SIMULATION ANALYSIS OF CONFLICT BETWEEN INTERNATIONAL DEPARTURE FLIGHTS FROM JAPAN AND OVERFLIGHTS

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ABSTRACT

The purpose of this study is to examine the actual and future situation of the operational conflicts between international departure flights from Japan and overflights at the pacific oceanic airspace. The Monte Carlo simulation model based on the actual operational characteristics of the flights from Asian region to US is developed to analyze the operational conflicts at the entry fixes to the pacific oceanic airspace. From the simulation analysis where the several traffic condition scenarios are assumed, the probability and the degree of the operational conflicts at the target airspace can be obtained. The major evaluation indexes are the flight level (closer altitude to the requested optimal one is bettter), the delay of the flights and environmental impacts (Fuel and CO_2 emission). The results from this study can be one of the important materials to design more efficient and fair air traffic control and management in the oceanic airspace in the future.

KEYWORDS: Air Traffic Control, Oceanic Airspace Operation, Optimal Flight Level, Delay

1. Introduction

In recent years, the world air passenger transport volume increases buoyed by the economy progresses of the Asian region. Particularly, according to the ICAO, air transport demand will increase to 2,980 billion kilometers in 2025 from 967 billion kilometers in 2005 in the route between Asia and US region[1)]. The increase of flights from East Asia countries to North America, Hawaii and South Pacific results in the increase of overflights above Japan which locates at the gateway to the Pacific oceanic airspace[2)]. Airlines usually select the cruise altitude and route by considering various factors such as aircraft type and weather conditions to enhance fuel efficiency and service level for passengers. However, if the number of overflight above Japan will increase, the departure flights from Japan will have more difficulty to obtain their desirable cruise altitude especially in the Pacific oceanic route because efficient altitudes may be preoccupied by the overflights from Asian countries. In such cases, the departure flights from Japan which conflict with overflights in the same route and altitude (Flight Level: FL) need to change flight altitude to different FL (usually less operationally efficient) or delay their departure time. The flights in less efficient altitude use more fuel and GHG emissions also increase. In order to design more efficient and balanced air traffic management among international regions and to design the market-based measures for reducing GHG emissions such as Emission Trading System, the impact of such geographical conditions, the capacity of oceanic route and future demand increase on flight efficiency need to be analyzed.

The purpose of this study is to examine the actual and future situation of the operational conflicts between international departure flights from Japan and overflights at the pacific oceanic airspace by using actual flight trajectories which can be obtained in the web-based flight monitoring system. And the Monte Carlo simulation model based on the actual operational characteristics of the flights from Asian region to US is developed to analyze the operational conflicts at the entry fixes to the pacific oceanic airspace. From the simulation analysis where the several traffic condition scenarios are assumed, the future probability and the degree of the operational conflicts at the target airspace is analyzed.

2. Overview of Air Traffic Control in Japan

2.1. Controlled airspace

Fukuoka FIR (Flight Information Region) is controlled by Japanese ATC and locates in the gateway position to the Pacific oceanic airspace. (see Figure-1). Furthermore, the Fukuoka FIR is divided into five sectors, and each sector is controlled by Sapporo Air Traffic Control Center, Tokyo Air Traffic Control Center, Fukuoka Air Traffic Control Center, Naha Air Traffic Control Center and the Air Traffic Management Center.

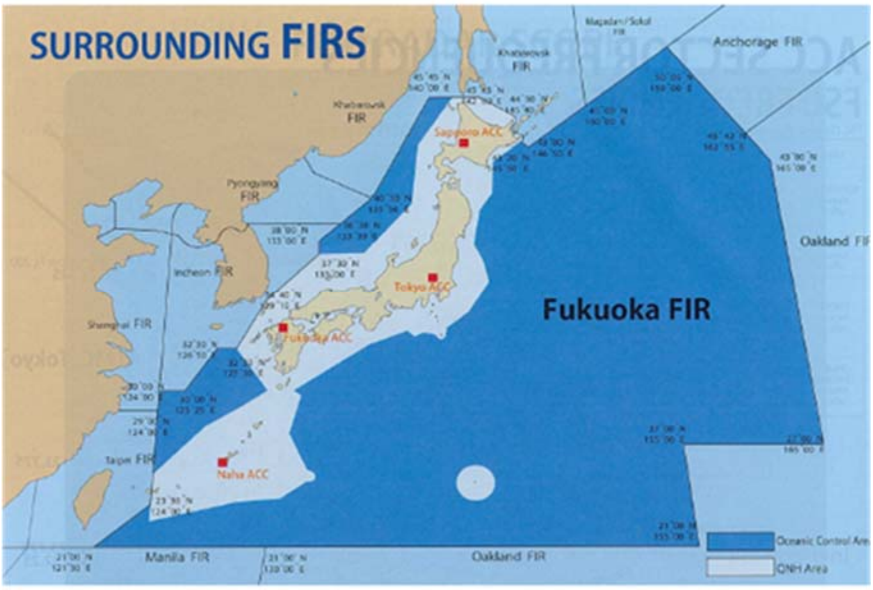

Figure-1 Fukuoka FIR[3)]

2.2. Pacific Route

The aircrafts from many Asian countries including Japan to North America use NOPAC route that are fixed routes or PACOTS that are variable routes that is set by ATC every day in consideration of weather data. UPR and DARP enabling more efficient flight is carried out experimentally recently.

In the oceanic airspace, satellite-based navigation and control system is adopted while the domestic airspace where ground facilities for transmitting a radar are maintained. Communications between ATC and pilots were carried out by voice communication using HF conventionally, but data link communication system is now mainstream.

2.3. The actual situation of the ATC in the Kanto east sector

There is 22 sectors in the airspace controlled by Tokyo Air Traffic Control Center which is most congested airspace in Japan. Kanto east sector is one of those sectors, and it is airspace that aircrafts toward the North America area from the countries of the Asian region such as Inchon and Beijing, Shanghai, Singapore passes.

The Kanto east sector assigns the flight altitude to all of the flight which fly through this sector including international departure flights from Japan (see Figure-2). The Kanto east sector forecast flight altitude and passing time of the overflights coming in Kanto east sector by using Flight Plan data, and adjusts altitude and departure time of departure flights from Japan such as Narita Airport in order to avoid the conflict with overflights and international departure flights from Japan. Kanto east sector play an important role in solving such conflicts -and once flight altitude is determined in Kanto east sector and the following oceanic route the aircrafts will have a little chance to change their altitude to more efficient one due to the limited capacity of the oceanic route especially in the congested period.

In this study, we set three major gateway FIXs (PUTER, ADNAP, AVBET) to oceanic routes in Kanto east sector as a conflict point (CP) which almost all flights from Asia to US must pass through(see Figure-3) and conduct an actual flight trajectories data analysis and conflict analysis using the Monte Carlo simulation.

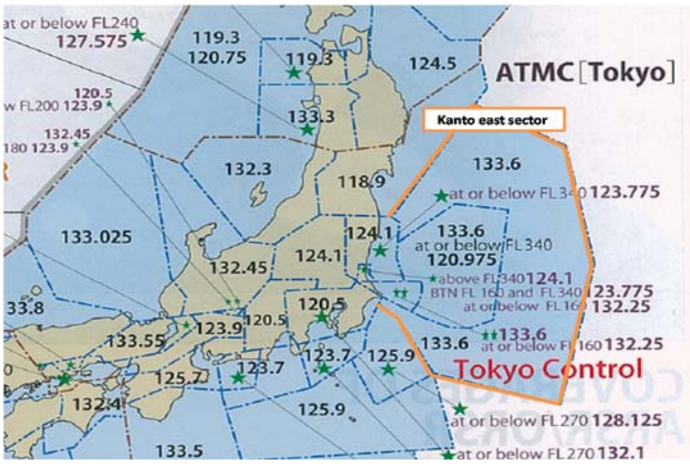

Figure-2 Kanto east sector

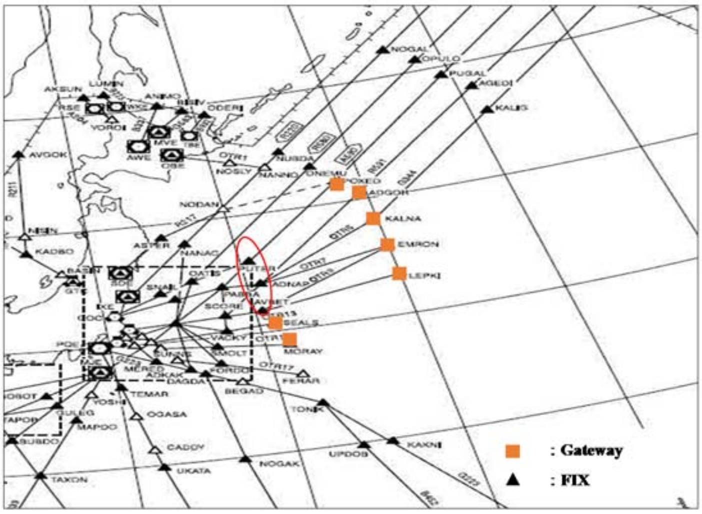

Figure-3 Gateway and FIX

3. **Actual flight trajectories data analysis**

3.1. The flight altitude analysis of the same aircraft type and destination

The flight altitude may be affected by destination and aircraft type. Therefore, we analyzed the flight altitude of overflights and international departure flights from Japan of the same aircraft type and destination.

We obtained actual fight trajectory data such as altitude, speed and aircraft type (October 1 to November 20, 2013) from the website "Flight aware (http://flightaware.com/)" which is flight monitoring website. But Flight aware provides limited data because it includes only the data of ADS-B equipped flights.

Table-1 shows the mean and variance of the actual flying altitude at CP of the sampling aircrafts going to JFK. From this result, flights from Japan flew at significantly lower altitude than overflights. In addition, the variance of altitude of the flights from Japan is also significantly larger than overflights. The optimum altitude is expected to be similar if the aircraft type and destination (remaining flight distance) is the same. Therefore, it was proved that international departure flights from Japan fly low altitude than overflights at the CP.

Table-1 Comparison of the flight altitude at conflict point: flights from Japan and overflights from Korea (same aircraft type and destination)

to JFK	AAR222	ANA10	ANA1010	JAL6
aircraft type	B777-300ER	B777-300ER	B777-300ER	B777-300ER
departure airport	Incheon International Airport	Narita International Airport	Narita International Airport	Narita International Airport
the number of observations	23	23	22	23
average altitude(ft)	32478	30870	30573	30870
variance	988142.3	1118577	1692554	1754940
F-number		0.88	0.58	0.56
t value		5.3	5.5	4.7

Figure-4 shows the flight altitude of overflights and flights from Japan in all observation day. Figure-5 shows the share of the altitude of each flight.

From these figures, it can be seen that overflights flew the highest altitude on most days and the flight altitude of the flights from Japan was sometimes very low.

From Figure 5, the altitude distribution of flights from Japan is different from overflights clearly. The overflights flew more than 31000ft in all days and the high altitude more than 33000ft could be observed in more than half of the days. On the contrary, flights from Japan rarely fly altitude more than 33000ft, and there were many days that international departure flights from Japan flew the lowest altitude.
Therefore, international departure flights from Japan were more likely to change their desired flight altitude to different altitude in order to avoid the conflict with the overflights by ATC's instruction.

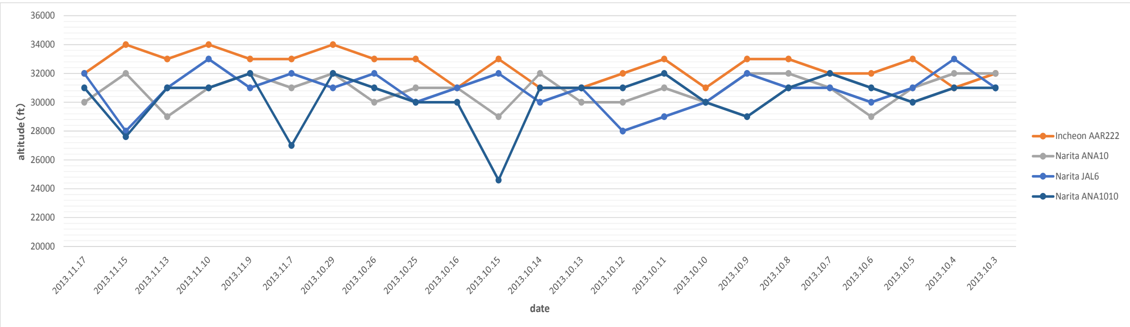

Figure-4 Flight altitude at CP of each flight in all observation day

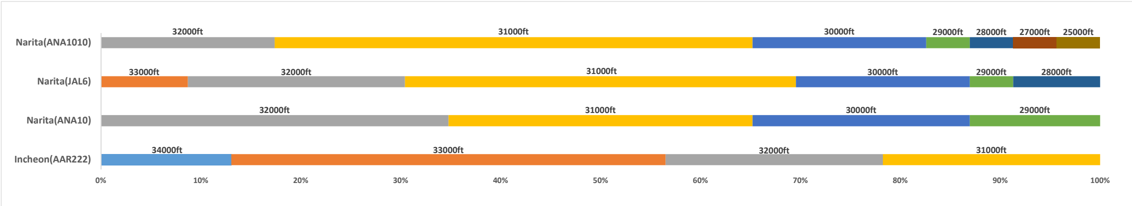

Figure-5　Distribution of the flight altitude at CP of each flight

3.2. Analysis of the flight altitude at the same distance from a departure airport

In the previous section, the flight altitudes at the same fix (CP) are compared between overflights and flights from Japan. In this section, we analyze the flight altitude of overflights and flights from Japan at the same distance from a departure airport.

Table-2, Table-3 and Figure 6 show the data of flights from Narita, Kansai, Incheon and Taiwan Taoyuan. Although the aircraft type and destination are not the same, almost all of the flight from Japan (Narita, Kansai) flew lower than the flights from other airports. We can see that only two aircrafts (JAL8 and CAL5148) in flights from Japan fly relatively high altitude. JAL8 used B787 which can fly higher altitude with high efficiency.

Table-2　The altitude data of international departure flights from Japan

	ANA10	ANA2	JAL6	ANA12	JAL10	JAL8	CAL5148
aircraft type	B777-300ER	B777-300ER	B777-300ER	B777-300ER	B777-300ER	B787-8	B747-400
departure airport	Narita	Narita	Narita	Narita	Narita	Narita	Kansai
arrival airport	JFK	Washington Dulles	JFK	Chicago O'Hare	Chicago O'Hare	Logan	Anchorage
the number of observations	38	37	29	36	32	35	23
average altitude(ft)	30758	30649	30966	30750	31031	35831	33626
variance	1283044	1567568	1820197	1735714	1321573	1418101	1270198

Table-3　The altitude data of overflights

	CAL5156	KAL35	KAL81	KAL93	AAR222	KAL73
aircraft type	B747-400	A380-800*	A380-800	B777-200	B777-300ER	B777-200
departure airport	Taiwan Taoyuan	Incheon	Incheon	Incheon	Incheon	Incheon
arrival airport	Los Angeles	Atlanta	JFK	Washington Dulles	JFK	Toronto
the number of observations	8	37	37	39	37	26
average altitude(ft)	31750	344401	35757	32364	32594	33385
variance	1071429	4230811	1800300	24243941	1025526	1046154
	EVA610	EVA636	EVA652	EVA696	EVA638	EVA668
aircraft type	MD-11	B747-400	B747-400	B747-400	B747-400	B747-400
departure airport	Taiwan Taoyuan	Taiwan Taoyuan	Taiwan Taoyuan	Taiwan Taoyuan	Taiwan Taoyuan	Taiwan Taoyuan
arrival airport	Anchorage	JFK/Anchorage	Anchorage	Anchorage/Dallas	Anchorage	Anchorage
the number of observations	3	8	11	10	11	7
average altitude(ft)	31667	33750	32327	32700	33636	33286
variance	1333333	500000	1308182	1122222	254545	904762

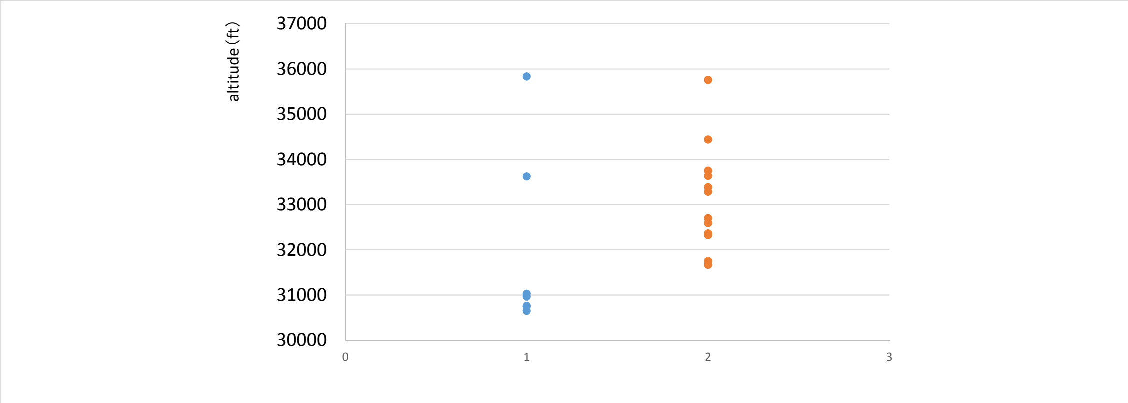

Figure-6　Distribution of the average altitude

4. Conflict analysis by Monte Carlo simulation

4.1. Development of the simulation for conflict analysis

In the previous chapter, we compare the actual flight altitudes of the departure flight from Japan and the overflights bound for US by using web-based flight trajectories open system (Flight Aware) data, and the results of the analysis indicated that the flight altitude of the flight from Japan are significantly lower than that of the overflights. However the data used in that analysis are the sampling data and the conflicts among different flights cannot be analyzed due to the limited data samples (only the data of ADS-B equipped flights can be obtained).

In this chapter, we develop the monte carlo simulation which demonstrates the conflict of the flights from Asian region to US at the entry (gateway) FIXs to pacific oceanic airspace. Figure-7 shows the simulation flow by incorporating the function of altitude or departure time adjustment by ATC into this simulation, we can calculate not only the degree of the operational conflicts but also the loss of the altitude and delay time of each flight at the target airspace.

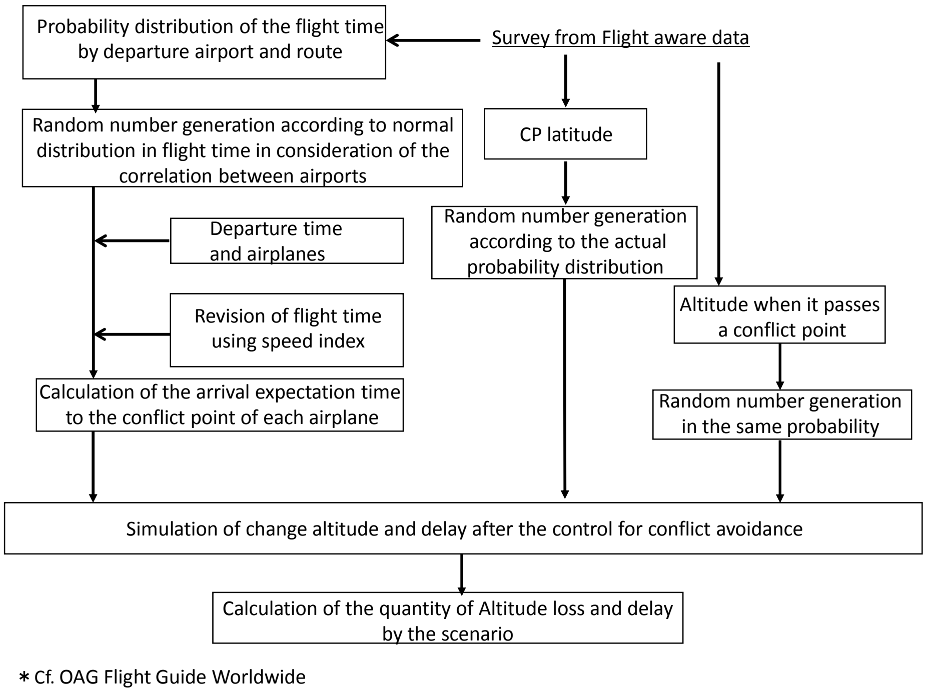

Figure-7 The procedure of simulation development

In this simulation, the target departure airports are Narita, Haneda, Kansai, Inchon, Taiwan, Hong Kong, Shanghai, Guangzhou and Beijing that is the major airport in the Asian region, and arrival airports are Anchorage, Atlanta, Boston, Washington, JFK, Chicago O'Hare, Los Angeles, Toronto, Dallas, Vancouver, San Francisco, Calgary, San Jose and San Diego in US/CANADA. The major random variables in the simulation are flight time from departure airport to CP, CP latitude and the flight altitude of each flight. These random variables are generated based on the probability distributions of the observed data from “Flight Aware”. The correlation of the data such as flight time among the departure airport is also considered (see Figure-8). OAG time table are used for the departure time of each flight. First, the arrival times at CP of all of the target flight are calculated and the conflicts that are defined as the separation less than 15 minute (minimum separation in the conventional ATC procedure rule) are detected. We assumed that aircrafts of earlier departure time is priority when the same altitude is hoped. And then the conflicts are resolved by adjusting the flight altitude or departure time of the flights from Japan (see Figure-9). We run 100 times of the simulation by generating the different random variables in each scenario and analyzed the conflict situation.

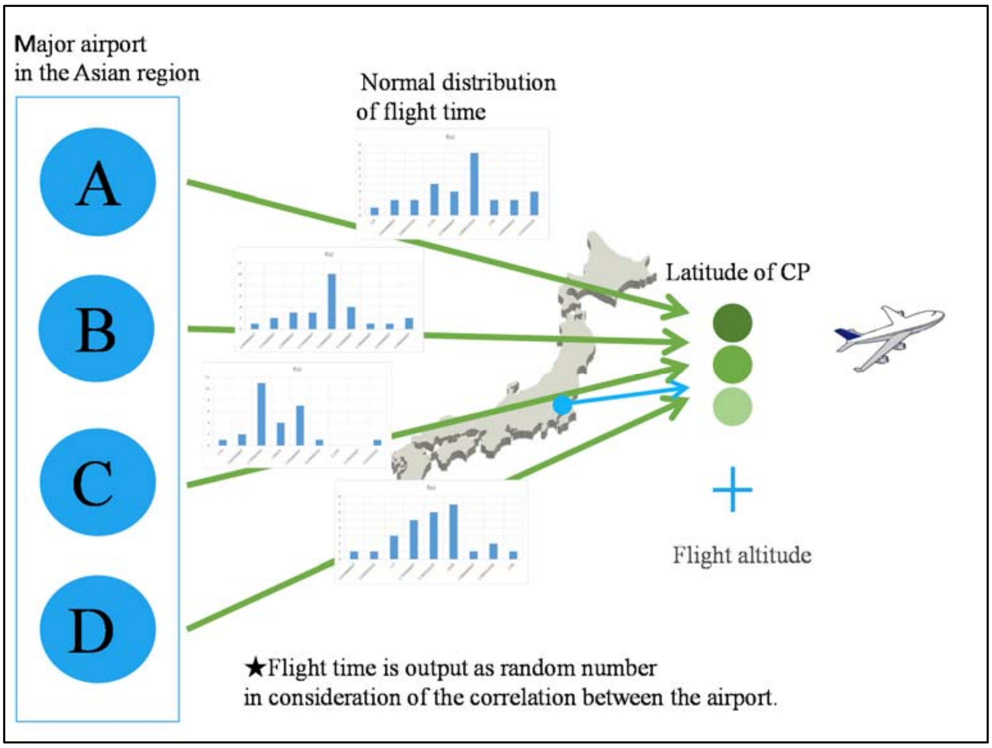

Figure-8 Image of flight simulation

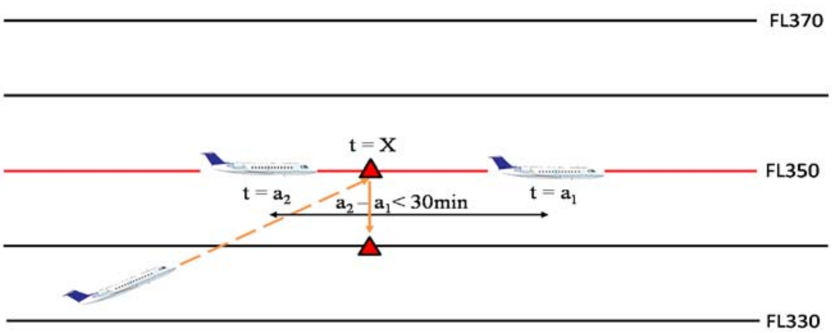

Figure-9 Example of altitude adjustment for avoiding the conflict

4.2. Results

We defined the “total-loss-altitude (TLA)” and “total-loss-time (TLT)” for flights from Japan in each scenario and Figure-10 and Figure-11 show the mean, quartile value and maximum/minimum value of the results of the simulation in each scenario. Those index indicate the difference from original desired (optimum) altitude and departure time. The results show that TLA increases by 3.8 times and TLT increases by 9.7 times if the traffic volume of departure flights from Japan and overflights increase that is based on a demand forecasting of 2022 by Japanese government. In the case that old aircrafts update to new one of international departure flights from Japan, the TLA increases by 1.5 times and the TLT increases by 1.8 times. Because the new aircraft type like B787 have high ability for climbing, initial altitude tends to become higher than old one. Therefore, it is thought that the TLA and TLT increase due to increase in altitude that may cause the conflict with the overflights.

Table-4 Simulation scenarios

1	Base case: present condition (2013)
2	Demand increase: Flights from Japan=1.7 times (2020 forecast by Japanese government)
3	Demand increase: Flights from Japan=2.0 times
4	Demand increase: Overflights=1.8 times (2020 forecast by Japanese government)
5	Demand increase: Overflights=2.0 times
6	Demand increase: Flights from Japan=1.7 times & Overflights=1.8 times
7	Demand increase: Flights from Japan=2.0 times & Overflights=2.0 times
8	Aircraft type update: All flights from Japan change fleet to B787 (flight altitude is assumed to change to 35000ft)
9	Runway capacity expansion of Narita airport: increase of peak time demand

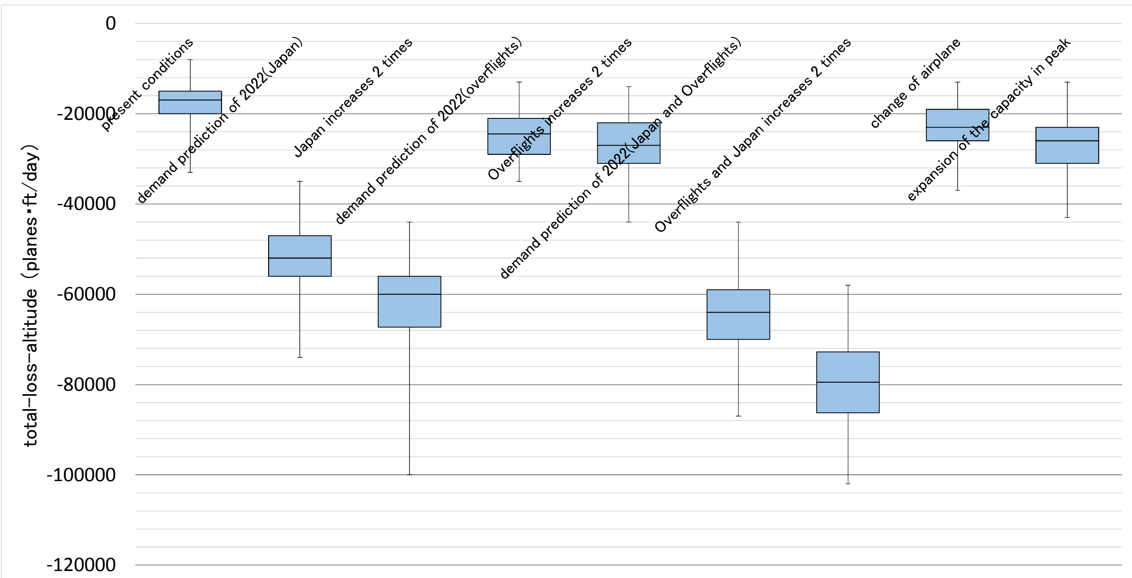

Figure-10 The total-loss-altitude in each scenario

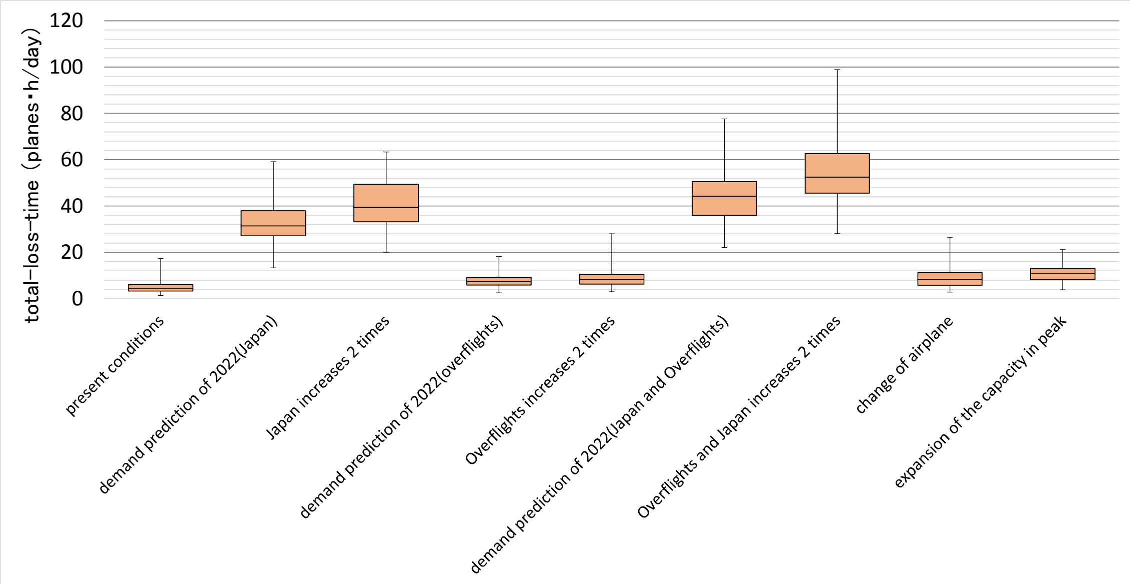

Figure-11 The total-loss-time in each scenario

4.3. The impact of CP capacity on the runway capacity expansion at peak time at Narita Airport

In recent year, the capacity expansion measures have been considered at Narita airport and/or the other airports in Tokyo metropolitan area for future air traffic demand increase. We analyze the impact of gateway FIXs capacity (CP capacity) on the runway capacity expansion in peak time of Narita International Airport from the viewpoint of departure delay. In this case, we assume that all of the departure flights from Narita could get take-off slot (time) according to their desired departure time by enough runway capacity expansion. Currently significant number of the flights cannot get the desired take-off slot and change the departure time. We can see the actual difference between the desired departure time and actually obtained take-off slot in the MLIT material[4)]. We simulated such a case which capacity of the Narita International Airport expand and adjust the departure time after having considered calculated delay time so that conflict at CP does not happen.

Figure-12 shows a result. The departure flights which gathered in peak time without airspace restriction like CP conflicts disperse in subsequent time under the influence of departure delay to avoid CP conflicts. This indicates that it is important to think the airspace capacity including gateway FIXs to pacific oceanic routes a well when thinking about the capacity expansion of the runways.

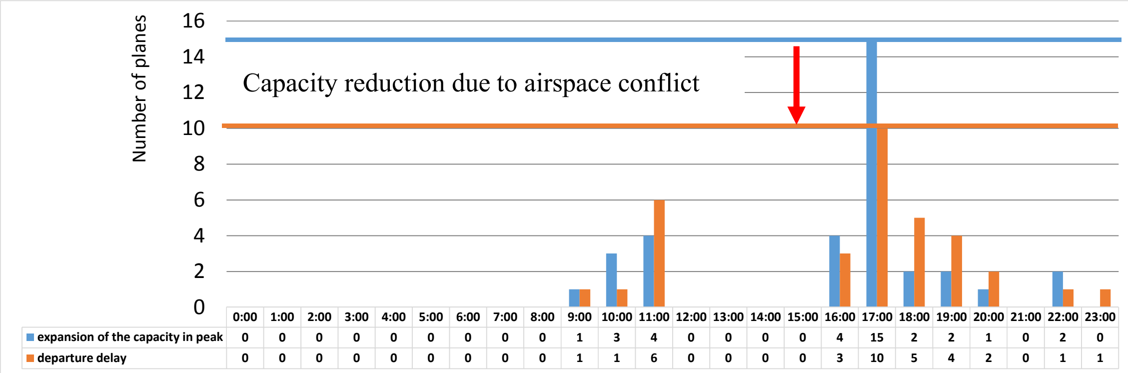

Figure-12 Capacity reduction due to airspace conflict

4.4. Rough estimation of the impact of overflights condition on the total fuel consumption and CO2 emission of the flights from Japan to US

As mentioned above, airlines usually select the cruise altitude and route by considering various factors. When a flight cannot fly at the desired optimum altitude, fuel consumption and CO2 emission increases consequently. Once flight altitude is determined in Kanto east sector which is the gateway sector to pacific oceanic airspace, the aircrafts will have a little chance to change their altitude to more efficient one throughout the oceanic route due to the limited capacity of the oceanic route especially in the congested period. In this section, the impact of overflights condition on the total fuel consumption and CO2 emission of the flights from Japan to US are estimated by assuming that the loss of the flight altitude due to the other surrounding aircrafts will continue throughout the flight to the destination. The detail estimation conditions are shown in Table-5. And we assume that 1000ft lower altitude can increase fuel consumption by 0.05 kg/sec roughly (reference: BADA data). We estimate the fuel and CO2 increase in three cases of scenarios (present conditions, overflights traffic=1.8 times, overflights traffic=2 times).

Table-6 shows the result that calculated the total-loss-fuel based on the total-loss-altitude. As a result, the average of total-loss-fuel is 36.72(planes・t/ day) in the case of present conditions traffic. When overflights traffic increase to double, the average of total-loss-fuel increase to 58.32 (planes・t/ day).

Table-7 shows the result CO2 emissions estimation from fuel consumption. CO2 emission is estimated by using coefficient of kl-TOE and t-CO2/TOE (0.8767[TOE/kl], 2.789[t-CO2/TOE] respectively)[5]. The CO2 emissions increased from 268 (t-CO2) to 297 (t-CO2) when altitude fell from 33000ft to 28000ft. This is a value of approximately 1.1 times than the case that flew in 33000ft. From these results, the altitude loss due to the overflights can increase the fuel consumption and CO2 emission significantly.

Table-5 Detailed condition of the flight for estimating fuel consumption and CO2 emission

pair of the flight city	Narita - New York
flight time	12 hours
cruising speed	Mach 0.83
all up weight (AUW)	237600kg
aircraft type	B777-300
desirable cruise altitude	33000ft

Table- 6 Total-loss-fuel in each scenario

	minimum total-loss-fuel (planes・t/day)	average total-loss-fuel (planes・t/day)	maximum total-loss-fuel (planes・t/day)
present conditions	17.28	36.72	71.28
Overflights traffic increases 1.8 times	28.08	52.92	75.6
Overflights traffic increases 2 times	30.24	58.32	95.04

Table-7 Fuel consumption and CO2 emission in each altitude

	fuel consumption (kg/s)	convert into CO_2 (t-CO_2)
33000ft	2.03	268
30000ft	2.15	284
28000ft	2.25	297

5. Conclusions

This study examines the actual and future situation of the operational conflicts between international departure flights from Japan and overflights at the pacific oceanic airspace by using actual flight trajectory data and the developed Monte-Carlo simulation. From the simulation analysis where the several traffic condition scenarios are assumed, it is indicated that the probability and the degree of the operational conflicts at the target airspace will be significantly increased in the future. Those conflicts will link to the delay of the flights and environmental adverse impacts (Fuel and CO_2 emission). Also, the importance of the consideration of such airspace restriction when planning runway capacity expansion of large international airport like Narita is analyzed. In the future study, we are planning to consider how to design more efficient and balanced air traffic control and management in the oceanic airspace in the future.

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