

Original Study

Open Access

Yuki Yagi*

The Imperial Japanese Navy and the battle of the Philippine Sea: An analysis of the main causes of defeat

DOI 10.2478/jms-2021-0006

Received: December 01, 2020; Accepted: April 07, 2021

Abstract: This article aims to demonstrate through mathematical analysis that the primary reason for the defeat of the Imperial Japanese Navy (IJN) in the battle of the Philippine Sea during World War II (WWII) was quantitative, and that the defeat is particularly attributable to the lack of force concentration. Scholars have placed much emphasis on the qualitative aspects of the forces involved, such as the skill of IJN pilots or the air defence capabilities of the United States Navy (USN), in seeking to explain the Japanese defeat. We, however, assert that in this naval battle, quantitative factors played a more important role than qualitative ones. Accordingly, we offer an improved version of the mathematical model of Armstrong and Powell, which was previously used to analyse battles between aircraft carriers (CVs). The coefficients in our mathematical model will then be estimated and verified using historical data from the main battles between CVs of the IJN and USN during WWII. Finally, we will analyse the factors underlying the IJN's defeat in the Battle of the Philippine Sea using the model. This study proposes a useful technique for evaluating quantitative and qualitative aspects of naval forces.

Keywords: naval tactics, military history, combat modeling, Word War II

1 Introduction

This article aims to identify the major cause of the Imperial Japanese Navy's (IJN) defeat in the Battle of the Philippine Sea between the IJN and the United States Navy (USN) during World War II (WWII). Relying on mathematical analysis, it will be shown that the IJN's defeat was not for

qualitative reasons, as has usually been emphasised, but for quantitative ones, particularly the lack of force concentration. This naval battle, fought between large-scale carrier forces, took place off the Mariana Islands from June 19 to 20, 1944 (防衛庁 [Defense Agency of Japan] 1971d, p. 473–475). The IJN launched a large-scale, pre-emptive strike from nine aircraft carriers (CVs) against USN task forces, but the air defence systems (Combat Air Patrols (CAPs) and Anti-Air (AA) fire from ships) of the latter severely hampered this attack. Far from damaging the enemy CVs, the IJN lost most of their attacking aircraft (防衛庁 [Defense Agency of Japan] 1971d, p. 473–475). Meanwhile, the IJN carrier group was attacked by USN submarines and naval aviation from the task force, losing three CVs. As a result of this battle, the IJN's carrier group exhausted most of its air power and consequently lost air operational capabilities (防衛庁 [Defense Agency of Japan] 1971d, p. 636).

In Japan, the deterioration in the quality of Japanese pilots and improvements in USN air defence systems were pointed out as the main factors behind this defeat (防衛庁 [Defense Agency of Japan] 1971d, p. 637–638). During the battle, the IJN attempted to exploit the longer range of its planes by attacking the USN task force while remaining outside the operational range of USN aircraft. As a result, it has been noted that IJN aircraft that were responsible for carrying out the attacks were forced to undertake difficult, long-distance flights, even before they could begin to attack their opponents (防衛庁 [Defense Agency of Japan] 1971d, p. 638). Also, as the number of skilled IJN pilots had been depleted by air operations over New Guinea and earlier battles, the skill levels of Japanese naval aviators overall had significantly declined since the commencement of the war (由良 [Yura] 2012). Conversely, the USN had dramatically improved its air defence capabilities (防衛庁 [Defense Agency of Japan] 1971d, p. 638). Consequently, it has been argued that the main factors in the IJN's failure in the operation were qualitative, including IJN pilot skill and USN air defence capability (防衛庁 [Defense Agency of Japan] 1971d, p. 638).

*Corresponding author: Yuki Yagi, Master of Arts, Master of Engineering, Escort Flotilla 4, the Japan Maritime Self-Defense Force; E-mail: y.yagi.jmsdf@gmail.com

In this article, we assert that quantitative factors played a more important role in the battle than qualitative ones, and we introduce a mathematical model for battles between aircraft carriers. Thus, we first offer an improved version of the mathematical model of Armstrong and Powell (2005), who analysed the Battle of the Coral Sea, also fought between aircraft carriers. Second, the coefficients in the mathematical model will be estimated and verified using historical data from the Battles of the Coral Sea, Midway, the Eastern Solomons and the Santa Cruz Islands, all of which represent the principal battles between the aircraft carriers of the IJN and USN during WWII. Finally, we analyse the factors underlying the IJN defeat in the Battle of the Philippine Sea using the model. This analysis indicates that the main cause of the IJN's defeat was not related to any lacuna in pilot skills or air defence capabilities, but rather to a lack of force, which was caused by the dispersion of IJN resources. Thus, we also introduce a useful technique to evaluate quantitative and qualitative aspects of naval forces.

2 Mathematical model

2.1 Formulation

In this section, we improve the mathematical model for battles between CVs introduced by Armstrong and Powell (2005). Their analysis of the Battle of the Coral Sea, based on the Hughes Salvo Model (1996), is as described below:

$$(A\alpha - B\beta)E = D \quad (1)$$

A : number of attackers

α : ratio of the number of attackers arriving on the battlefield to the number launched from CVs

B : number of fighters on CVs

β : probability of successful interception by CAPs

E : CVs lost per surviving attacker

D : number of CVs lost

α , β , and E are expressed as follows:

$$\alpha = \frac{a}{A} \quad (2)$$

$$\beta = \frac{b}{B} \quad (3)$$

$$E = \frac{df}{(a-b)} \quad (4)$$

a : number of attackers arriving on the battlefield

d : number of hits on CVs

f : CVs lost per hit

In this model, the number of attackers that dropped bombs or torpedoes on an enemy CV is represented by $(A\alpha - B\beta)$. When multiplied by E , representing the number of CVs lost per attacker, the number of carriers likely to be destroyed in battle can be determined.

The coefficients A , B , a , b , and D may be determined using historical data. f is calculated based on data from Hughes (2000, p. 157) and using the average displacement of each carrier. α , β , and E are calculated using Eqs (2)–(4). Armstrong and Powell (2005) used this model to analyse the results of the battle, under counter-factual circumstances, such as an increase in the number of USN CVs or a change in the ratio of defending fighters to attacking fighters.

Armstrong and Powell (2005) cautioned that their model could not be applied to other naval battles due to the fact of different circumstances prevailing and a lack of data. Furthermore, the accuracy of their model could be criticised for relying on the following simple assumptions about the effectiveness of air defences (naval AA fire and CAP):

1. All destroyed attackers shall be deemed to have been shot down by CAPs.
2. All destroyed attackers shall be deemed not to have dropped a bomb or torpedo.
3. All surviving attackers shall be deemed to have dropped a bomb or torpedo on a CV.

These assumptions do not necessarily hold in an actual battle. For example:

1. Multiple attackers were shot down by AA fire from ships, including CVs. It was reported that about 35% of damage sustained by IJN attackers during the Battle of the Coral Sea was due to an AA fire caused by USN ships (防衛庁 [Defense Agency of Japan] 1971a, p. 319–320).
2. Some attackers were shot down after dropping bombs or torpedoes. In the Battle of the Coral Sea, about half of IJN's attackers appear to have been shot down after completing their attacks (防衛庁 [Defense Agency of Japan] 1971a, p. 310–319).
3. Not all surviving attackers actually participated in an attack. It was noted that six USN attackers simply returned to their CVs at the Battle of Midway, having

been damaged by IJN fighters, though not destroyed (防衛庁 [Defense Agency of Japan] 1971a, p. 351).

We suggest modifications to the mathematical model of Armstrong and Powell to ensure generality and to more accurately incorporate the effects of air defence systems. To obtain detailed data, Japanese records on the military history of WWII (戦史叢書 [Senshi-soshō]) are used in conjunction with US materials. The following mathematical models are introduced in this article:

$$(A_t \alpha_t - S\gamma) P = d \quad (5)$$

$$\alpha_t = \frac{a}{A_t} \quad (6)$$

A_t : number of attackers on IJN CVs

α_t : ratio of the number of attackers arriving on the

battlefield to the number of attackers on IJN CVs

a : number of attackers arriving on the battlefield

γ : distraction effect per CAP fighter

S : number of CAP fighters

P : hit ratio of bombs and torpedoes per attacker

d : estimated number of hits on USN CVs

In this model, $S\gamma$ represents a defensive effect of CAPs, including obstruction of attackers, and $(A\alpha - S\gamma)$ indicates the number of attackers that dropped bombs or torpedoes on CVs. Multiplying this by P (the hit-ratio of bombs and torpedoes per attacker) yields d (the estimated number of hits on CVs). The effect of AA fire from ships, including CVs, is included in P . In this model, α_t , γ and P are assumed to follow a normal distribution, allowing their means ($\mu_\gamma, \mu_p, \mu_{\alpha_t}$) and variances ($\sigma_\gamma^2, \sigma_p^2, \sigma_{\alpha_t}^2$) to be estimated from historical data. Several sets of coefficients (A_t, a, S, d) can be obtained from data for each of the naval battles in which IJN carrier groups attacked USN task forces. The values of each coefficient in the case j are then defined as A_{tj}, a_j, S_j and d_j . Eqs (7)–(12) for each of these three cases may then be written as elucidated in the forthcoming Cases. Since this model does not rely on the assumptions of Armstrong and Powell (2005), it incorporates the effects of air defence systems more accurately. Moreover, it uses a statistical method based on data from several cases to ensure generality. The data for each case is given in the Appendix.

Case 1: Battle of the Coral Sea

Strike from Shokaku and Zuikaku on USS Yorktown and USS Lexington

$$(A_{t1} \alpha_t - S_1 \gamma) P = d_1 \quad (7)$$

$$\alpha_t = \frac{a_1}{A_{t1}} \quad (8)$$

Case 2: Battle of Midway

Strike from Hiryu on USS Yorktown

$$(A_{t2} \alpha_t - S_2 \gamma) P = d_2 \quad (9)$$

$$\alpha_t = \frac{a_2}{A_{t2}} \quad (10)$$

Case 3: Battle of the Eastern Solomons

Strike from Shokaku and Zuikaku on USS Enterprise, USS Saratoga, and USS Wasp

$$(A_{t3} \alpha_t - S_3 \gamma) P = d_3 \quad (11)$$

$$\alpha_t = \frac{a_3}{A_{t3}} \quad (12)$$

Thus, the values of the coefficients α_t , γ and P derived from these equations are the following:

$$\{\gamma, P\} = \{0.885, 0.320\}, \{0.807, 0.267\}, \{0.834, 0.306\}$$

$$\{\alpha_t\} = \{0.567\}, \{0.778\}, \{0.600\}$$

From these values, the mean ($\mu_\gamma, \mu_p, \mu_{\alpha_t}$) and variance ($\sigma_\gamma^2, \sigma_p^2, \sigma_{\alpha_t}^2$) of each coefficient is estimated as follows:

$$\mu_\gamma = 0.842$$

$$\mu_p = 0.298$$

$$\mu_{\alpha_t} = 0.648$$

$$\sigma_\gamma^2 = 0.507 \times 10^{-3}$$

$$\sigma_p^2 = 1.037 \times 10^{-3}$$

$$\sigma_{\alpha_t}^2 = 8.587 \times 10^{-3}$$

The mean (μ_d), variance (σ_d^2) and expected number ($E[d]$, confidence interval: 95%) of hits in an IJN attack may then be calculated as follows:

$$\mu_d = (A \mu_{\alpha_t} - S \mu_\gamma) \mu_p \quad (13)$$

$$\sigma_d^2 = A \left(\sigma_{\alpha_t}^2 \sigma_p^2 + \mu_{\alpha_t}^2 \sigma_p^2 + \mu_p^2 \sigma_{\alpha_t}^2 \right) - S \left(\sigma_\gamma^2 \sigma_p^2 + \mu_\gamma^2 \sigma_p^2 + \mu_p^2 \sigma_\gamma^2 \right) \quad (14)$$

$$\mu_d - 1.96 \sqrt{\sigma_d^2} \leq E[d] \leq \mu_d + 1.96 \sqrt{\sigma_d^2} \quad (15)$$

2.2 Verification

To verify the validity of this mathematical model, we compared the results of the calculation with historical data. The Battle of the Santa Cruz Islands, which occurred after the three cases that are used to implement the model, is used for validation. The calculation results (mean (μ_{d_4}), variance ($\sigma_{d_4}^2$) and expected value ($E[d_4]$, confidence interval: 95%)) are as elucidated in the forthcoming Cases. The historical data used are shown in the Appendix.

Case 4: Battle of the Santa Cruz Islands

Strike from Shokaku, Zuikaku and Zuiho on USS Hornet and USS Enterprise

$$\mu_{d_4} = (A_4 \mu_\alpha - S_4 \mu_\gamma) \mu_p = 8.997 \quad (16)$$

$$\sigma_{d_4}^2 = A_4 \left(\sigma_{\alpha_i}^2 \sigma_p^2 + \mu_{\alpha_i}^2 \sigma_p^2 + \mu_p^2 \sigma_{\alpha_i}^2 \right) - S_4 \left(\sigma_{\gamma_i}^2 \sigma_p^2 + \mu_{\gamma_i}^2 \sigma_p^2 + \mu_p^2 \sigma_{\gamma_i}^2 \right) = 0.0767 \quad (17)$$

$$8.454 \leq E[d_4] \leq 9.540 \quad (18)$$

The actual number of hits was nine ($d_4 = 9$) (Morison 1984, p. 212–218), which agreed with the calculation results (Eqs (16) and (18)), suggesting that the results derived from the mathematical model are valid.

2.3 Analysis

In this section, the decision of Vice Admiral Ozawa, the IJN carrier groups' commander at the Battle of the Philippine Sea, is analysed. Prior to the battle, Ozawa knew that his carrier group had a smaller air force when compared to that of the USN task force. The IJN group consisted of three CVs and six light aircraft carriers (CVLs), while

Ozawa had received information that the USN task force comprised seven CVs and eight CVLs (防衛庁 [Defense Agency of Japan] 1971d, p. 531). However, the IJN carrier group proceeded with their first strike against the USN despite having inferior air forces because Ozawa considered that a pre-emptive strike would be effective in a battle between carrier groups (防衛庁 [Defense Agency of Japan] 1971d, p. 390).

For Case 5, we analyse this battle using the mathematical model introduced in this article. First, since data on the number of aircraft in CAPs could not be located, we have estimated the number of fighters protecting the USN task force from the incoming IJN strike. This is assumed to be proportional to the total number of fighters on board the CVs. The number of fighters on board each CV, and those on CAP in each battle, are shown in Table 1. The average ratio between the number of fighters available, and those on CAP, was found to be 0.503. As the USN carried 470 fighters in the Battle of the Philippine Sea (Hughes 2000, p. 107), the number in the CAP is estimated at 236. The data used are shown in the Appendix. The result of the calculation is given in Eq. (19).

Case 5: Battle of the Philippine Sea

$$\mu_{d_5} = (A_5 \mu_\alpha - S_5 \mu_\gamma) \mu_p = -7.058 \quad (19)$$

The negative result in Eq. (19) signifies that the mean number of IJN attackers breaking through the USN CAPs is negative ($A_5 \mu_\alpha - S_5 \mu_\gamma = -23.712 < 0$). The expected number of IJN attackers breaking through the USN air defence ($E[A_5 \mu_\alpha - S_5 \mu_\gamma]$, confidence interval: 95%) is represented by the following equation:

$$-24.255 \leq E[A_5 \mu_\alpha - S_5 \mu_\gamma] \leq -23.169 \quad (20)$$

This indicates that the IJN attackers would not be able to break through the USN CAP's defence.

Tab. 1: Ratio of the number of fighters on CAP to the total number on CVs¹

	Number of fighters on CAP	Total number of fighters on CVs	Ratio of fighters on CAP to total number on CVs
Battle of the Coral Sea	17	42	0.405
Battle of Midway	14	25	0.560
Battle of the Eastern Solomons	53	100	0.530
Total	84	167	0.503

¹ Data from 防衛庁 [Defense Agency of Japan] 1971a, p. 86–87

防衛庁 [Defense Agency of Japan] 1971c, p. 396, 436–437

Morison 1984, p. 84–87, 93

Lundstrom 2007, p. 312

Lundstrom 2006, p. 188

Sherman 1950, p. 106–109.

This result suggests that Ozawa's decision was reckless. In the actual battle, the IJN attackers were destroyed without causing damage to the USN CVs; this result is similar to that predicted by the mathematical model. Ozawa's assumption—that a relatively small air strike force could produce good results in the battle between CVs if it could attack first—was proven wrong. The fact deserves to be reiterated that Armstrong (2014) pointed out that, in the battle between aircraft carriers, it is advantageous to attack first. However, as shown in this article, even if an attack is launched first, it cannot achieve a positive result if attacking aircraft are unable to break through the enemy's air defences. As demonstrated by Hughes, this indicates the importance of force concentration and pre-emptive attack ('attack effectively first') (Hughes 2000, p. 41–46). Accordingly, it can be said that the main factor that resulted in the IJN's defeat was that it could not concentrate its forces sufficiently to damage the USN CVs.

3 Discussion

Qualitative aspects of the forces involved, such as the lack of skilled pilots and the dramatic evolution of USN air defences, have usually been the focus of explanations for the failure of the IJN's attack in the Battle of the Philippine Sea. Although the skills of IJN pilots at the beginning of the war were highly regarded, these had significantly diminished by 1944, since many experienced aircrews had been lost in previous battles, such as the Battles of Midway or New Guinea (防衛庁 [Defense Agency of Japan] 1971d, p. 376; 由良 [Yura] 2012). Tanaka and Okumiya, who were aviation staff officers of the IJN's Combined Fleet Command, also pointed out that the quality of pilots had deteriorated by that time (防衛庁 [Defense Agency of Japan] 1971d, p. 380). Furthermore, the USN had improved its air defence system drastically (防衛庁 [Defense Agency of Japan] 1971d, p. 680). Thus, the significant role of these qualitative factors in the failure of the IJN attacks has been heavily emphasised (防衛庁 [Defense Agency of Japan] 1971d, p. 638; 奥宮 [Okumiya] 1993, p. 617).

Conversely, quantitative factors could have also been major contributors to the failure of the IJN. In the mathematical model presented in this article, coefficients were determined based on data from cases in which the deterioration in the skill of the IJN air force and the improvement in the capability of the USN air defences have small effects. It has been pointed out that a major cause of the decline in the skills of IJN pilots was the attrition in New Guinea, which had been going on since 1943 (由良 [Yura], 2012). Furthermore, the introduction of proximity fuses

(VT fuse) in 1943 had a significant impact on AA performance (H. Q., Commander in Chief, US Fleet, 1945). Therefore, the analysis presented in this article clearly shows that IJN forces (especially the number of attackers) were insufficient to damage the USN effectively, even excluding the qualitative disparities in its capabilities.

A major cause of the IJN's inability to concentrate its forces was the failure of coordination between the carrier group and land-based air forces. In this operation, both naval and land-based aircraft were intended to focus their attacks on the USN task forces (防衛庁 [Defense Agency of Japan] 1971d, p. 333). In early June 1944, the land-based air force was numerically well equipped, comprising of approximately 500 aircraft (including 240 strike aircraft) (防衛庁 [Defense Agency of Japan] 1971d, p. 408). Also, as of June 15, just before the start of the operation, reinforcements of approximately 60 attackers had arrived (防衛庁 [Defense Agency of Japan] 1971d, p. 569); thus, the land-based air force was able to operate 300 attack aircraft. Some of this force, however, had been diverted to New Guinea. Furthermore, the land-based air force had already engaged in repeated counterattacks in response to USN air raids on its bases in the Mariana Islands before the operation began (防衛庁 [Defense Agency of Japan] 1971d, p. 479–480). Since forces had been depleted even before the commencement of operations, joint operations were difficult (防衛庁 [Defense Agency of Japan] 1971d, p. 479–480).

For Case 6, we consider a situation in which the IJN could concentrate its forces, using a mathematical model which incorporates the influence of qualitative factors. These factors include the reduced skill of IJN pilots and the increased efficiency of USN air defences, particularly AA fire. In the mathematical model (Eq. (13)), the decline in the skills of IJN pilots would increase γ and decrease P . Similarly, the improvement of USN AA fire would reduce P . Therefore, the mathematical model is expressed as follows:

Case 6: Battle of the Philippine Sea (counter-factual)

IJN attacks with combined land-based and carrier forces.

$$\mu_{d_6} = \left[A_6 \mu_{\alpha_i} - \frac{S_6}{R} \mu_{\gamma} \right] \frac{\mu_p R}{I} \quad (21)$$

$$\sigma_{d_6}^2 = \frac{A_6 R}{I} \left(\sigma_{\alpha_i}^2 \sigma_p^2 + \mu_{\alpha_i}^2 \sigma_p^2 + \mu_p^2 \sigma_{\alpha_i}^2 \right) - \frac{S_6}{I} \left(\sigma_{\gamma}^2 \sigma_p^2 + \mu_{\gamma}^2 \sigma_p^2 + \mu_p^2 \sigma_{\gamma}^2 \right) \quad (22)$$

R : coefficient expressing reduction in IJN pilot skill

I : coefficient expressing improvement in USN AA fire

To evaluate pilot skill, we used total flying time as an indicator. The following is an estimate of the average total flying time of IJN carrier force pilots at the Battles of the Santa Cruz Islands (October 1, 1942) and the Philippine Sea (June 1, 1944) (川崎 [Kawasaki] 2007, p. 308–309).

October 1, 1942: 1,146 h

June 1, 1944: 853 h

Thus, the average total flying time decreased by about 15.9%. Assuming that total flight time is proportional to the skill of the pilot, $R = 0.841$ is estimated. Next, the efficiency of AA fire by the USN is measured by the number of aircraft shot down. As the USN improved its capabilities, such as by increasing the number of AA batteries on ships or introducing proximity fuses, the loss of IJN attackers rapidly increased (H. Q., Commander in Chief, US Fleet, 1945). In fact, AA fire shot down only 16.8 planes per month in 1942, compared with 28.5 in early 1944 (H. Q., Commander in Chief, US Fleet, 1945). Assuming that the frequency of IJN attacks on the USN in 1942 and 1944 was the same, the efficiency of AA fire is considered to have improved by a factor of 1.7; thus $I = 1.7$ is estimated. Assuming that two-thirds of IJN land-based attackers could strike jointly with the carrier force, the results of the mathematical model can be expressed as follows. The data used are shown in the Appendix.

$$\mu_{d_6} = \left[A_6 \mu_{\alpha_i} - \frac{S_6}{R} \mu_{\gamma} \right] \frac{\mu_p R}{I} = 10.066 \quad (23)$$

$$\sigma_{d_6}^2 = \frac{A_6 R}{I} \left(\sigma_{\alpha_i}^2 \sigma_p^2 + \mu_{\alpha_i}^2 \sigma_p^2 + \mu_p^2 \sigma_{\alpha_i}^2 \right) \quad (24)$$

$$- \frac{S_6}{I} \left(\sigma_{\gamma}^2 \sigma_p^2 + \mu_{\gamma}^2 \sigma_p^2 + \mu_p^2 \sigma_{\gamma}^2 \right) = 0.172$$

$$9.252 \leq E[d_6] \leq 10.879 \quad (25)$$

According to Armstrong and Powell (2005), the damage sustained by USN CVs per IJN attacker's bomb or torpedo was as follows:

1 Val 250 kg bomb = 0.2433 firepower kills per hit

1 Kate torpedo = 0.5459 firepower kills per hit

'Firepower kill' means 'knock out of the battle, though not necessarily sink' (Armstrong and Powell, 2005). Therefore, we assume that IJN attacks average 0.395 firepower kills per hit. The expected number of CVs lost ($E[D_6]$, confidence interval: 95%) due to IJN attacks, assuming the IJN carrier group and land-based air force operated in a concentrated manner, is expressed in the form of the following equation:

$$3.655 \leq E[D_6] \leq 4.297 \quad (26)$$

This indicates that the IJN could potentially have defeated over 30% of the USN task force. These losses would have forced the USN to halt its invasion of the Mariana Islands temporarily. It could thus be said that the IJN might have achieved its objectives by improving quantitative factors through cooperation with land-based air forces, even if qualitative factors are taken into account. In other words, the main cause of defeat in this naval battle was not qualitative in nature, but quantitative, through the failure to concentrate forces.

4 Conclusion

This article demonstrates that the main factor underlying the IJN's defeat at the Battle of the Philippine Sea was not qualitative factors, such as lack of pilot skills or improvement in USN air defences, but quantitative, specifically the failure to concentrate forces adequately. We first improved the mathematical model of Armstrong and Powell (2005), to incorporate the effectiveness of air defence systems accurately and to ensure its generality. We then confirmed that the mathematical model produced reasonable results by comparing these results with battle-related data, not including data used for parameter determination. Finally, we sought to identify the main cause of the failure of the IJN's attack in the Battle of the Philippine Sea, using this mathematical model. Our results confirmed that the IJN's attack had little chance of success due to the limited forces employed, even excluding the impacts of reduced pilot quality and improvement in USN air defences. We also demonstrated that the IJN could have achieved their objective by concentrating their land-based and carrier forces, as indicated in the IJN's operational plan. This demonstrates that the main factor in the IJN's defeat was quantitative (primarily, lack of force concentration).

Previous Japanese analyses of the main causes of defeat in this battle seem to have been influenced by cultural attitudes. The role of qualitative factors was particularly emphasised, especially in the IJN. For example, Okumiya, then an aviation staff officer in the combined fleet, claimed that the cause of the failure was an inadequacy in the quality of the pilots deployed in the operations comprising the battle, for the operational plan (奥宮 [Okumiya] 1993, p. 617). The reason for the IJN's focus on pilot skill may lie in a cultural emphasis on quality. As Japan's national power had been smaller relative to competitors such as Russia or the USA, the IJN had traditionally focused on improving the capabilities of its forces through training, to bridge the numerical gap.

Marshal-Admiral Togo, the Commander in Chief of the Combined Fleet of IJN during the Russo-Japanese War, commented that '[w]hen we understand that one gun which scores a hundred percent of hits is a match for a hundred of the enemy's guns each of which scores only one percent, it becomes evident that we sailors must have recourse before everything to the strength which is over and above externals' (New York Times 28 Feb., 1906, p. 4), highlighting the importance of improvement in quality over quantity. This cultural predisposition may have influenced earlier analyses by prompting a focus on qualitative matters.

In Japan, the culture of compensating for quantitative shortfalls with qualitative improvements persists today. In fact, Ito points out that even contemporary Japanese companies have a culture of improving performance through the qualitative advantage of a small number of employees (伊藤 [Ito] 2014). In matters of security, too, although it has been pointed out that the Japan Self-Defense Force (JSDF) is quantitatively inferior to the People's Liberation Army of China (PLA) (Yoshihara 2020), some have suggested that this can be countered qualitatively. For example, the retired general of the JSDF suggested that the JSDF could counter the PLA in some islands of the East China Sea by emphasising the qualitative aspects. (渡部 [Watanabe] 2020, p. 144-148). However, if a huge numerical difference exists, such as in the numbers of assets in a naval battle, it may be difficult to overcome this gap purely through qualitative improvement. As Hughes (1996) pointed out, the difference in the number of ships is directly related to the difference in military strength. The relationship between qualitative and quantitative factors must be carefully considered in evaluating military capabilities.

References

- Armstrong, M. (2014). The salvo combat model with a sequential exchange of fire. *Journal of the Operational Research Society*, 65(10), pp. 1593–1601.
- Armstrong, M. J. & Powell, M. B. (2005). A Stochastic salvo model analysis of the battle of the Coral Sea. *Military Operations Research*, 10, pp. 27–37.
- c. Headquarters of the Commander in Chief, UNITED STATES FLEET, (1945). *Antiaircraft Action Summary · World War II*. Naval History and Heritage Command, USN, available at: <https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/a/antiaircraft-action-summary.html>
- Hughes, W. (2000). *Fleet tactics and coastal combat*, 2nd ed, Naval Institute Press, Annapolis.
- Hughes, W. P. (1996). A salvo model of warships in missile combat used to evaluate their staying power. *Naval Research Logistics*, 42(2), pp. 267–289.
- Lundstrom, J. B. (2006). *Black Shoe Carrier Admiral*. Naval Institute Press, Annapolis.
- Lundstrom, J. B. (2007). *Shattered Sword*. Naval Institute Press, Annapolis.
- Morison, E. S. (1984). *The Struggle for Guadalcanal August 1942–February 1943*. Little, Brown and Company, Boston.
- N. D. (1906). President Lauds Togo as a Model for us; Reproduces in Army Order Admiral's Address to his Navy. Must be ever Prepared Mr. Roosevelt Insists that the Fighting Services be Kept at Highest Efficiency, (1906, Feb., 28), *The New York Times*, P. 4.
- Sherman, F. C. (1950). *Combat Command the American Aircraft Carriers in the Pacific War*. E. P. Dutton & Company, INC., New York.
- Yoshihara, T. (2020). *Dragon against the Sun: Chinese Views of Japanese Seapower*, CSBA, available at: <https://csbaonline.org/research/publications/dragon-against-the-sun-chinese-views-of-japanese-seapower>
- 伊藤大一[Ito T.] (2014). ブラック企業問題と日本的雇用システム ['Black' company problem and Japanese employment system], *The Ritsumeikan Economic Review*, 62(5), pp. 500–518.
- 奥宮正武[Okumiya M.], (1993). *太平洋戦争と十人の提督* [The Pacific War and Ten Admirals], Asahi Sonorama, Tokyo.
- c. 川崎まなぶ[Kawasaki M.] (2007). *マリアナ沖海戦* [A New View of the Battle of Philippine Sea], DainipponKaiga, Tokyo.
- 防衛庁防衛研修所戦史研究室[The War History Office, National Institute for Defense, Japan Defense Agency] (1971a) *戦史叢書* [Senshi-sosho] 南東方面海軍作戦[The naval operation in the South east theater] <1>, Asagumo Shinbunsha, Tokyo.
- 防衛庁防衛研修所戦史研究室[The War History Office, National Institute for Defense, Japan Defense Agency] (1971b) *戦史叢書* [Senshi-sosho] 南東方面海軍作戦[The naval operation in the South east theater] <2>, Asagumo Shinbunsha, Tokyo.
- 防衛庁防衛研修所戦史研究室[The War History Office, National Institute for Defense, The Defense Agency of Japan](1971c) *戦史叢書* [Senshi-sosho] ミッドウェー海戦 [The battle of Midway], Asagumo Shinbunsha, Tokyo.
- 防衛庁防衛研修所戦史研究室[The War History Office, National Institute for Defense, The Defense Agency of Japan] (1971d) *戦史叢書* [Senshi-sosho] マリアナ沖海戦[The battle of the Philippine Sea], Asagumo Shinbunsha, Tokyo.
- 渡部悦和[Watanabe Y.](2020). 自衛隊は中国人民解放軍に敗北する! [Will the Japan Self-Defense Forces be defeated by the People's Liberation Army of China?], Fusosha, Tokyo
- 由良富士雄[Yura F.](2012). *太平洋戦争における航空運用の実相* [Reality of Air Operations in the Pacific War], NIDS military history studies annual, 2012, pp. 65–91.

Appendix

Tab. A1: Case 1 (Battle of the Coral Sea)²

IJN forces	2 CVs (Shokaku and Zuikaku)
USN forces	2 CVs (USS Yorktown and USS Lexington)
A_1	90
α_1	51
S_1	40 (13 fighters and 17 bombers)
d_1	5

²Data from 防衛庁[Defense Agency of Japan] 1971a, p. 189, 307, 310, 319
Lundstrom 2006, p. 188
Sherman 1950, p. 106–109.
CV, aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.

Tab. A2: Case 2 (Battle of Midway)³

IJN forces	1 CV (Hiryu)
USN forces	1 CV (USS Yorktown)
A_2	36
α_2	28
S_2	14
d_2	5

³Data from 防衛庁[Defense Agency of Japan], 1971c, p. 396, 436–437
Lundstrom 2007, p. 293–295, 311–314.
CV, aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.

Tab. A3: Case 3 (Battle of the Eastern Solomons)⁴

IJN forces	2 CVs (Shokaku and Zuikaku)
USN forces	3 CVs (USS Enterprise, USS Saratoga, and USS Wasp)
A_3	90
α_3	54
S_3	53
d_3	3

⁴Data from 防衛庁[Defense Agency of Japan], 1971a, p. 545, 569
Morison 1984, p. 79–107.
CV, aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.

Tab. A4: Case 4 (Battle of the Santa Cruz Islands)⁵

IJN forces	2.5 CVs (Shokaku, Zuikaku, and Zuiho)
USN forces	2 CV (USS Hornet and USS Enterprise)
A_4	96
S_4	38
d_4	9

⁵Data from 防衛庁[Defense Agency of Japan] 1971b, p. 268–317
Morison 1984, p. 199–210.
According to Hughes (2000, p. 105), CVL (Zuiho) is assumed to be 1/2 CV.
CV, aircraft carrier; CVL, light aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.

Tab. A5: Case 5 (Battle of the Philippine Sea)⁶

IJN forces	6 CVs (Shokaku, Zuikaku, Taiho, etc.)
USN forces	11 CVs (USS Hornet, USS Yorktown, USS Wasp etc.)
A_5	270
S_5	236
d_5	0

⁶Data from 防衛庁[Defense Agency of Japan] 1971d, p. 268–317, p. 408.
As a CVL is assumed to be 1/2 CV, the IJN force (3 CVs and 6 CVLs) is regarded as 9 CVs and the USN force (7 CVs and 8 CVL) is regarded as 11 CVs.
CV, aircraft carrier; CVL, light aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.

Tab. A6: Case 6 (Battle of the Philippine Sea)⁷

IJN forces	6 CVs + land-based air force
USN forces	11 CVs
A_6	430 (270 (+ 300(× 2/3 (Defense Agency of Japan, 1971d: 408, 569)))
S_6	236

⁷Data from 防衛庁[Defense Agency of Japan] 1971d, p. 268–317, p. 408, 569.
We assume that the IJN land-based air force could devote 2/3 of its aircraft to a joint attack with the carrier group.
CV, aircraft carrier; IJN, Imperial Japanese Navy; USN, United States Navy.