

Noise Reduction-Oriented Flight Aircraft Type

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Abstract

With the rapid development of civil aviation and raising public awareness of environmental issues, it is extremely crucial to reduce airport noise impact in the vicinity of airports. Reduction of noise at source and operation restrictions are two prominent noise abatement approaches, both of which reduce aircraft noise impact by selecting appropriate aircraft types for flights. However, reduction of noise at source requires high cost while operation restrictions would restrict the ability of full operation of the airport. To tackle with the above issue, the paper studies the problem of aircraft type selection for noise reduction, the target of which is to select aircraft type with the lowest noise from a variety of candidate types. To this end, the paper employs weighted equivalent continuous perceived noise level to measure the noise level, and then utilizes Integrated Noise Model (INM) to calculate noise impact area at the interval of noise level. Experimental results on Beijing International Airport noise monitoring dataset show that the proposed algorithm can indeed obtain the aircraft type with minimal aircraft noise impact.

Keywords: aircraft noise abatement ; aircraft type selection; weighted equivalent continuous perceived noise level; Integrated Noise Model (INM)

1. Introduction

Airport noise mainly refers to the noise radiation from aircraft during taking off, landing, taxiing, sliding and running engine, which has the characteristics of sudden, intermittent, high sound pressure level, a wide affecting range and long-time influence *etc* [1]. Airport noise not only interferes with the public daily work, study and rest, but also can damage hearing, induce nervous system and cardiovascular diseases and so on, making the airport noise problems increasingly prominent. Therefore, how to effectively control the impact of airport noise on the areas around the airport is an important subject.

Reduction of noise at source and operation restrictions are two noTable noise abatement approaches, both of which reduce aircraft noise impact by selecting appropriate aircraft types for flights. However, Reduction of noise at source requires high cost while operation restrictions would restrict the ability of full operation of the airport. To tackle with the above issue, the paper studies the problem of aircraft type selection for noise reduction, the target of which is to select aircraft type with the lowest noise from a variety of candidate types. On one hand, the results of this study can help airlines choose appropriate models for a specific flight in order to reduce the environmental impact around the airport areas. On the other hand, it can help administrative departments select the optimal flight time for combination of different flight models, to reduce the impact of aircraft noise.

The main contribution of this paper is as follows: 1) By analyzing the noise data caused during the flight, we point out the phenomenon that different aircraft types perform the same flight in different date is common existing, and based on the T-

test, we find the noise levels are significantly different when different aircraft types perform the same flight ; 2) Aiming at the appearance that each flight has several candidate types to choose, we conduct a study to choose the minimum noise aircraft types from all the candidate types.

2. Related Work

According to the management and research methods of airport noise, The International Civil Aviation Organization (ICAO) analyzes the various measures available to reduce noise using four principal elements [2]: reduction at the source, land-use planning and management, noise-abatement operational procedures, and operation restrictions. Reduction at the source can be further divided into two categories: one is structural modification of aircraft (such as wings, engine) from the perspective of manufacturing industry; the second is the ICAO and countries all of the world have developed relevant noise standards for civil aviation aircraft [3], eliminating greater noise of vintage aircraft. At present, the most stringent noise standard is the fourth generation, whose cumulative noise value of taking off, lateral and approach are smaller of 10EPNdb than third-generation noise standards. Noise-abatement operational procedures is mainly through the optimization about flight path, speed and operation process of aircraft take-off and landing. One hand it can avoid vehicle collision with an obstacle, in order to the plane land and take off safely. On the other hand, it can reduce the environmental influence of the area around the airport during aircraft taking off and landing [4-5]. At present, Noise Abatement Departure Procedures (NADP), established by ICAO in 2006 is often used internationally as noise abatement procedures for departure [6]. And Continuous Descent Approaches (CDA) is often used as noise reduction procedure for approach and landing [7]. In 2006 Prats and his partners generated RNAV trajectory to reduce noise annoyance on residents based on a comprehensive optimization tools [8]. In 2010 S. Alam and his partners studied on a dynamic continuous descent approach methodology (Dynamic CDA) for low airport noise and emission [9]. Operation restrictions is implemented by the specific provisions of the aircraft speed, altitude and thrust in flight procedures, to avoid aircraft flying over densely populated areas. Research of land-use planning and management focuses on airport site selection and design, the design and planning of runway, and design of external noise buffer for residential areas.

Reduction at the source and operation restrictions are two prominent noise abatement methods, both of which reduce aircraft noise impact by selecting appropriate aircraft types for flights. However, reduction at the source requires high cost while operation restrictions would restrict the ability of full operation of the airport. In fact, for a particular airport, when runway trends, the number of flights, weather condition and flight procedures are determined, we can low airport noise by selecting aircraft type for specific flight. But little research has been associated both at home and abroad.

3. Aircraft Type Selection of Single Flight for Noise Reduction

3.1. Research Motivation

3.1.1. The Phenomenon of Different Aircraft Types Perform the Same Flight is Widespread

Through statistical analysis of the observational data of 33 monitoring points at capital airport between August 14, 2007 to August 18, 2010, we find the phenomenon of different aircraft types performing the same flight is widespread. And the ratio of at least two aircraft types performing a same flight is 65.16%, as shown in Figure 1. In Figure 1,

the horizontal axis represents the number of aircraft types used in the same flight and the vertical axis represents the number of flights performed by different number of aircraft types. The total number of flights is 8924 while the number of at least two aircraft types performing the same flight is 5815. The statistical results show that the different aircraft types performing the same flight is a common phenomenon, and further explain the study has wide application scenarios.

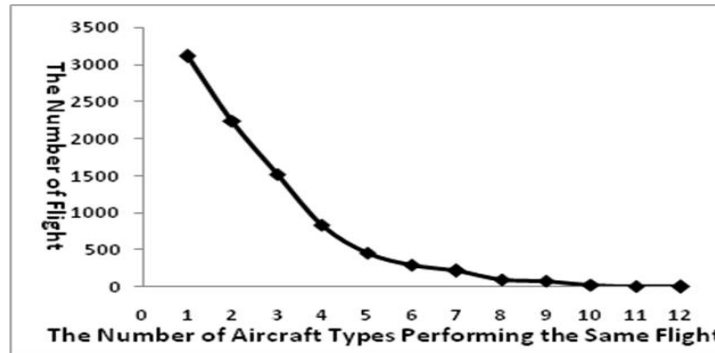


Figure 1. The Number of Different Aircraft Types in the Same Flight

3.1.2. The Noise Level Generated by Different Aircraft Types for the Same Flight Has Significant Difference

In order to test whether the noise level generated by different aircraft types performing the same flight has a significant difference, this paper first defines a evaluation index which evaluates noise levels generated by two aircraft types performing the same flight whether have significant differences.

$$\text{isDiff}(t_i, t_j; Flight) = \begin{cases} 1 & \exists k, t_i(k) \text{ significantly diff from } t_j(k) \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

In equation (1), $Flight$ refers to a specific flight, that is described by the data including departure airport, destination airport, runway, flight track and so on. $t_i(k)$ is described as the average noise value generated by aircraft type t_i on noise monitor point k for the given flight $Flight$. Its calculation is the average of noise observation values at the monitoring point k for all the same flights $Flight$ during August 14, 2007 to August 18, 2010. The intuitive meaning of the above formula is: the necessary and sufficient condition of generating significantly different noise level for two different aircraft types performing the same flight is that there is at least one point in the 33 points, making significantly different noise level on average at this point generated by two different models performing the same flight.

Therefore, this paper tests the significance about difference of average noise level at the same monitoring point for two models performing the same flight using T-test statistical methods. Statistical results are shown in Table 1.

Table 1. The T-Test Results of Noise Differences Between different Aircraft Types in the Same Flight

Number of Theoretical comparison	Number of T-test comparison	Confidence Interval	Number of difference	Occupied Ratio
33528	14824	90%	5412	36.51%
33528	14824	95%	4132	27.87%

In Table 1, the number of theoretical comparison refers to the total comparative numbers that need to do in one T-test for any two aircraft types performing the same flight in theory, while the number of T-test comparison refers to T-test comparison that is able to carry out actually. We can see from Table 1, the number of theoretical comparison is 33528 and the number of T-test comparison is 14824. The noise monitoring data establishes scheduled time (usually 10s), resulting in noise monitoring point below the noise monitoring data of 10s are ignored, which makes it focus on noise monitoring data without noise monitoring data existing in some flight event. Some two models cannot carry out test flight T-test, because data of each group for the T-test has at least two noise samples. The actual log of T-test is lower than that in theory, and the root reason is that the noise monitoring data of flight has its scheduled times (usually 10s). So the data at monitoring points which are below 10s will all be neglected, and this can be lead to some flight events contain nothing at noise monitoring data set. Also, T-test requires more than two noise samples for each data set, not allowing the performance of T-test inspection with two models for some flights. The number of aircraft types which has significant difference on noise is 5412 when the confidence interval is 90%. The proportion is 36.64% based on the total models. When the confidence interval is 95%, the number and proportion of the aircraft type will be 4132 and 27.87%.

According to the title 2.1.1 and 2.1.2, we can see that it is a common phenomenon with one same flight using different models, also the effect is different. This can be illustrated that the aircraft type selection does have the influence on reducing airport noise, and can be further explained the ubiquity and rationality of the questions mentioned in this paper.

3.2. Research Motivation

In the period from August 14th 2007 to August 18th 2010, there are 65.16% of flights performed by at least two models (see Figure 1) based on 33 monitoring points' observation data near the capital airport. So the main research question of this paper is: for flight with a variety of candidate models, how to choose their models which have minimal impact on aircraft noise. More specifically, when fixing flight, flight path and flight time, how to choose models from a number of candidate models with the smallest aircraft noise models.

Before introducing the optimization objective of this article, this paper first discusses necessary mathematical symbols. The symbol of Flight refers to a specific flight, described by the data of departure airport, destination, runway and track. While $\{t_1, t_2, \dots, t_k\}$ refers to all possible candidate aircraft types of flight, in which k represents the total number of all candidate models for flight Flight . In addition to the above information, we also need to determine an evaluation index to measure the impact of noise. Currently, the number of people affected by noise around airport are often used as evaluation index of noise [10-12], calculated mainly by the distribution of noise, an area affected by noise and the population density of noise area. Because data's of population density are difficult to obtain, the paper took the area effected by aircraft noise as the noise assessment value, in which the index of calculating noise impact is weighted equivalent continuous perceived noise level (WECPNL). The reason of choosing WECPNL is that it adds up noise energy generated by a series of discrete noise aircraft event and it is able to represent noise level around the airport area of certain days such as residential buildings, hospitals, schools and sport venues. It is often used as an important indicator of airport land planning [13-15]. The noise value generated by aircraft is divided into three decibel segments, which is less than 70 decibels, between 70 to 75 decibels and greater than

75 dB. And the paper further count areas falling into various noise decibel segments. Therefore, the optimization goal of this paper is defined as:

$$\min_{t \in \{t_1, \dots, t_k\}} \left\{ \text{area} \left(L_{wecpnl}(t) < 70 \text{ dB} \right), \right. \\ \left. \text{area} \left(70 \text{ dB} \leq L_{wecpnl}(t) \leq 75 \text{ dB} \right), \text{area} \left(L_{wecpnl}(t) > 75 \text{ dB} \right) \right\} \quad (2)$$

In order to calculate the area affected by noise falling into each segment decibels of the noise in formula (2), the article imported the data of radar track, aircraft models and runway to the noise calculation model INM [16], and then calculated the area affected by noise falling into each segment decibels of the noise for different models performing the same flight. The radar tracks of this paper came from radar data from March 22, 2013 to July 14, 2013 at Capital airport. The radar tracks of the same aircraft model performing the same flight in the radar data set came from different dates, leading to different tracks for the same aircraft model performing the same flight. To avoid causing the error of only calculating the noise effect of single radar track on the same model on random, we calculates the area effected by noise for each track on the same aircraft model and flight. And then averages areas affected by noise for each track on the same flight and aircraft model. Finally, the mean of the noise area is used as the area effected by noise of used model for the same flight. The algorithm in this paper is shown in algorithm 1.

Algorithm 1

Input	<p>① a specific flight $Flight$: flight number, departure airport, destination, take-off time and runway</p> <p>② Radar track of flight $Flight$ $P = \{\bar{p}_1, \dots, \bar{p}_n\}$, where $\bar{p}_i (1 \leq i \leq n)$ is a specific radar track, and in this paper, it refers to the radar tracks of flight $Flight$ a day</p> <p>③ $T = \{t_1, \dots, t_k\}$ is a set of candidate aircraft types of flight $Flight, t_i$ refers to aircraft type i</p>
optimization procedure	<p>For every aircraft type $t_i (1 \leq i \leq k)$</p> <p> For every radar track $p_j (1 \leq j \leq m)$</p> <p> calculate the noise effecting area of t_i performing the radar track p_j $a_{ij} = \{L_{wecpnl} < 70 \text{ dB}, 70 \text{ dB} \leq L_{wecpnl} \leq 75 \text{ dB}, L_{wecpnl} > 75 \text{ dB}\}$</p> <p> End For</p> <p> Calculate noise level on average of each aircraft type t_i :</p> $\bar{a}_i = \frac{1}{m} \sum_{j=1}^m a_{ij}$ <p> End For</p> <p>Find a model with minimum noise level</p> $t^* = \arg \min_{t \in \{t_1, \dots, t_k\}} (\bar{a}_i)$
Output	Output a optimal aircraft type $t_i (1 \leq i \leq k)$, making the impact of airport noise minimal

4. Experimental Design

4.1. Research Motivation

4.1.1. Experiment Setting

The experimental original data of this paper is monitoring data of flight event from August 14, 2007 to August 18, 2010 at Beijing Airport, which records the noise level generated of flight event at 33 monitoring points near the airport each day. Each row of a data set is noise monitoring value at one noise monitoring point on a flight event, including monitoring points, monitoring date and time, noise value, flight number, departure or destination, aircraft type, runway, and the three-dimensional distance, two-dimensional distance and height between noise monitoring point and aircraft when the maximum noise occurs. The format is shown in Figure 2.

14	20070814	00:01:23	91.2	CCA1616	ARR	B733	36R	2431	2423	191
14	20070814	00:03:54	90.0	CCA1136	ARR	B733	36R	4000	3997	152
19	20070814	00:14:57	82.9							
19	20070814	00:19:53	79.5							
19	20070814	00:21:39	82.9	CES5715	ARR	B737	36L	1089	1076	170
19	20070814	00:29:41	82.4							
19	20070814	00:32:53	79.9							
19	20070814	00:35:29	80.8							
17	20070814	00:36:29	77.2	CCA1548	ARR	A320	36L	3395	3378	341
19	20070814	00:37:41	85.2							

Labels below the table:
 Nmnt Number: 14, 19, 17, 19
 Event_start Date and Time: 20070814, 20070814, 20070814, 20070814
 Event_sel: 00:01:23, 00:03:54, 00:14:57, 00:19:53, 00:21:39, 00:29:41, 00:32:53, 00:35:29, 00:36:29, 00:37:41
 Flight Number: CCA1616, CCA1136, CES5715, CCA1548
 Operation: ARR, ARR, ARR, ARR
 Aircraft Type: B733, B733, B737, A320
 Runway: 36R, 36R, 36L, 36L
 Distance_3d: 2431, 4000, 1089, 3395
 Distance_2d: 2423, 3997, 1076, 3378
 Height: 191, 152, 170, 341

Figure 2. Monitoring Data of Flight Event

In order to calculate the noise effect of one flight event generated by different aircraft types performing the same flight, the paper uses radar track data at the same time. Radar data of this paper refers to flight information that radars get every second from March 22, 2013 to July 17, 2013, which records all of flight information and geographic information of the aircraft within one day. It mainly includes date, time, aircraft number, the code of answering machine, latitude, longitude, height, speed, flight number, aircraft type, departure airport, destination, registration number of aircraft and operation type of aircraft (landing or departure). The data format is shown in Figure 3.

Date Time	Aircraft number	Latitude	Longitude	Altitude	Velocity	Flight number	Aircraft type	Departure airport	Destination	Regis	Operation
2013-03-22 00:00:00	257-123	36.453396	114.772346	8410	0	CXA8209	A320	ZBAA	ZHHH	B6609	DEP
2013-03-22 00:00:00	265,3032	35.857979	117.580193	9480	0	CS29572	B738	ZBAA	ZSWX	B5050	DEP
2013-03-22 00:00:00	307,3060	36.700714	117.360451	10700	0	CES5574	A320	ZBAA	ZSHC	B2229	DEP
2013-03-22 00:00:00	328,0007	37.236340	117.240128	11310	0	CES5134	B738	ZBAA	ZSW2	B5101	DEP
2013-03-22 00:00:00	369,6327	37.330101	116.749649	9070	0	CCA178	A332	ZSPD	ZBAA	B6113	ARR
2013-03-22 00:00:00	381,0333	36.656361	115.059586	10090	0	CCA1804	B738	ZHYC	ZBAA	B5312	ARR
2013-03-22 00:00:00	387,4550	36.592918	115.006760	8110	0	CHH7136	B763	ZGHA	ZBAA	B2491	ARR
2013-03-22 00:00:00	32,0015	38.509708	114.619736	8410	0	CXA8148	B738	ZBAA	ZGHA	B5632	DEP

One of original radar data

Figure 3. Original Radar Data and Their Flight Information

4.1.2. Data Pretreatment

In order to carry out the work successfully, we need to pre-process the monitoring data of flight and the radar data in air traffic.

The process is divided into three steps, first to remove the data which have no records about the flight information from the monitoring data set, next to filter the two datasets to ensure they have the same flight, for there exist different flights in both monitoring data set and radar data, and finally to estimate the speed on each radar surveillance, this is because the radar track we put in INM need to provide the speed of the aircraft, but the truth is that in the actual radar data they have no such related information. In this paper, we use the average speed with continuous time in same flight as the instantaneous velocity for the later monitoring point. One core issue is how to calculate the distance between continuous monitoring points. In order to solve this problem, this paper presents a distance formula between two points by latitude and longitude of two points.

$$s = 2 \arcsin\left(\sqrt{\sin^2\left(\pi \times \frac{lat_i - lat_j}{360}\right) + \cos\left(\frac{\pi \times lat_i}{180}\right) \times \cos\left(\frac{\pi \times lat_j}{180}\right) \times \sin^2\left(\pi \times \frac{ln g_i - ln g_j}{360}\right)}\right) \times 6318.137 \quad (3)$$

In equation (3), $ln g_i$ and lat_i are longitude and latitude of monitor point i, while $ln g_j$ and lat_j are longitude and latitude of monitor point j.

4.2. Experimental Result

The number of radar tracks each flight is at least 100, and in order to evaluate noise influence of each flight track, the INM software needs to delineate the real track based on radar track manually, which costs manpower extremely. The paper uses the top nine flights that its occurrence number in the monitor data of flight event is largest as experimental objects, the flight information as shown in Table 2. The noise effected area generated by different aircraft types performing the same flight are shown in Table 3, in which the bold terms represent the models that generate smallest noise effect. The experimental results show that different models performing the same flight generate different noise affected area. For example, Flight CCA931 uses aircraft of B733, B737, B738, B744, B752, A320, A319, A321 and A330, in which noise area that affected by A319 is smaller than other aircraft types. While A321 and B752 generate relative less noise area than other aircraft types.

Table 2. The Related Information of Nine Flights

Flight Number	Operator	Departure Airport	Destination	Runway	Occurrence Number
CCA1654	Approach	ZYTX	ZBAA	01	875
CDG4855	Approach	ZSYT	ZBAA	01	544
CCA1662	Approach	ZYCC	ZBAA	01	539
CDG4651	Approach	ZSQD	ZBAA	01	530
CCA1572	Approach	ZYHB	ZBAA	01	529
CCA1640	Approach	ZYYJ	ZBAA	01	527
CCA931	Approach	ZYTX	ZBAA	01	523
CCA1858	Approach	ZSSS	ZBAA	01	514
CCA1610	Approach	ZYCC	ZBAA	01	511

Table 3. The Noise Impactive Area for Different Aircraft Types in the Same Flight

Flight Number	Aircraft Number	Time	Area of Noise Impacting		
			<70dB	[70dB,75dB]	>75dB
CCA1662	A321	9.129h	28.386	0.216	0.053
	B733		44.775	0.187	0.04
	B737		52.158	0.115	0.01
	B738		52.659	0.107	0.013
CDG4651	B733	7.915h	55.729	0.262	0.053
	B737		65.308	0.168	0.016
	B738		67.977	0.146	0.02
CCA1572	B737	11.16h	39.53	0.12	0.53
	B738		38.589	0.183	0.053
	B733		34.587	0.137	0.086
CCA1640	A321	9.832h	24.449	0.248	0.06
	A332		56.702	1.719	0.754
	B733		36.677	0.209	0.053
	B737		42.557	0.155	0.028
	B738		42.212	0.199	0.048
	B744		110.934	2.029	0.635
	B772		47.416	0.449	0.11
CCA931	B733	9.915h	1.364	0.115	0.008
	B737		35.99	0.049	0
	B738		37.702	0.046	0
	B744		90.3	2.238	0.539
	B752		27.352	0.051	0
	A320		27.393	0.369	0.048
	A319		13.292	0.025	0
	A321		22.382	0.13	0.011
	A330		40.187	1.252	0.0356
CCA1858	A321	9.237h	23.453	0.146	0.036
	A333		58.148	1.561	0.709
	B737		45.426	0.079	0.003
	B738		45.693	0.081	0.005
	B744		113.744	2.031	0.595
	B752		32.239	0.075	0.007
	B762		86.784	0.688	0.141
	B763		103.23	0.858	0.54
CCA1610	B772	11.57h	49.93	0.17	0.027
	B733		22.328	0.079	0.01
	B737		24.718	0.038	0.001
	B738		23.632	0.045	0.001
	B752		17.314	0.047	0.001
	B763		68.577	0.577	0.084
	A319		8.004	0.029	0
CDG4855	A321	12.75h	15.234	0.099	0.017
	B733		44.554	0.226	0.044
	B737		52.618	0.147	0.01
	B738		50.265	0.134	0.013
CCA1654	A321	8.785h	45.448	0.734	0.156
	B733		56.656	0.256	0.053
	B737		66.27	0.165	0.016
	B738		69.036	0.146	0.02
	B763		149.026	1.447	0.299

4.3. Experimental Analysis

In order to explore the reasons that different aircraft types performing the same flight task generate different noise level, this article conducts the research of the internal structure of aircraft. This paper studies the thrust, the number of engine and maximum gliding distance when landing from Integrated Noise Model (INM), as shown in Table 4. It can be seen from the Table, number of engines, maximum static thrust, maximum gross landing weight and maximum landing weight are relatively small. And it is the root cause that A319 generates minimal noise effect. Noise generated by aircraft is mainly limited to the net thrust of aircraft, and in all the models A319 is with minimal thrust of landing.

Table 4. The Information about the Internal Structure of Aircraft

Aircraft Model	Weight Class	Engine Number	Maximum Gross Landing Weight	Maximum Landing Distance	Maximum static thrust
A319	Large	2	137800lb	4740ft	22000lb
A321	Large	2	171500lb	5440ft	30000lb
B752	Large	2	210000lb	4640ft	40100lb
B733	Large	2	114000lb	4580ft	20000lb
B737	Large	2	129200lb	4445ft	24000lb
B738	Large	2	146300lb	5435ft	27300lb
B744	Heavy	4	652000lb	6989ft	56800lb
A330	Heavy	2	412300lb	5126ft	71100lb
A320	Large	2	145505lb	4911ft	25000lb

5. Conclusion

The paper finds the phenomenon of different aircraft models performing the same flight is widespread through the analysis of noise monitoring data of Capital Airport. And further validates that different aircraft models performing the same flight generate significantly different noise.

The research of aircraft type selection of single flight for noise reduction carries out in this article, And we model this problem as a multi-objective optimization problem, which describes each sub-goal as the area of each segment decibels affected by different models performing the specific flight event.

Experimental results show that the proposed algorithm can select the model with the smallest noise, and prove the effectiveness of the proposed algorithm by analyzing the correlation between thrust of aircraft models and landing distance.

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