５．福岡 FIR と隣接 FIR 間の交通流解析

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1. INTRODUCTION

The Fukuoka Flight Information Region (FIR), shown in Figure 1, is situated between Asia and North America and has significant cross-boundary air traffic that is expected to increase by around 80% between 2013 and 2030 [1]. It will therefore be necessary to increase *en route* airspace capacity while also offsetting the environmental impact of the increased traffic by improving flight efficiency. We have begun a research project looking at applying *free routeing* concepts to achieve this.

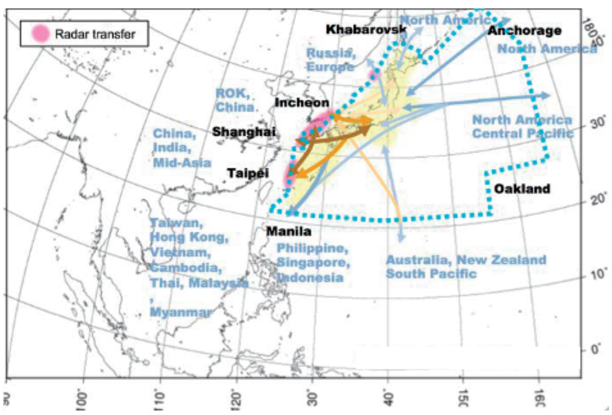

Figure 1: Major Fukuoka FIR cross-boundary air traffic flows

We consider the difference between a flight's planned route and a corresponding ideal minimum flight time route as an indicator of its efficiency. Currently, most flight planned routes are based on a network of Air Traffic Service (ATS) routes which concentrate traffic along them (Figure 2). Enabling flights to operate closer to their ideal routes will increase individual flight efficiency, but on the other hand could increase route dispersion and consequently airspace *complexity*, which makes airspace harder to manage and can thereby reduce capacity. There is therefore a balance to be made between alleviating route constraints for efficiency and imposing structure on air traffic flows for air traffic management reasons.

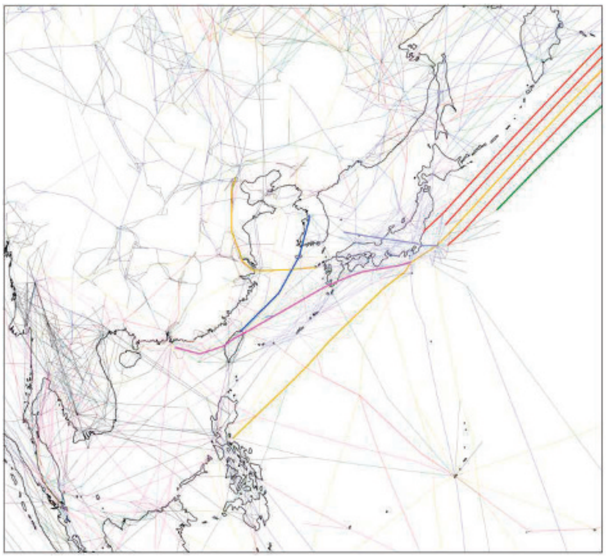

Figure 2: ATS Routes around Fukuoka FIR. Routes are coloured according to their designators A=Amber, G=Green, R=Red, M=Magenta. RNAV routes are in light blue.
Highlighted routes are discussed in this paper.

Even if route efficiency is improved within an FIR, however, cross-boundary traffic flow constraints can reduce end-to-end flight efficiency. Currently, many flights are constrained to cross FIR boundaries at fixed "co-ordination" points, causing bottlenecks. Reasons for such constraints include differing communication / navigation / surveillance (CNS) capabilities and air traffic management (ATM) procedures in adjacent FIRs, and lack of communication and integration between ATM systems that can allow automated coordination of flights and cross-boundary flow management. Europe has been introducing blocks of 'Free Route Airspace' [2] that increase route flexibility and eliminate the need to cross FIR boundaries at fixed points within the blocks by harmonising ATM procedures and increasing system integration, and has a cross-border network flow management function. Similar initiatives are needed in the Asia-Pacific region.

Before suggesting ways to improve air traffic flows, we must first understand the current situation and constraints. A preliminary analysis [1] identified some of the major air traffic flows in the Fukuoka FIR and potential boundary choke points; in particular, we identified air traffic flows between South Korea and Japan, China and southeast Asia as the densest cross-boundary traffic flows in the Fukuoka FIR. We then analysed their characteristics and identified the key FIR boundary points in radar-controlled airspace [3]. We have also started to look at oceanic airspace, and have analysed traffic along the North Pacific (NOPAC) fixed ATS routes between Fukuoka FIR and Anchorage FIR [4].

This paper presents a summary of our analyses of cross-boundary flows in radar controlled airspace and NOPAC oceanic airspace. Section 2 presents the methodology and the traffic flows considered, and section 3 outlines their analyses. Section 4 concludes the paper.

2. METHODOLOGY

2.1 Source Information

These analyses used data from the Japan Civil Aviation Bureau's (JCAB) Flight Data Management System (FDMS) which are provided to the Electronic Navigation Research Institute (ENRI) for research purposes. FDMS data contain flight plan and operational information for each air transportation flight operating in the Fukuoka FIR under Instrument Flight Rules. In particular, the analyses used abeam-waypoint information in the Segment Data Block records which contain abeam times and altitudes at certain significant points derived from surveillance data. For the non-oceanic traffic flows in this analysis, data for Japanese Fiscal Year 2016 (FY2016: 1 April 2016—31 March 2017) were used. For the NOPAC analysis, data for the one-year period from 1 July 2016—30 June 2017 were used.

2.2 Major Traffic Flows

We consider traffic flows across the (radar controlled) boundaries with Incheon, Shanghai, Taipei and Manila FIRs, the boundary points of which are shown in Figure 3, and along the oceanic NOPAC routes to and from Anchorage FIR shown in Figure 4.

For NOPAC traffic, traffic passing the significant points NIPPI (on ATS route R220), OMOTO (R580), POXED (A590), ADGOR (R591) and KALNA (G344), that is, the entry points into Fukuoka FIR NOPAC airspace along the respective routes, were classified as NOPAC traffic. Because the distributions of traffic between the NOPAC routes can vary from day to day, the routes are aggregated in the analysis. Traffic was classified as eastbound or westbound according to the prefix of the International Civil Aviation Organization (ICAO) code of the destination airport in the flight plan.

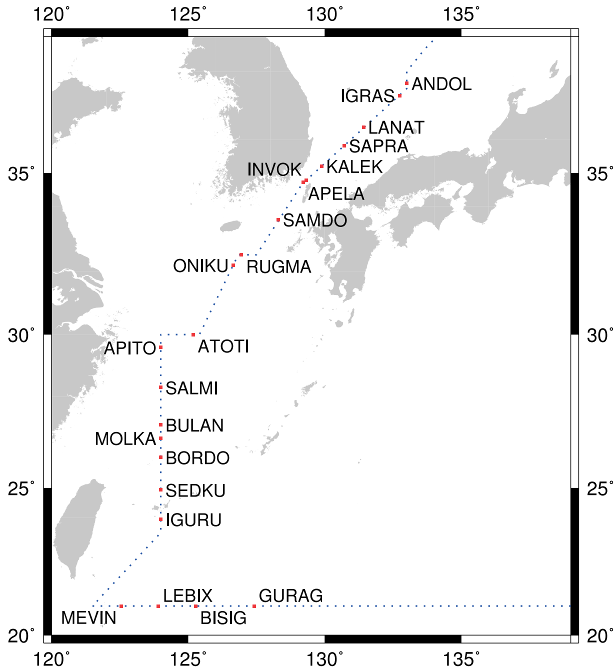

Figure 3: FIR boundary points with Incheon, Shanghai, Taipei and Manila FIRs

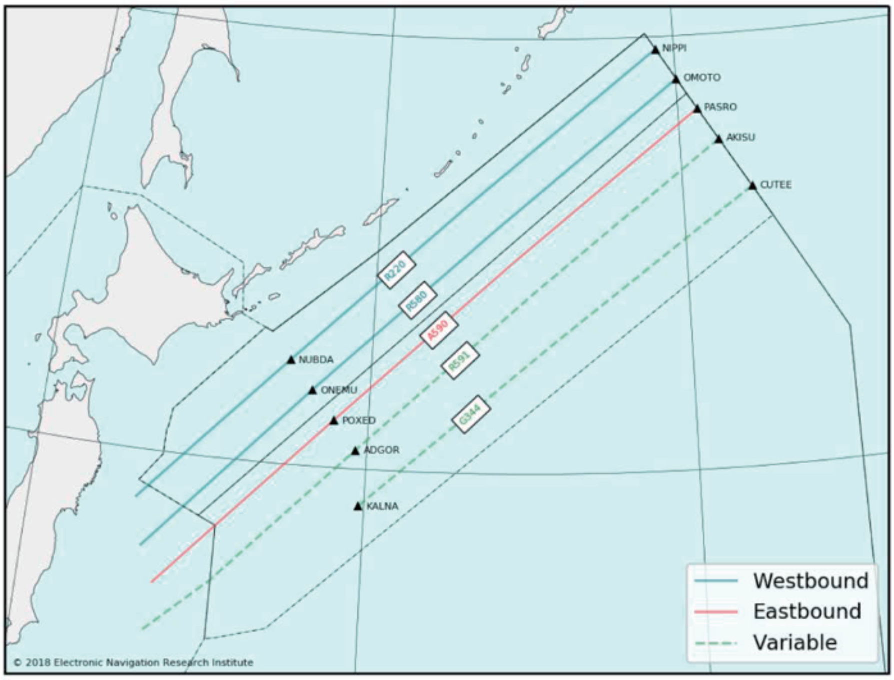

Figure 4: North Pacific (NOPAC) routes in the Fukuoka FIR

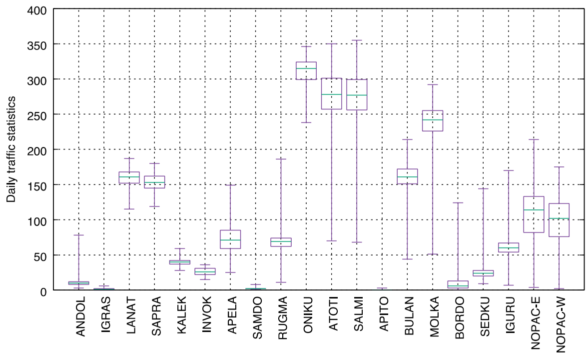

Figure 5: Selected daily traffic statistics

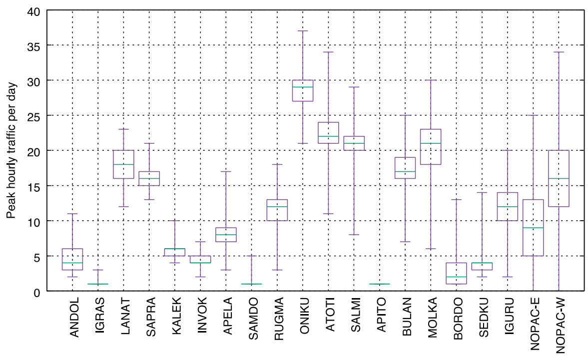

Figure 6: Selected peak hour traffic statistics

3. Analysis

3.1 Traffic Flow Statistics

Figure 5 shows statistics of numbers of flights passing selected significant points and NOPAC eastbound and westbound flows each Japan Standard Time day (00:00–24:00 JST) in the one year analysis periods. The tops and bottoms of boxes indicate the 25th and 75th percentile values and the whiskers indicate maxima and minima, while the green lines indicate the median (50th percentile) values. (Only days with traffic were counted in the statistics.) Figure 6 similarly shows statistics of traffic counts during the peak hour at selected significant points. (In the case of the NOPAC routes, these are the counts of traffic crossing the entry waypoints into Fukuoka FIR NOPAC airspace.)

It can be seen from the figures that some significant points can be regarded as “pairs”. SALMI and ATOTI both lie on the B576 route that carries traffic between Incheon FIR and SE Asia, so their characteristics are very similar. LANAT and SAPRA are respectively on eastbound and westbound that carry traffic between Tokyo and Seoul. BULAN and

Table 1 Summary of Main Fukuoka FIR Inter-FIR Traffic Flows:
Radar-controlled boundary points and NOPAC routes

Significant Points	ATS Routes	Main traffic flows				
		Region A-> Region B		Region B-> Region A		Prop.
LANAT/ SAPRA	G597/G585	KOR-JP	28,502	JP-KOR	30,097	51%
		CHN-JP	16,030	JP-CHN	16,317	28%
		KOR-NAM	8,636	NAM-KOR	5,828	15%
ONIKU	A593	CHN-JP	42,367	JP-CHN	42,951	74%
		CHN-NAM	13,049	NAM-CHN	4,201	15%
ATOTI/ SALMI	B576	ASEAN-KOR	23,428	KOR-ASEAN	28,586	52%
		CHN-KOR	12,049	KOR-CHN	13,576	25%
		TW-KOR	10,080	KOR-TW	12,049	22%
BULAN/ MOLKA	Y751/M750	TW-JP	31,441	JP-TW	31,852	42%
		CHN-JP	20,440	JP-CHN	19,084	26%
		CHN-NAM	11,470	NAM-CHN	5,257	11%
NIPPI, OMOTO / POXED, ADGOR, KALNA	R220, R580/ A590, R591, G344 (NOPAC)	JP-NAM	11,367	NAM-JP	15,867	36%
		CHN-NAM	15,773	NAM-CHN	7,411	31%
		KOR-NAM	8,071	NAM-KOR	6,201	19%
		TW-NAM	4,187	NAM-TW	5,043	12%

MOLKA are similarly associated with southwest-bound and northeast-bound traffic respectively on parallel ATS routes between Fukuoka FIR and Taipei FIR.

For some significant points with relatively high median daily traffic, the difference between the median and minimum daily count values is much greater than the difference between the median and maximum (e.g. ONIKU, ATOTI, SALMI, BULAN and MOLKA), while the reverse is true for some points with relatively low median daily traffic (e.g. ANDOL, APELA, RUGMA, BORDO, SEDKU and IGURU). This is thought to the due to phenomena such as severe weather or volcanic ash clouds forcing traffic from normally high traffic routes onto less frequently used routes.

We identify the primary traffic boundary flows as associated with significant points or ATS routes with median daily traffic of more than 100 flights/day and traffic peaks of 9 flights/hour or more. The main traffic flows, with inter-regional breakdowns in each direction, are listed in Table 1. The ‘regions’ are individual states or groups of states aggregated according to economic characteristics, from our earlier study [1]: KOR (South Korea), JP (Japan), CHN (China including Macao and Hong Kong but excluding Taiwan and Mongolia), TW (Taiwan), NAM (North America: Canada, Alaska and the contiguous United States), OCE (Oceania, including Australia, New Zealand, Hawaii, Guam and Saipan), ASEAN (Association of Southeast Asian Nations), SWASIA (Southwest Asia, including India and the Middle East). The figures for each region show the number of flights in each flow over the one-year analysis periods, and the “Prop.” column shows the ratios of specific inter-regional traffic flows in both directions to the total flow traffic. Inter-regional flows with less than 10% of total traffic on a flow are omitted.

3.2 Inter-Regional Traffic Flow Asymmetry

For the traffic flows in Table 1 we would expect the traffic flow from region A to region B to be very similar to that from region B to region A. However, the analysis identifies an asymmetry regarding flights between North America and Asia. Table 2 shows the number of flights transiting the Fukuoka FIR between North America and each other region in FY2016. Especially for flights between North America and KOR, CHN and ASEAN, there are significantly more eastbound flights than westbound flights that transit the Fukuoka FIR. We speculate that one reason is that eastbound trans-Pacific flights select Northern Pacific oceanic tracks to take advantage of the easterly Polar Jet Stream winds, and return via routes that do not pass through the Fukuoka FIR to avoid headwinds.

Table 2 Traffic between NAM and each region passing through Fukuoka FIR in FY2016

Region	To NAM	From NAM
CHN	26,087	10,559
JP	21,441	21,559
KOR	12,495	7,717
TW	8,126	7,402
ASEAN	2,023	1,446
SWASIA	128	0
OCE	32	75
Total	70,442	48,758

3.3 KOR traffic flows

By far the majority of flights to and from Korea that transit the Fukuoka FIR is traffic to or from Seoul. Traffic flows are to and from Japan, NAM, Oceania, SE Asia, Taiwan and Hong Kong.

The parallel ATS routes G597 and G585 primarily carry traffic between Seoul and Tokyo, Kansai (Osaka) and Chubu (Nagoya) airports (around 50%), as well as traffic between Tokyo and Beijing (nearly 30%). SAPRA is almost on the Great Circle between Kansai and Incheon airports, while LANAT is slightly north of the Great Circle between Incheon and Chubu airports. These ATS routes therefore seem a reasonable compromise of shortest distance between Seoul and major Japanese metropolitan areas. However, Table 1 indicates that almost traffic between KOR to NAM on the NOPAC routes pass through LANAT and SAPRA, which is longer than the most efficient route due to the need to avoid restricted airspace during the day. At night, a conditional route allows a short cut, but traffic is low during that time period. Initiatives to allow more flexible use of such restricted airspace, such as improved military/civil co-ordination, could increase efficiency.

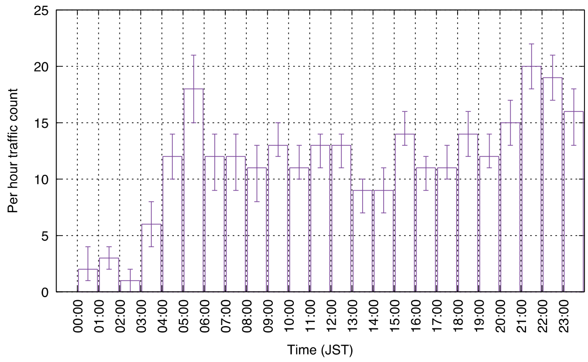

Figure 7: Hourly traffic flow at ATOTI

Another major traffic flow is between Korea and SE Asia, Taiwan and Hong Kong along the B576 route that passes through Fukuoka FIR between ATOTI and SALMI. Figure 7 shows the per hour statistics of traffic passing ATOTI in FY2016. The bars indicate median per-hour counts, while the whiskers indicate the 25th and 75th percentiles. Traffic flow exceeds 9 flights/hour for more than 20 hours of the day, and has peaks of more than 15 flights/hour twice a day. Regarding in-trail separation (that is, longitudinal separation between two successive flights travelling on the same route at the same altitude) around 30% of traffic was 12 min. or less in trail and 10% were 8 min. or less in trail at SALMI. Compared to the 30NM (approximately 4 min.) radar separation minimum, this indicates there is still room for capacity growth. However, airspace capacity is typically constrained by controller workload rather than physical separation limits. Most of the traffic between SALMI and ATOTI is “straight through” the Fukuoka FIR, but there is some branching and merging of flights between Taipei and Japan at BOLOD between them. Also, the flight time between SALMI and ATOTI is less than 15 min. at 500KT and the traffic is handled by a single sector, which implies a significant controller handoff workload at peak times. As traffic increases in the future, it is this handoff workload that will have to be addressed first.

B576 is prone to disruption by severe weather in certain seasons. The data appear to suggest that when typhoons affect B576 (which tend to move southeast to northwest in that area), traffic tends to use more easterly tracks via BORDO, SEDKU and IGURU, which Figure 5 shows tend to have relatively low median daily traffic during normal times but high maximum traffic.

The Great Circle routes between Seoul and Hong Kong, Singapore, Bangkok, Kuala Lumpur and Jakarta are further west than B576, passing through Shanghai FIR, but the airspace in the vicinity of Shanghai is highly congested, as will be discussed later. There is significant traffic between Seoul and holiday destinations Guam and Saipan, via APELA. This traffic was not investigated since the volume is comparatively low, but its interaction with crossing traffic flows should be examined in the future.

3.4 CHN and TW traffic flows

We identify the following major traffic origins and destinations in mainland China and Taiwan:

- Beijing
- Hong Kong
- Shanghai
- Taipei

Traffic between Tokyo and Beijing accounts for nearly 30% of traffic on the G597/G585 routes as discussed above. Traffic between Hong Kong/Taipei and Korea largely uses the B576 route, also as discussed above.

Much of the traffic flow between Japan/NAM and Shanghai and Guangzhou passes through ONIKU along a single bidirectional route A593 through the Akara-Fukue Corridor (Figure 8), a 50NM-wide corridor between Fukuoka and Shanghai FIRs. The airspace and traffic flows in this vicinity are quite complex. The north-south B576 route between Seoul and SE Asia crosses the Akara corridor at NIRAT. There is also traffic between Shanghai and Seoul that “turns the corner” at NIRAT. The need to accommodate north-south traffic crossing with east-west traffic and also some turning traffic means that only a limited number of flight levels are available, as Figure 9 shows. The position of the FIR boundary is disputed, and while the chart in Figure 8 shows that the airspace between ONIKU and LAMEN is in Incheon FIR, traffic is handed off directly between Shanghai and Fukuoka FIR controllers, and traffic between Seoul and Shanghai are coordinated through Fukuoka Air Traffic Management Center (ATMC).

ONIKU had a median 315 flights/day in FY2016, making it the Fukuoka FIR’s busiest cross-boundary traffic flow point. As shown in Figure 10, the median hourly traffic flow reached 25 flights/hour or more during peak periods, and was greater than 15 flights/hour for 10 hours each day. Analysis suggests that the Akara corridor occasionally operates at close to minimum in-trail separation, at least during peak times, with a significant proportion of flights with in-trail separations of 3–9 minutes. (Three minutes corresponds to around 18NM at 500KT, while typical *en route* radar separations might be 20NM.)

Approximately 75% of traffic on the Akara corridor is between Shanghai and Japan, and 15% is between CHN and NAM (primarily Los Angeles and Anchorage). Just under two thirds of traffic is Shanghai arrivals and departures, while the remainder is mainly traffic to and from Guangzhou. It is noted that there is only 116NM along A593 between the end of the Akara corridor at LAMEN and Pudong VOR, making it close to the top of descent for Shanghai arrivals. Shanghai controllers have to handle traffic not only along the East-West Akara corridor, but also on ATS routes B221 to the north (traffic to/from Qindao and Dalian) and W13 to the south.

Increasing Shanghai area congestion is thought to be responsible for a sharp increase in flow control restrictions imposed on westbound aircraft on A593 in recent years, including altitude restrictions and increased minimum in-trail separations. Recently, coordination between Japan, Korea and China at the

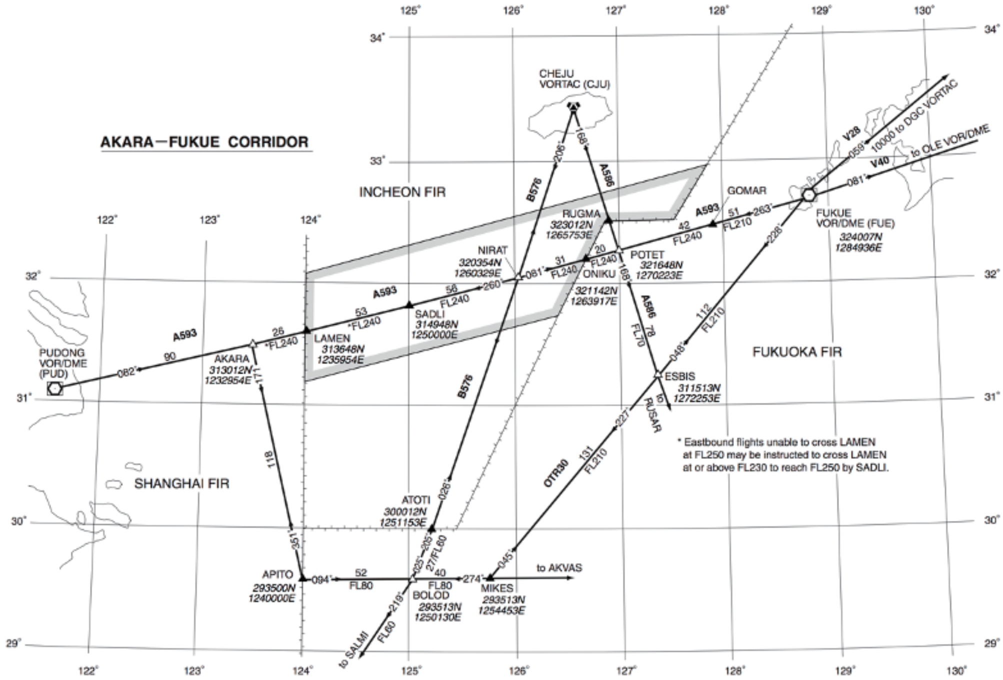

Figure 8: Akara-Fukue Corridor (from Japan AIP ENR 3.5.1)

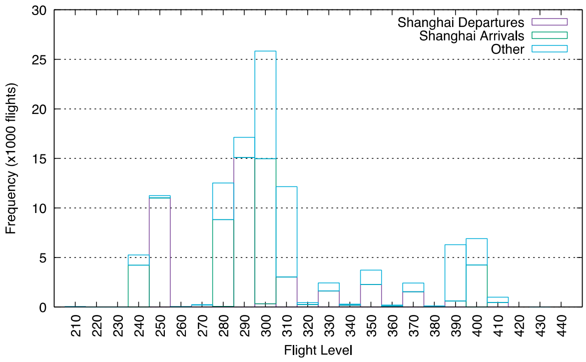

Figure 9: Altitude distribution of traffic crossing ONIKU

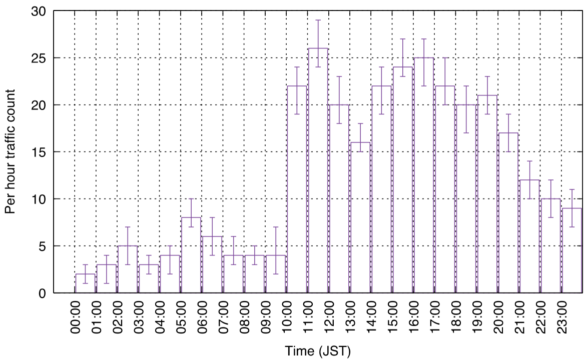

Figure 10: Hourly traffic flow at ONIKU

NARAHG(North Asia Regional AFTM Harmonization Group) forum has resulted in steps to improve coordination between Shanghai and Fukuoka FIRs, including establishing data communication between Shanghai and Fukuoka Air Traffic Management Center.

Traffic between Japan and Taiwan/Hong Kong, and between NAM and Taiwan/Hong Kong, uses the pair of unidirectional ATS routes Y751/M750 via BULAN and MOLKA. Around 42% of the flow comprises Japan-Taiwan traffic, of which 75% is to and from Taipei. 26% of the flow is between Japan and Hong Kong. The flows between JP-TW and JP-Hong Kong and TW-NAM are largely symmetrical, but others are not; in FY2016, 6,347 flights from Kota Kinabalu, Singapore and the Philippines to Seoul operated on M750 but there were only eight reciprocal flights on Y751.

3.5 NOPAC Traffic

The North Pacific fixed ATS routes (NOPAC) are a set of five parallel tracks between Fukuoka FIR and Anchorage FIR (Figure 4). From Table 1, just over a third of the traffic is between Japan and NAM, a little under a third is between CHN and NAM (with significantly more eastbound than westbound traffic) and the remainder is between NAM and Korea and

NAM and Taiwan.

As shown in Figure 5 and Figure 6, the aggregated eastbound and westbound NOPAC routes carried medians of 114 and 102 flights/day between from 1 July 2016 to 30 June 2017, with peak hour flows of 9 and 16 flight/hour, respectively. While these figures seem low compared to the other ATS routes in this paper, it should be borne in mind that NOPAC routes are in oceanic airspace, without radar surveillance and lacking VHF voice communication, so minimum separations are greater than in radar controlled airspace. Due to increasing traffic, restructuring of the NOPAC airspace is being discussed at the Informal Pacific ATC Co-Ordinating Group (IPACG) forum, which has members including airlines, JCAB and the Federal Aviation Administration. Options being considered including reducing lateral separation between tracks to allow expansion of the North Pacific flexible tracks area and introducing bidirectional ATS routes. Since NOPAC is oceanic airspace, reducing separation minima requires satellite-based CNS systems that might not be supported by older aircraft, so equipage policy must be considered.

4. CONCLUSION

This paper presented an analysis showing the state of some of the cross-boundary air traffic flows in the Fukuoka FIR. Many of the major traffic flows are on a North-South axis (between Taiwan, Hong Kong, SW Asia and ASEAN and Korea, Japan and North America), while there are also East-West traffic flows between Beijing, Shanghai and Seoul and North America and Oceania. There are also east/west traffic flows across the Pacific which we have not yet analysed.

To increase route efficiency and capacity, we intend to explore whether “free routeing” concepts can be applied to the Fukuoka FIR. Japan already has a dense network of ATS routes that allow efficient routeings for many domestic city pairs. On the other hand, given the projected 80% increase in international traffic in the Fukuoka FIR, cross-FIR free routeing concepts should be explored. The ATM systems of Taiwan, Korea and Japan are linked electronically and could be further integrated and ATM procedures could be harmonised to alleviate cross-boundary routeing constraints. Aside from political issues, challenges will include accommodating restricted airspaces reserved for defence purposes, connecting airspaces with different CNS performance (radar controlled and oceanic airspaces), integrating domestic and international traffic flows, and addressing the balance between route flexibility to improve individual flight efficiency and the need to impose structure to increase capacity.

In mainland China, ATS routes are sparse but traffic volumes are growing. Bottlenecks exist on the Akara corridor (A593) and between Incheon and Shanghai FIRs (G597), and congestion at Shanghai and Beijing causes flow restrictions. Free routeing on the Shanghai FIR boundary will be hard to apply for political reasons as much as technical, but cross-boundary flow control and collaborative decision making might be feasible to implement in a few years even if airspace or route restructuring cannot be achieved. Regional, sub-regional and inter-regional fora will be critical for tackling ATM issues.

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