hundreds" of men to slide from their feet on the flight deck aft all the way down to a fiery hell as they fell helplessly into the open fire-filled No.3 elevator; others tried to hang on for dear life. [Translator made grave expression as he read this, saying that the translation is describing *exactly* the effect of the movie Titanic which he had seen - just as horrible as the end. This made clear many otherwise vague words. Ed.].

At 2:10 the carrier finally "swung straight up" and with a "groaning roar" disappeared. Survivors remaining in the water began to sing with "blood tears" the Shokaku's ship song. The account gave the figures of 570 survivors, with 1,272 officers and men lost, and specifically called attention to the fact that the death toll was greater than carrier KAGA, which means the Japanese felt that flattop's casualty count keenly late in the war----a poignant detail.

[11] Cavalla, Report of War Patrol No. 1, No serial, 3 August 1944.

CAVALLA's report reveals:

(using "I" time zone reference, per own current position)

1119 First torpedo of six fired hits Shokaku after 50 second run, followed by 2 and 3 at 8 second intervals, the next three miss.

1320 By now, only one destroyer (Urakaze?) is still working the Cavalla over of the three that initially pounced on her.

1330 Depth charging moves further away, but remains between Cavalla and scene of attack. About this time JP sound gear "began to report loud water noises in the direction of the attack."

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1352 Cavalla commences planing up to periscope depth, with depth charges still heard intermittently, as well "could loud disturbance still be heard by JP in direction of attack."

1408-1411 "Four terrific explosions were heard in direction of attack. These were not depth charges or bombs, as their rumbling continued for many seconds."

1421 Cavalla reaches periscope depth:"Nothing in sight, visibility poor due to rain squalls all around."

1429 Cavalla secured from depth charge and silent running.

Note: Cavalla's Patrol Report gives the initial siting position as: 11°49' N, 137°52' E, and the attack is conducted at position 11°50' N, 137°57' E. This a steady easterly march of Shokaku at 25 knots on course 115 True. The Mobile Fleet Diary gives sinking position of Shokaku as: 12°00' N, 137°46' E.

Kossler's Radio Report:

"Hit Shokaku class carrier with three out of six torpedoes at zero two one five...accompanied by two Atago-class cruisers three destroyers possibly more..received 105 depth charges during three hour period...hull induction flooded...no other serious trouble...sure we can handle it...heard four terrific explosions in direction of target two and one half hours after attack...believe that baby sank."

[12] Kimata, Jirō. *Nihon kubo senshi [The History of Japanese Carrier Operations]*. Tokyo: Tosho Shuppansha, 1977.