An Exploration of Various Aircraft Noise Contour Models and the Ways in Which These Models Fail as Effective Land-Use Planning Tools

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Report prepared at the request of The Vancouver International Airport Authority (YVR) in fulfillment of UBC Geography 419: Research in Environmental Geography, for Dr. David Brownstein

Executive Summary

The impacts of noise generated from airports affect many surrounding communities and present a significant issue for the airport operators, airlines, and aircraft and engine manufacturers. Airports are therefore required to create noise contour maps of the noise measured around the surrounding communities and communities that experience high levels of noise. These noise contour maps should then be used as a land-use planning tool in order to assist developers to make noise sensitive decisions when building on or near high-noise level areas. However, in this paper, I identify three essential limitations of noise contour model that can have negative implications to the surrounding community and airport authorities:

1) The inability for noise contour metrics to adequately incorporate community perception of noise,
2) Public inability to accurately interpret resulting contour maps, and
3) Non-legally binding land-use requirements for surrounding communities.

Further, this paper explores the possible ways that Vancouver International Airport (YVR) can overcome these limitations. For the first limitation, those representing YVR should choose metrics that accurately map noise perceived, rather than noise measured. This speaks to the issue between acoustic and non-acoustic factors influencing noise perception. For the second limitation, those representing YVR should be ready to fully describe the details of the noise emitted by airports and aircraft in that community. While, doing this, YVR should take the “good neighbor” strategy outlined by Upham et al (2003) in order to show the public that they are taking these concerns seriously by publicly setting targets for mitigation. Finally, the last limitation is responsibility of the developers and municipalities to follow governmental land-use recommendations in regards to high levels of noise.

I. Introduction

Noise generated from airports affect many surrounding communities and presents a significant problem for the airport operators, airlines, and aircraft manufacturers. As the demand for flights rapidly increases, airports and airlines around the world must accommodate increased arrivals and departures. However, public noise concerns often inhibit airport development, even as aircraft are becoming quieter. For this reason, airports direct great effort towards noise monitoring and mitigation strategies. A successful noise management strategy includes noise management at the source, operational procedures, and compatible land-use planning for surrounding communities (YVR Noise Team 2013). While aircraft operations and procedures can be clearly defined and legally enforced, procedures to ensure compatible land use planning around airports involves high subjectivity and lacks governmental enforcement. This produces significant complications for municipal developers, as well as residents, land-use managers, and airport authorities.

Many governments require airports to produce noise contour maps, using complex models to assist surrounding districts with land-use planning. Generally, governments determine the noise metric that should be used and the value at which they discourage development to occur. The most common noise metrics are the Noise Exposure Forecast (NEF), the Australian Noise Exposure Forecast (ANEF), the N70, and the Yearly Day-Night Sound Level (YDNL), further discussed in later sections. These metrics forecast five, ten, and twenty years into the future to assist with future city planning. These metrics are provided to ensure that developments are built in areas that will not be exposed to non-compatible noise levels in the future. The resulting noise contour maps should be of great use and importance in land-use planning

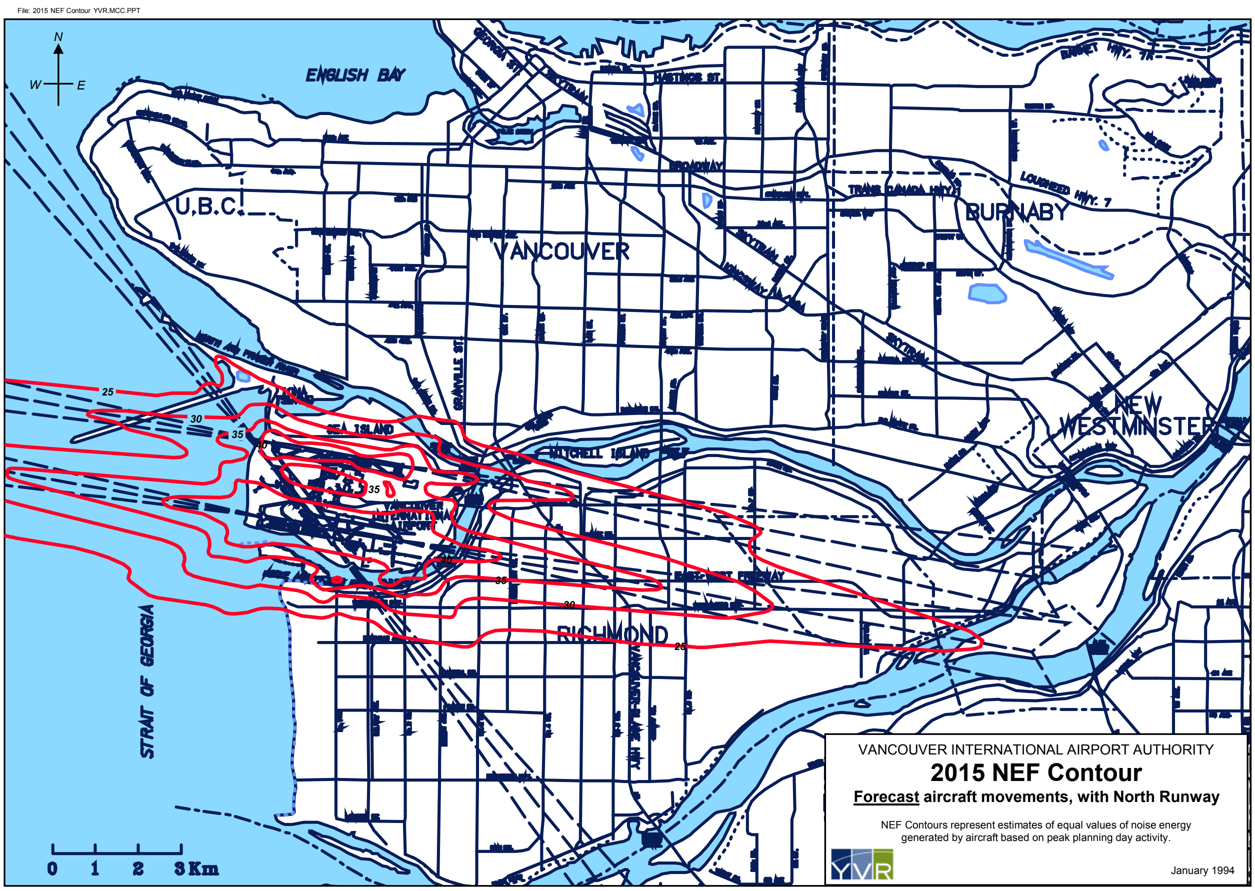

Figure 1 Vancouver International Airport's NEF (Noise Exposure Forecast) contour map created in 1994 to forecast the noise contours for 2015, 20 years into the future (Vancouver International Airport Authorities 2013)

however, there are many complications linked to the inability of noise contour maps to successfully present intended information. This paper will first look at the metrics used by different countries in order to compare and contrast different models and the inputs involved. Furthermore, this paper will strive to uncover the reasons why noise contour maps fail as effective land-use tools through a meta-analysis of studies done on this subject.

II. Different Noise Contour Models

The Vancouver International Airport (YVR) currently employs a traditional method of a 20-year planning horizon for NEF modeling of noise exposure surrounding YVR. The current noise contour plan was created in 1994 for predicted noise production in 2015 (see figure 1). I compare YVR's current model with four other countries including Australia, the United States, China (specifically Hong Kong), and the United Kingdom in order to compare YVR's current model in place.

In order to fulfill the comparisons, the following questions must be answered for each country:

1) What noise models and metric is recommended?
2) What are some of the major input requirements and methodology associated with each model (e.g., traffic mix, night-time weighting penalties, planning day activity, etc.)?
3) What value corresponds to discouraging non-compatible land use?
4) What defines a planning day (annual average, 95^{th} percentile, etc.)?
5) What is the prescribed planning horizon (5, 10, 20-years, etc.)?

The International Civil Aviation Organization (ICAO) has drafted standards regarding aircraft noise that all countries in the United Nations should incorporate into legislation (ICAO 2012). At the regional level, there is a set of regulations and guidelines issued by the European Union, commenting on recommended input units in the noise contour maps for all members of the European Union (European Commission 2002). Finally, at the national level, there is one document for each nation of interest issued by the government of the corresponding country. These national documents discuss the input measurements and values by which all corresponding airports must abide. Additionally, academic articles on metric recommendations and critiques will be consulted to evaluate the metric's compatibility as effective land-use tools. This analysis, in combination with the documents provided by the governments, will contribute to the support for the superior metric.

Country	Major Inputs
Canada (NEF)	- Number of arrivals for each aircraft type - Number of departures for each aircraft type (destination/ flight path) - Time of operation (night-time or day time) - Runway layout - Departure routes - Arrival routes - EPNL (Taken from Trans. Can 2005)
Hong Kong (NEF)	- Runway location, length, & orientation - Aircraft fleet mix for average day - Number of daytime operations (7:00-21:59) - Runway utilization rates - Primary arrival and departure flight tracks, & flight track utilization rates - Arrival and departure flight profile (Taken from HKIA Master Plan 2030)
United States (DNL)	- Runway length, alignments, landing thresholds, and takeoff start-of-roll points - Airport boundary - Flight tracks - Number of aircrafts by aircraft types in both daytime (0700-2200 local time) and nighttime (2200-0700 local time) - Glide slopes, glide slope intercept altitudes, and other information needed to indicate landing profiles - Takeoff profiles including relationship of altitude to distance from start-of-roll along with the engine power levels and take off weight - Topographical or airspace restrictions - Airport elevation and average temperature (Taken from FAA, 14 CFR Part 150)
United Kingdom (L_{Aeq}; N70)	- Sound level exposure of individual events - A-weighted average sound level over 16-hour period (0700-2300) - A-weighted average sound level over the 8-hour period of (2300-0700) (Taken from Airp. Commission 2013)
Australia (ANEF)	- Aircraft types - Runway utilization - Flight path - Aircraft movements - Nighttime weightings (Taken from Air Services – Airport Master Plans)

Country	Value corresponding to non-compatible land-use	Defined planning day	Planning horizon
Canada (Transport Canada)	> 30 NEF	95th percentile	5-10 years
United States (Federal Aviation Administration)	> 65 YDNL	Annual Average daily basis	> 5 years
United Kingdom (Airport Commission)	> 70 dB(A)	Day-Evening-Night Level	5 years
Australia (Air Services)	20 ANEF	Annual average day	> 20 years
Hong Kong (Civil Aviation Department)	> 25 NEF	95th percentile	20 years

Figure 2 Table for all five countries incorporating all major inputs into the corresponding models. Table including information on the values corresponding to non-compatible land-use, the planning day, and planning horizon as recommended by the corresponding government.

National Level Regulations on Aircraft Noise

The Noise Exposure Forecast (NEF) metric is recommended by the Canadian and Hong Kong governments. The NEF of Canada and Hong Kong incorporate very similar inputs with very minor differences.[1] For example, Transport Canada recommends that Canadian airports use the NEF contours for five to ten years into the future, while the Civil Aviation Department of the Hong Kong Special Administrative Region recommends forecasting twenty years into the future (Trans. Can. 2005; Airport Authority HK). Both systems, however, attempt to incorporate the response of an average human ear to differing frequencies and duration of aircraft noises using the Effective Perceived Noise Level (EPNL), expressed as EPNdB (Trans. Can. 2005). This frequency weighting system is the NEF model's attempt to predict annoyance to aircraft noise based on aircraft flight characteristics. The Canadian government considers any land within the 30 NEF contour lines as non-compatible land-use, in contrast, the Special Administrative Region

[1] See Figure 2

of Hong Kong considers any land within the 25 NEF contour lines as non-compatible for any land-use.[2]

The Federal Aviation Administration (FAA) of the United States government requires contours to be developed for Yearly Day-Night Sound Levels (DNL) of 60, 65 and 75 (FAA 2004). Any land exposed to 65 DNL is considered non-compatible land. These contour lines are developed using the FAA approved computer program, the Integrated Noise Model (INM). Inputs into the system are the most clearly defined, in contrast to the other systems investigated in this research.[3] This methodology has received the least amount of criticism and therefore many countries try to replicate this system into their own modeling practices.

As the United Kingdom is part of the European Union, it must abide by the guidelines outlined in the European Union Directive 2001/49/EC. Since 1975, the Airport Commission, appointed by the United Kingdom government, has been using the Equivalent Continuous Sound Level (L_{Aeq}) to describe longer periods of noise exposure (Airport Comm. 2013). This L_{Aeq} takes into account sound exposure level of individual noise events and the length of time the noise events occur using the A-weighted scale (the weighting system that is correlated well with responses to the human auditory system).[4] In accordance to the EU directive, the L_{Aeq} weights evening (19:00-23:00) and nighttime (23:00-7:00) flights with an additional five A-weighted decibels and ten A-weighted decibels respectively. However, the L_{Aeq} receives high amounts of criticisms and thus, the United Kingdom utilizes the N70, or the Number Above, contours as a supplement to the L_{Aeq} contour map. The N70 contour lines represent the number of events that have a maximum level of 70 dB(A) or more.

[2] Speech interference occurs at 30 NEF, but developers should be aware that annoyance could occur at much lower noise exposures.
[3] See Figure 2
[4] See Figure 2

In the 1980s, the Australian Noise Exposure Forecast (ANEF) was created to assist developers with defining non-compatible usage of land. Non-compatible land use is defined, by the Australian government, to be any land exposed to 25 ANEF or higher.[5] The inputs to the model are similar to those of metrics previously discussed, but inputs are more loosely defined[6]. Many Australian airports also use the N70 contour lines as a supplement to the ANEF contours due to high criticism that the ANEF metric receives, as seen in the case of the United Kingdom's L_{Aeq} system.

The NEF, DNL, N70, and ANEF require different inputs, planning horizons, and defined planning days. However, they all lack in some respect, the ability to accurately present noise experienced and the low influence on development plans surrounding airports. These failures have important implications on the people experiencing this noise pollution and to the airport authorities providing these maps. The issues arising from these failures are discussed in the next section.

III. Limitations to noise contour models

Noise contours are produced by airports or governments for the sole purpose to aid and encourage compatible land-use planning in surrounding communities. However, it is common for non-compatible lands uses to proceed against government recommendation and guidelines. This can potentially lead to further public discomfort and a higher volume of complaints received by the airport. Increased complaints creates negative public attitude towards the airport, making it harder for airports to fulfill its capacity to satisfy increasing demands. I identify three essential

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[5] See Figure 2
[6] See Figure 2

limitations of noise contour model that can have negative implications to the surrounding community and airport authorities:

4) The inability for noise contour metrics to adequately incorporate community perception of noise,
5) Public inability to accurately interpret resulting contour maps, and
6) Non-legally binding land-use requirements for surrounding communities.

Noise Contour Maps Inability to Incorporate Community Perception to Noise

Most of the criticisms of specific noise contour models are due to the inability for the measurements to accurately associate the noise emitted to the noise experienced every day by residents. The L_{Aeq} system used by the United Kingdom was under criticism because residents expressed concern that the resulting contours did not convey what people within those areas were experiencing (Air. Comm. 2013). Further, those interpreting the L_{Aeq} system's resulting map cannot identify if the area experiences a low number of high A-weighted events, or a high number of low A-weighted events (Air. Comm. 2013). The N70 attempts to solve this problem, but lacks communication of different noise level exposure and the duration of the noise events (Air Comm. 2013). Moreover, most of the metrics use some variety of an average as the described planning day. This method has also been criticized as communicating an unrepresentative noise level experienced. There is generally a large variation of noise experienced on a daily basis; therefore the average noise level projected is not characteristic of a typical day (Southgate 2000; Kroesen et al 2008; Cidell 2008). For every noise contour metric, there is a trade-off between the information that can be presented in one resulting map. This expresses the need for further explanation of the noise contour map.

Moreover, perception of noise develops from more than just the response of the auditory system. There are very significant social and cultural factors that influence how aircraft noise is perceived (Upham et al. 2003; Maris et al. 2007; Kroesen et al 2008). This presents the crucial issue to identify the difference between acoustic and non-acoustic factors (Upham et al. 2003). Acoustic factors are inputs that models can very accurately incorporate, such as the sound levels emitted by individual aircraft, the number noise events generated, and flight direction. Non-acoustic factors, on the other hand, are inputs that the models cannot currently incorporate, such as opinion towards aircraft, individual sensitivity to noise, and individual annoyance threshold (Suau-Sanchez et al 2011; Kroesen et al 2008; Maris et al 2007; Fields 1993). As more research is conducted, the importance of non-acoustic factors becomes increasingly more apparent. Gutski (1999) found that only about one-third of the variation in noise annoyance can be explained by acoustic factors, the other two-thirds can be explained by non-acoustic components and possibly other influences on noise annoyance not yet discovered (Suau-Sanchez et al 2011).

Public Inability to Accurately Interpret Contour Maps

The community's inability to correctly and easily interpret the resulting maps is the second limitation of noise contour models. These issues prompt negative attitudes towards airports, which increases non-acoustic influences on noise annoyance. The general public does not clearly understand what the differences are between DNL, NEF, A-weighted decibels, and decibels, and will not take the time to learn more about the models themselves. With the installation of the third-runway at Sydney Airport, many residents reported that the ANEF contour map communicated a lower noise level than the noise actually experienced (Southgate 2000; Southgate et al 2000). This observation has also been recorded (in regards to the DNL metric) to those living in Minnesota. Many residents were upset that the DNL contours did not give more realistic noise levels experienced in the local community (Cidell 2008). This misconception is mainly due to the problem that most complainants do not fully understand contour metric measurements. One might incorrectly conclude that NEF values directly equate to decibels such that 35 NEF equates to 35 decibels.

Furthermore, when the lay map-reader is introduced to noise contour maps, they assume that areas outside the contours will not experience aircraft noise (Southgate 2000; Cidell 2008). This is, of course, not true, but airport authorities are only required to map contour lines that represent areas exposed to the noise level corresponding to non-compatible land-use. This popular misinterpretation along with the problem of non-acoustic factors lead to high number of complaints. Southgate (2000) has found that ninety percent of the complaints to Sydney Airport came from residents living outside the contours. This pattern is also observed by YVR, where approximately eighty percent of the complaints originated from outside the contour lines in 2012 (Vancouver Airport Authority 2013). This implies that those living within contours do not complain simply due to expectation of aircraft noise. Residents that do not expect to hear aircrafts are more inclined to complain to airports when they hear planes above their houses.

Non-legally Binding Land-Use Regulations

Finally, the most problematic limitation of contour models as effective land-use planning tools is that municipalities and developers are not bound to comply with governmental land-use recommendations and guidelines. Some governments or commissions, such as the Metropolitan Airports Commission (MAC) for Minneapolis, Minnesota, provide some funding for noise insulation for specific properties within specific contour lines (Cidell 2008). These structural noise adaptations, however, should not be used to justify development within contours defining non-compatible land-use. Such noise insulation programs further promote adaptation methods rather than mitigation of noise exposed to residents. Furthermore, although noise is experienced as continual data, contour lines attempt to discretely divide the surrounding areas (Cidell 2008). Therefore, depending on where the contour line is drawn, one side of the street will be able to receive funding for noise insulation, while the other side of the street will not, even if identical level of noise is experienced. Municipalities must understand that high levels of noise exposure can cause potential harm and that these noise contour maps are created for the sole purpose of assisting communities and developers. If buildings with higher sensitivities to noise are built farther away from airports, negative attitudes towards airports might begin to subside protecting future airport capacity. Ensuring that noise sensitive areas are far from the contour lines may increase public comfort and decrease public complaints. It will also protect the airport from residential encroachment, as airports have no control over the events outside the airport boundaries. While this issue limits noise contour maps as effective land-use tools, this issue will not be discussed further, as it is the concern of municipalities to adhere to compatible land-use recommendations or amend regulations.

IV. Suggestions to mitigate the issues

After analyzing the information presented, I have come to the conclusion that NEF, or Noise Exposure Forecasts, appears to receive the least amount of criticism in terms of projecting real noise exposure experienced by people in surrounding neighborhoods and communities (Trans. Can. 2005). Therefore, YVR should continue utilizing the NEF metric to project noise contours in the future. Although, YVR uses a longer planning horizon than is recommended by

Transport Canada[7], it allows for a more strategic analysis for appropriate developments planned in the far future. Infrastructure currently constructed outside the contours projected can expect to be outside the projected contours for the next twenty years. I have no recommendations of specific inputs to the models, as I cannot speak to the complex mathematics and physics involved. However, I can suggest that more research should be done in order to evaluate how people living and working in the surrounding municipalities perceive noise emitted from aircraft movement in YVR. These results may further aid in the attempt to quantify noise experienced. If this is precisely defined, new inputs to include local noise perception can be incorporated, going beyond the EPNL already used in NEF contours.

In order to reduce public misinterpretation, airport authorities and representatives should provide more in-depth explanations of the contour maps produced and clearly define the implications of the resulting contours. By ensuring that the public clearly understands the maps, local opposition may be minimized. Upham and colleagues (2003) suggest taking the "good neighbor" approach when addressing the public. This strategy highlights the importance of providing key information for actions being done to mitigate the public's acoustic and non-acoustic perception of aircraft (Upham et al 2003). Publicly setting targets and implementing noise-monitoring systems will allow YVR to demonstrate potential progress that can and will be made. Implementing this approach could potentially increase positive attitudes towards airports generating fewer complaints and a higher capacity for airport growth.

Airport authorities and representatives should use simple language when speaking with the public. Southgate (2000) states that noise practitioners need to abandon the use of jargon and provide direct responses to questions brought about in discussion. Airport representatives should

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[7] Transport Canada recommends using a five to ten year forecast, while YVR uses a twenty-year forecast.

be ready to answer specific questions regarding the “where”, the “when”, and the “how many” for particular neighborhood blocks. It may seem extensive, but residents want to be informed on these specific details. Residents also prefer information on the noise levels emitted by individual flights rather than the accumulated noise level calculated from the annual average (Southgate 2000; Cidell 2008). During public consultation, airport representatives should also be prepared to explain that noise can be experienced in areas outside the contour lines, however, the areas within the contour lines experience higher levels of noise. One recommendation to alleviate the confusion, as outlined by Southgate (2003), would be to identify buffer zones that extend beyond the NEF contours. It may cause some people to conclude that all aircrafts will fly over buffer zones (Southgate 2003), however, I believe that only a short explanation is needed to alleviate this confusion. These buffer zones can also protect airport authority from receiving increased criticisms. Finally, airport authorities should be ready to justify the methods used to create the contours, as most people attending the consultations already have concerns with aircraft noise and will probably enter the discussion with preliminary scrutiny of the metrics used.

V. Conclusions

Although the aviation industry has spent billions of dollars to reduce the noise generated by aircraft and engine, and stricter international noise standards have evolved over time, noise annoyance continues to present a significant issue for communities in the vicinity of airports. As discussed, noise annoyance is highly dependent on the individual’s perception of the source of the noise, or non-acoustic factors. Therefore, the “good neighbor strategy” is the most important aspect to incorporate while discussing noise annoyance to the public. While employing the “good neighbor strategy”, representatives should also include in-depth explanations of the noise contour maps to decrease public confusion resulting in further decreased public frustration and discontentment. The creation of legally binding policies should be further deliberated by municipal governments, in partnership with the airport, to ensure that sensitive land-uses are not exposed to noise levels above 30 NEF. The recommendations outlined in this paper will assist airports to increase positive attitudes towards the airport and decrease the number of complaints. By decreasing the number of complaints, airports will have one less barrier to overcome in order to satisfy increasing flight demands.

Bibliography

Airport Authority Hong Kong. Hong Kong International Airport Master Plan 2030: Technical Report. *Hong Kong International Airport*. Retrieved from www.threerunwaysystem.com.

Airports Commission. (2013 July). Aviation Noise (Discussion Paper 05). London, England. Retrieved January 27, 2014 from https://www.gov.uk/government

Cidell, Julie. 2008. Challenging the contours: critical cartography, local knowledge, and the public

Civil Aviation Department. (2013 Nov). *Aircraft Noise Management*. Retrieved January 27, 2014 from http://www.cad.gov.hk/english/ac_noise.html

Cohney, D. 2005. Airport Noise and Ldn 50-55 Issue. []. Retrieved on March 2 2014 from http://s3.amazonaws.com/zanran_storage/www.ecan.govt.nz/ContentPages/352814368.df

European Commission. (2002). *The Environmental Noise Directive* (Directive 2002/49/EC). Brussels, Belgium: Official Journal of the European Communities. Retrieved January 27, 2014 from http://ec.europa.eu/environment/noise/directive.htm

Federal Aviation Administration. (2004). *Airport Noise Compatibility Planning* (14 CFR Part 150). Washington, D.C.: US Government Printing Office. Retrieved from http://www.faa.gov/airports/environmental/airport_noise

Fields, J. M. 1993. Effect of personal and situational variables on noise annoyance in residential areas. *Journal of the Acoustical Society of America* 93(5): 2753-2763.

Girvin, R. (2009). Aircraft Noise-Abatement and Mitigation Strategies. *Journal of Air Transport Management*, 15, 14-22. doi:10.1016/j.jairtraman.2008.09.012.

Graham, B. and C. Guyer. 1999. Environmental sustainability, airport capacity, and European air transport liberalization: irreconcilable goals? *Journal of Transport Geography* 7: 165-180.

International Civil Aviation Organization. (2002). Procedures for the Noise Certification. N.P. Retrieved January 27, 2014 from http://www.icao.int

Kroesen, M., Molin E. J. E. and B. van Wee. 2008. Testing a theory of aircraft noise annoyance: A structural equation analysis. *Journal of the Acoustical Society of America* 123 (6): 4250-4260

Maris, E., Stallen, P. J., Vermunt, R., and H. Steensma. 2007. Evaluating noise in social context: The effect of procedural unfairness on noise annoyance judgments. *Journal of the Acoustical Society of America* 122(6): 3483-3494.

Suau-Sanchez, P., Pallares-Barbera, M., and V. Paül. 2011. Incorporating annoyance in airport environmental policy: noise, societal response, and community participation. *Journal of Transport Geography* 19: 275-284.

Southgate, D. 2000. Rethinking our approach to aircraft noise information – going beyond the ANEF. *Acoustics Australia* 28: 11-14.

Southgate, D., Aked, R., Fisher, N., and Rynehart, G. 2000. Discussion Paper: Expanding Ways to Describe and Assess Aircraft Noise. *Sydney Environment Section*. Retrieved on March 2, 2014 from http://www.infrastructure.gov.au/aviation/environmental/

Transport Canada. (2005). *Aviation: Land Use in the Vicinity of Airports* (Report No. TP 1247E). Ottawa, ON. Retrieved from http://www.tc.gc.ca/Publications

Upham, P., Thomas, C., Gillingwater, D., and D. Raper. 2003. Environmental capacity and airport operations: current issues and future prospects. *Journal of Air Transport Management* 9: 145-151.

Vancouver Airport Authority. 2012. 2012 Aeronautical Noise Management Report. *Vancouver International Airport*. Retrieved March 1 from http://www.yvr.ca/Libraries/ENV_Docs/

Vogiatzis, K. (2012). Airport Environmental Noise Mapping and Land Use Management as an Environmental Protection Action Policy Tool: The Case of the Larnaka International Airport (Cyprus). *Science of Total Environment,* 424, 162-173. doi:10.1016/j.scitotenv.2012.02.036