10.004 Advanced Mathematics II 1D Project - Fall 2019

Part II : Mathematical Modelling

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Executive Summary

Analysis of Risk of Hearing Loss among Singaporeans due to Aircraft Noise

In 2008 and 2017, Changi Airport Terminal 3 and Terminal 4 were opened respectively. This was to accommodate for the increasing global air traffic. Inevitably, with the influx of aircraft travel, noise levels in Singapore rose. An immediate impact of the heightened noise levels is that Singaporeans are at risk of hearing loss. To check on the severity of the current situation, we need to measure this risk with present data.

The higher the risk, the more immediate the solution needs to be. With this task in mind, we had to relate data on hearing loss among Singaporeans in recent years with data on the flight paths of aircraft over Singapore, together with the overall approximated geographical distribution of Singaporeans around the island and the maximum noise intensity experienced in each subzone.

We assumed that all aircraft use similar engines that emit similar sound intensities and each aircraft can be modelled as point sources of sound energy that emit sound in all directions. Although sensitivity differs between individuals, to simplify our model, we assumed that loud noises lead to hearing loss with equal probability for all individuals. We also assumed that Singapore's terrain has uniform altitude, that all planes follow the same flight profile and all flight paths have similar frequency of flights.

We modelled the number of people at risk of hearing loss against their location in Singapore and the flight routes taken by aircraft. Using the data we calculated, we were able to approximate the severity of risk of hearing loss of Singaporeans due to aircraft noise.

Our model is simple and realistic, and the inputs can change according to the flight path detected by the programme. Since this is a multivariable function, our model needed to be versatile, we programmed an application that outlined the flight path, its altitude and the maximum noise level of each subzone in Singapore. However, the downsides of our model are that Singapore actually has buildings of varying altitudes and this would affect our prediction since higher floors are more affected by aircraft noise than lower floors. The other flaw is that bad weather is not taken into account which would affect our results because aircraft may choose different flight paths when the original flight path is cut off due to bad weather.

Nonetheless, our model still fulfils its purpose to provide a quick prediction of the risk severity of hearing loss among Singaporeans due to aircraft noise.

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Problem Statement

"How many Singaporeans are at risk of hearing loss due to aircraft noise?"

Assumptions

1. All aircraft use similar engines and emit similar intensities of sounds.
2. Aircraft can be modelled as a point sources of sound energy that emits equally in all directions — ignore atmospheric attenuation, Doppler effect and similar effects.
3. Loud noises lead to hearing loss with equal probability for all individuals.
4. Singapore's terrain has a uniform altitude.
5. All planes follow the same flight profile (Climb angle etc.).
6. All runways / flight paths have similar frequency of flights.

Variables

<u>Independent</u>	**<u>Dependent</u>**
Location in Singapore (Latitude, Longitude) Active flight routes (Array of GPS coordinates)	Number of people at risk of hearing loss (Categorically spilt by severity)

Problem Solution

First, we get data[2] on how Singaporeans are distributed around Singapore. The data we got merely tell us subzone and population at that region (See Figure 1). To get a more precise definition of the subzones, we further wrote a script that will query OpenStreetMap Nominatim[1] and scrape the associated GPS latitude and longitude coordinates.

Research was also done on flight paths in and around Singapore using online flight tracking services[6][7] that stored historical flight data as well as instrument approach procedure charts[9] for Changi and Seletar. As a bonus we also implemented unclassified RSAF flight corridors[5]. We then got the sequences of GPS coordinates that determined these paths (See Figure 2).

These datasets represent the variables we fed into our model.

Figure 1: Screengrab from GENERAL HOUSEHOLD SURVEY 2015 Table 7[2]

Planning Area	Subzone	Total
Total	Total	3,902,690
Ang Mo Kio	Total	174,770
	Ang Mo Kio Town Centre	5,020
	Cheng San	29,770
	Chong Boon	27,900
	Kebun Bahru	23,910
	Sembawang Hills	6,890

Figure 2: Example GPS data we collected for Paya Lebar Airbase saved in JSON format

```
}, {
    "name": "Paya Lebar Airbase",
    "IATA": "PLAB",
    "startlatitude": 1.344842,
    "startlongitude": 103.902914,
    "stoplatitude": 1.37603,
    "stoplongitude": 103.916127,
    "flightpaths": [
        [
            [1.344842, 103.902914],
            [1.3787369310516904, 103.91736030578613],
            [1.3919509935369674, 103.92268180847167],
            [1.398386386808088, 103.9194202423095 6],
            [1.3970993095628597, 103.91169548034668],
            [1.3878323326208997, 103.90148162841797],
            [1.3731595449619909, 103.88843536376953],
            [1.2521572975992102, 103.65385284423828]
        ],
```

Next we embark on building a computer simulation which will fly agents along the flight routes and compute the maximum expected sound emissions received at our points of interest. We assumed the jet engine is at 150 dB[13] loud at a meter away. Later computations also rely on the following formulas for key calculation steps:

Sound dB at a distance for point source[10]

$$destDB = srcDB + 10 * log[(srcR/destR)^2]$$

where, ***srcDB*** is the known dB[14] and ***destDB*** is the unknown dB[14] at points ***srcR*** and ***destR*** away from the sound source respectively

srcDB	*srcR*	*destR*	*destDB*
150 dB[13]	1 m	2 km	≈ 84 dB
60 dB	10 m	1 m	80 dB

Figure 3: Example output from sndDB formula

3 dimensional distance with GPS coordinates

$$LOSdist = \sqrt{GPSdist(pLL, gLL)^2 + pAlt^2}$$

where, ***LOSdist*** is the direct distance between the plane at ***pLL***(latitude, longitude) and ***pAlt***(altitude) with the point at ***gLL***(latitude, longitude). ***GPSdist*** is the Haversine function[11].

Nothing too fancy, it is essentially pythagoras theorem encapsulating the Haversine formula[11] (something we found with an accompanying code implementation on StackOverflow)

Figure 4 shows the algorithm flow we use to calculate the expected noise intensities at each region of interest. We iterate through all active planes and update their three dimensional positions. They follow a climb angle of 15° above the horizon till they reach cruising altitude of 10km, both of which are reasonable assumptions[12] for a flight profile taken from our research. The plane then calculates its line of sight distance to each region of interest. Using that, it can also estimate the noise projected there (See formulas above). We save the maximum sound intensity (See Figure 6) for each point to pass on to the next part of our model. *Bonus: It runs at a time complexity of O(number of flight paths * number of regions)*

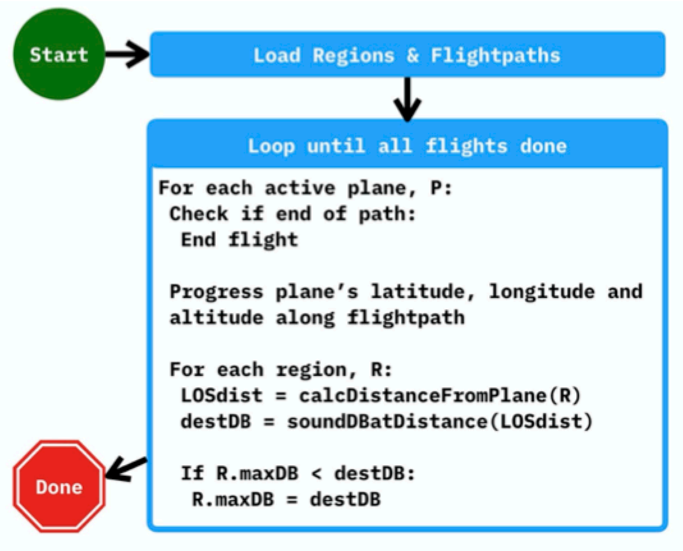
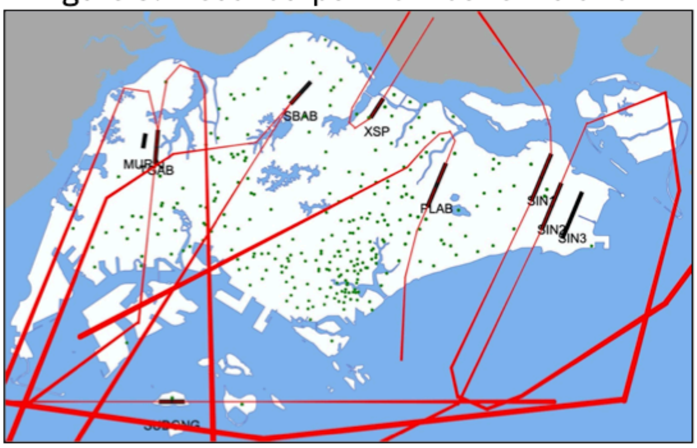


Figure 4: Pseudocode of algorithm flow

An example of our simulation is hosted on Ragul's server (See Appendix Figure 5)
Access it here using a modern browser: http://ragulbalaji.com/work/aircraftnoisemodel/

Figure 5: Visual output from our simulation



THE APPENDIX CONTAINS OTHER COOL EXAMPLES

Figure 6: Output data from our simulation

(…	name	population	latitude	longitude	maxnoise
0	"Ang Mo Kio"	174770	1.369842	103.8466086	78.86157349…
1	"Ang Mo Kio Town Ce…	5020	1.369842	103.8466086	78.86157349…
2	"Cheng San"	29770	1.340863	103.830391…	76.40918049…
3	"Chong Boon"	27900	1.36820695	103.856360…	78.38889116…
4	"Sembawang Hills"	6890	1.3723986	103.829029…	77.77775861…
5	"Shangri-La"	18510	1.311352	103.826629…	74.38619738…
6	"Tagore"	8350	1.3841414	103.8299403	80.16869311…
7	"Townsville"	23770	1.3594914	103.8551716	78.15368938…
8	"Yio Chu Kang"	30	1.3587904	103.8742217	79.14730691…
9	"Yio Chu Kang East"	4080	1.3587904	103.8742217	79.14730691…
10	"Yio Chu Kang North"	0	1.3587904	103.8742217	79.14730691…
11	"Yio Chu Kang West"	26550	1.3587904	103.8742217	79.14730691…
12	"Bedok"	289750	1.3239765	103.930216	78.53088171…
13	"Bayshore"	7480	1.3128118	103.939032…	79.75244622…
14	"Bedok North"	85930	1.3324018	103.9193052	83.05095217…
15	"Bedok Reservoir"	25400	1.3425058	103.925229…	82.44815678…
16	"Bedok South"	51190	1.3170871	103.9499069	81.88069835…
17	"Frankel"	33570	1.3183166	103.9147267	80.92949765…
18	"Kaki Bukit"	40820	1.3360277	103.9018509	83.88520042

By researching on the maximum allowable noise exposure to individuals per day[3][8], we found out that the risk of noise induced hearing loss starts after 80 dBA. The permissible exposure timing is halved for every increase in 3 dBA.

Using the assumption that each individual will be exposed to 8 hours of aircraft noise each day and the noise data from Figure 8, we categorised the severity of noise risk for every 10dBA increase from 80dBA.[13]

Figure 7: Maximum noise exposure duration

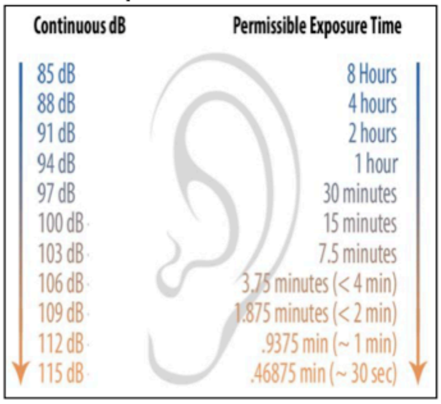


Figure 8: Risk Categorisation Data

name	population	latitude	longitude	max noise	Risk
Yishun East	54880	1.428136	103.8337	82.01436	5
Yishun Sou	38840	1.428136	103.8337	82.01436	5
Kaki Bukit	40820	1.336028	103.9019	93.8852	4
Changi	2530	1.352516	103.987	91.74552	4
Changi Airp	0	1.357338	103.9886	92.17884	4
Changi Poi	790	1.352516	103.987	91.74552	4
Changi We	1740	1.352516	103.987	91.74552	4
Lorong Hal	0	1.383123	103.9225	93.04032	4
Mandai	2120	1.423535	103.8033	96.49411	4
Mandai Ea	0	1.423535	103.8033	96.49411	4
Mandai We	0	1.423535	103.8033	96.49411	4
Airport Ro	0	1.337628	103.8962	92.41155	4
Pulau Pung	0	1.425123	103.879	91.40972	4
Seletar Aer	20	1.41635	103.8725	96.25262	4
Lorong Hal	0	1.383123	103.9225	93.04032	4
Tengah	10	1.366902	103.7108	90.04223	4
Tengah	10	1.366902	103.7108	90.04223	4
Port	140	1.408495	103.861	109.8329	3

Results Analysis

Based on the points obtained in Figure 6, the areas that are more severely affected are located closer to the airport since aircraft will take off with maximum power, which leads to higher levels of noise from the plane engines.
The results show that most Singaporeans are located in areas with low noise exposure risk and areas with higher risks are generally less populated (<50,000 pax).

Figure 9: Population affected (All Bases)

Risk Category		Affected Population
0	No risk	3475170
1	Extreme risk	0
2	Very high risk	0
3	High Risk	140
4	Moderate Risk	48040
5	Low Risk	4077760

Under the assumptions that military bases operate at the same frequency as civilian bases, our model shows that more people are affected by noise emitted from military aircrafts than civilian aircrafts. (Figure 9 vs 10) However, since these assumptions may not be true, more analysis of military aircrafts has to be made in order to confirm the greater impact by military aircrafts on risk of hearing loss.

Figure 10: Population affected (Civilian Airbases)

Risk Category		Affected Population
0	No risk	6916460
1	Extreme risk	0
2	Very high risk	0
3	High Risk	140
4	Moderate Risk	5080
5	Low Risk	679430

Model Assessment

Strengths

- Model outputs predictions that concur with our expectations: places where planes are low flying tend be impacted more severely due to aircraft noise.
  - SUTD receives the most sound intensities among all Singaporean universities due to civilian aircraft activities (See Appendix Figure 1)
- It takes into account where people actually live geographically (in terms of subzones) and therefore helps us better conclude the weighted impact due to aircraft activity.
- Program is coded is versatile and can be used to simulate hypothetical geographical locations of airports or flight routes to optimise noise management plans.
  - We tried to turn off military and civilian installations to see how different regions were affected by it (See Appendix Figure 2 and Figure 3)
  - You can also move/create bases in places where it may not be physically possible and still measure the hypothetical impact due to it
- Heatmaps produced by the simulation provides a visually simple model that carries information on the sound intensity per subzone. (See Appendix Figure 2 and Figure 3)

Weaknesses / Limitations

- There are no reputable websites that associate the intensity of noise level (dBA) to the risk of hearing loss (%) of each individual. We can only categorise risk of hearing loss based on the maximum allowable exposure to the respective noise level.
- We did not account for vegetation and other obstacles that would muffle the sound at ground level before it leaves the airport perimeter.
- The difference in height of buildings affects sound intensity, which is not taken into account in the model, hence reducing the reliability of the approximation.
- Little to no information on military aircraft and their activities (due to obvious security implications) but this data can help us better model aircraft noise emissions since we have more air bases by the numbers compared to civilian airports. They are also located nearer to population centers than Changi.
- Atmospheric conditions are not taken into account as they may impact not only the original aircraft path flight (the aircraft will change routes) but also sound attenuation may occur.

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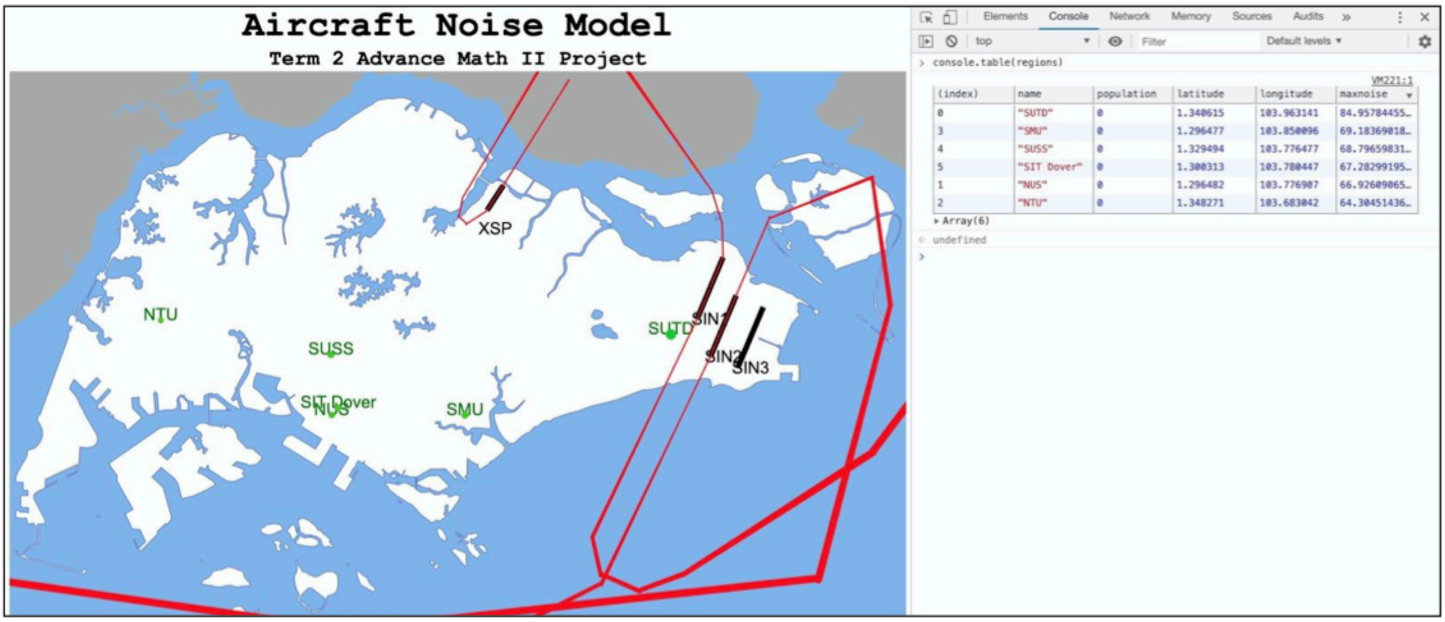
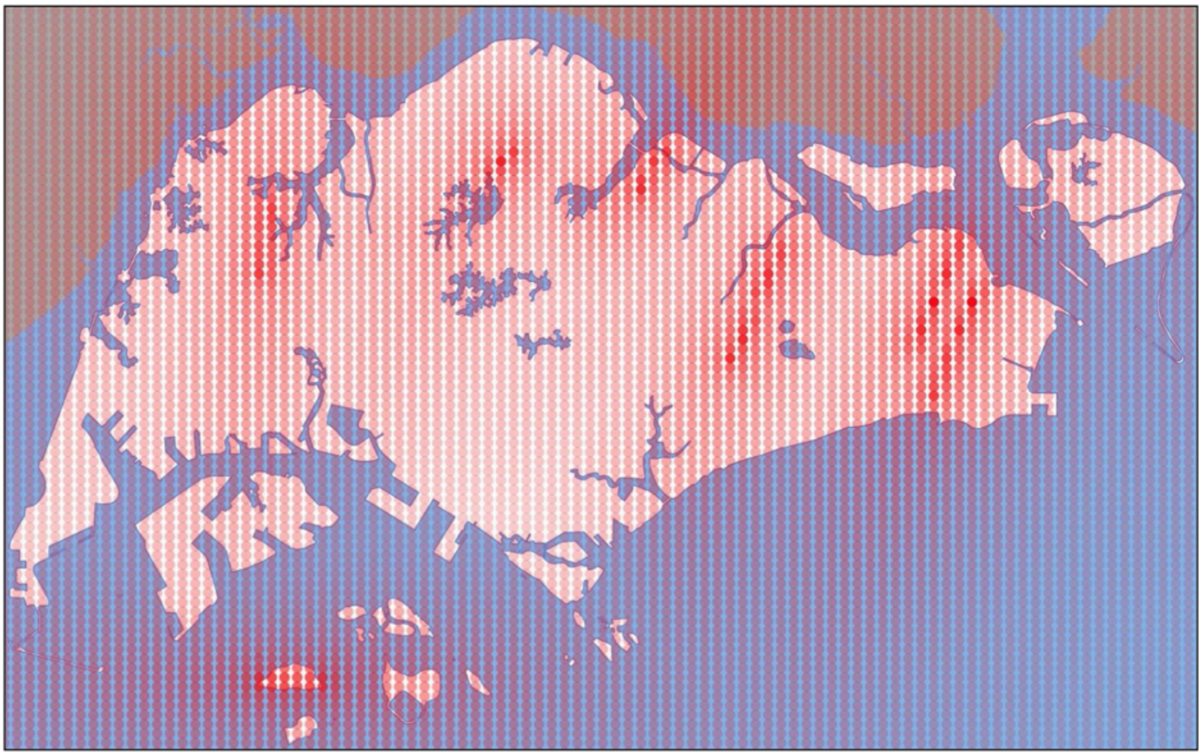
[14] Decibel, unit of measurement used to express the ratio of one value of a power or field quantity to another.
https://en.wikipedia.org/wiki/Decibel

Appendix

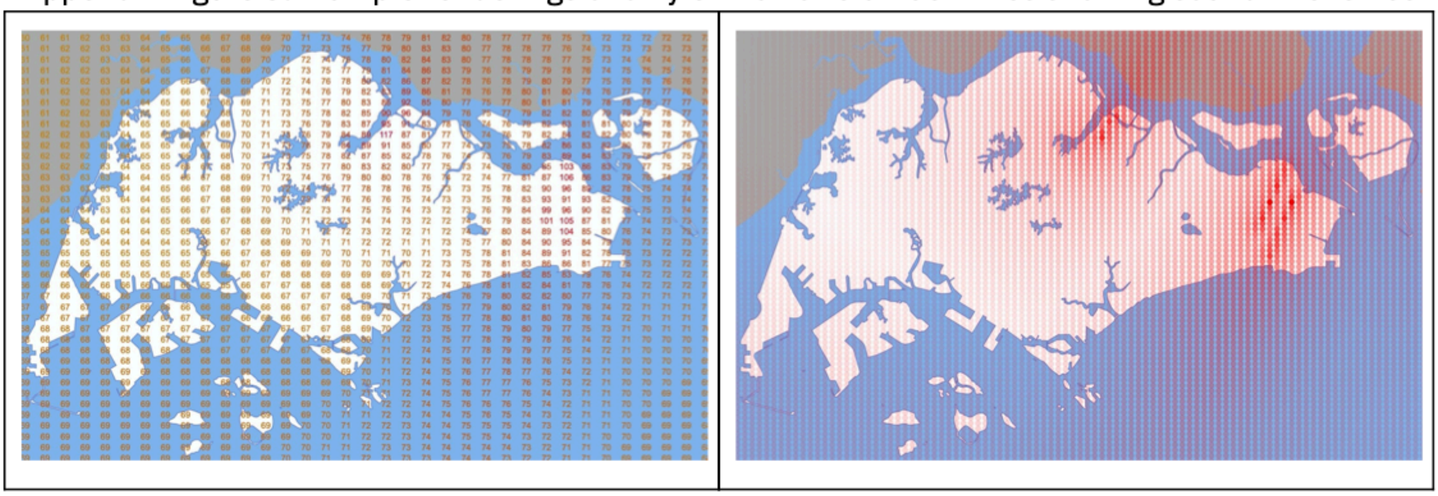
Appendix Figure 1: Noise model restricted to civilian aircraft and Singaporean universities



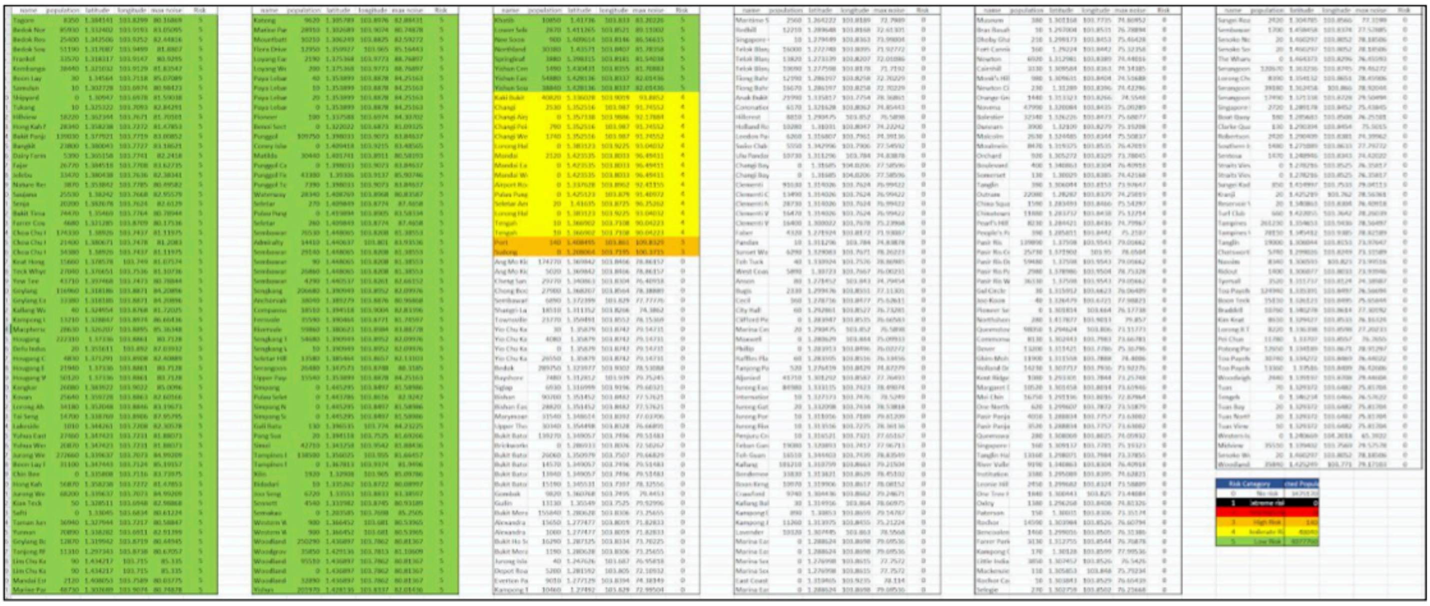
Appendix Figure 2: Sound intensity heatmap of aircraft activities both civilian and military



Appendix Figure 3: Multiple renderings of only civilian aircraft activities showing sound intensities



Appendix Figure 4: Excel sheet of subzones with associated risk profiles



Appendix Figure 5: All airfields enabled; radius of green dots indicate the max noise that point received; red lines indicate the flight path of each plane, red lines get thicker with planes' altitude.