Development and Assessment of Generic Airports for Fleet-Level Noise Modeling

Author: José E. Bernardo

Graduate Researcher, Aerospace Systems Design Laboratory (ASDL)
PhD Candidate from the School of Aerospace Engineering, Georgia Institute of Technology

Advisor: Dr. Michelle Kirby

Senior Research Engineer and ASDL Civil Aviation Division Chief

Advisor: Dr. Dimitri Mavris

Boeing Professor of Advanced Aerospace Systems Analysis and ASDL Director

Table of Contents

Abstract: *This research develops and executes a methodology for creating generic airports for fleet-level noise modeling in support of a generic framework for rapid fleet-level environmental analysis to reduce model complexity and runtime. Generic airports are comprised of generic runways, consisting of operational characteristics, and generic infrastructures, consisting of geometric characteristics. Groupings and validations were performed on both components and the final set of generic airports. The results show that airports can be grouped by their operational and geometric characteristics separately, and that these groupings can be leveraged to infer fleet-level airport noise trends of the generic class onto specific airports.*

Aerospace Systems Design Laboratory
School of Aerospace Engineering, Georgia Institute of Technology

José E. Bernardo
9th Annual Joseph A. Hartman Student Paper Competition

I. Introduction

A variety of different entities have recently projected dramatic increases in future demand for air transportation [1]. This increase in operations is a significant opportunity to continue the growth of the aviation industry and the role it plays in national and international transportation. Increased aviation, however, will also lead to exacerbated environmental effects, such as increased airport community noise. The range of potential adverse effects is varied, and can constitute a threat to public health and welfare as well as other social and economic systems [2] - [4].

Currently initiatives such as the Next Generation Air Transportation System (NextGen) are supported by technology and design programs that address the effects of increased aviation on noise, like the Continuous Lower Energy, Emissions and Noise (CLEEN) program, the Environmentally Responsible Aircraft (ERA) program, and the Subsonic Fix Wing (SFW) program [5] - [8]. Since the development costs of technologies are high, the strategic decision regarding which technologies to pursue in the long-term is critical. While addressing these issues is a challenge at the aircraft level, even further challenges are introduced at the fleet-level, particularly with respect to noise. The fleet-level effect of technology infusions must be considered, since the "environmental… impact of new aircraft is a function of both the aircraft performance and the airline's use of new and existing aircraft." [9], [10] Evaluating the fleet-level effects, interactions and tradeoffs of potential technology packages in detail, including the competing effects of technologies on the various environmental metrics is an expensive modeling process and would be infeasible to examine all possible options due to time constraints. Yet critical decisions must be made, so currently research is focused on developing methods to reduce the computational complexity of fleet-level emissions computations and particularly noise. One example is the push for a generic framework for evaluating future technologies and operational scenarios, including generic vehicles to represent the current and future fleets [11].

II. Background

Unlike other environmental emissions metrics, airport noise is a spatial issue, and therefore the airport-level is critical in arriving at fleet-level estimates with respect to noise. High-fidelity models such as the Aviation Environmental Design Tool (AEDT), designed to perform detailed aircraft-level to fleet-level analyses of noise, fuel burn, and emissions, complete it by creating airport-level contours for each airport included in any given study, naturally increasing the runtime required [12]. In support of a generic framework, the level of fidelity provided by unique airports is not particularly appropriate at this level of the decision-making process. With the large number of

Aerospace Systems Design Laboratory
School of Aerospace Engineering, Georgia Institute of Technology

potential airports of interest with unique operational, infrastructure, and atmospheric characteristics, there is a need to reduce the computational load via categorization. Such groupings have been employed at the vehicle-level in the past, such as those utilized to create generic vehicles and the aircraft 'families' developed by Isley [11], [13]. Much like generic aircraft are advantageous in their ability to rapidly aggregate fuel-burn and emissions with sufficient accuracy, a representative set of airports would be equally valuable with respect to fleet-level noise. In tandem with generic aircraft, generic airports would significantly improve the ability to perform fleet-level trades to evaluate technology options with respect to noise.

Several airport groupings currently exist, which aim to describe a large number of airports with a relative few, through technical similarities. These groupings are very problem specific, and have been developed to improve the efficiency of airport capacity impact assessments, and to study the feasibility of noise trading schemes [14], [15]. While the technical methods for grouping are compatible for generating airport groups suitable for fleet-level noise modeling, there are a number of unique issues with the current problem that require a new approach. For example, Bock's research with airport capacity impact assessment considers many variables that are irrelevant or too detailed, such as separation regulations or runway coordination regulations, which have no impact on a cumulative daily noise analysis [15]. With Ottl and Bock [14], there is no concern for the geometry of the airports, which can have a significant effect on noise contour area [9]. Bock's research does consider runway layouts, but the infrastructure variables that determine a noise contour shape are different than those relevant for airport capacity modeling [15]. While these grouping techniques provide a sufficient methodological background on which to build, there is still a lack of noise-specific groupings for the purposes of reducing fleet-level noise prediction runtime and total runs.

III. Approach

In order to create a set of generic airports for rapid fleet-level noise prediction, a systematic approach must be followed to ensure the results are repeatable. The first step consists of selecting a subset of airports to serve as the grouping sample, since it would be infeasible to consider all airports. One such subset is the MAGENTA 95, which are the airports that account for approximately 90% of the population affected by significant airport noise [16], [17]. Since this sub-categorization is entirely based on the magnitude of contribution to fleet-level noise of the entire system, it is appropriate to use in developing generic airports for the purposes of calculating fleet-level noise estimates.

Secondly, the variables relevant to grouping must be identified. For a long-term fleet-level analysis, the two main variable types of interest for this research are operational and infrastructure variables. The model selected to facilitate the analysis is the Airport Noise Grid Integration Method (ANGIM), which allows for variations in operational and infrastructure variable types [9]. If airports can be analyzed with respect to their operational and geometric characteristics, then it is expected that patterns will emerge, allowing for categorizations. In order to facilitate the groupings, the operational and geometric characteristics must be decoupled. For example, while Los Angeles International Airport (LAX) and Pittsburgh International Airport (PIT) both have four runways, LAX is a major international port with many more operations and diverse aircraft types than PIT. Therefore, the operational characteristics such as operations volume, fleet mix, and distribution of operations across that fleet will be used to generate groups that result in generic runway types. Meanwhile, the geometric characteristics, such as the number of runways and runway orientation, will be used to create generic infrastructure types. Combining the two will yield generic airports, numbering ideally between ¼ - ⅓ of the 95 sample airports, providing a sufficient reduction in airports while still articulating the basic differences operationally and geometrically between airports. The assumptions include that all runways operate in cross-flow, uniform utilization between all runways, with evenly mixed operation types, sea-level elevation, straight ground tracks, fixed runway length of 2 nautical miles, and minimal runway offset error.

In order to perform effective groupings, a useful set of data must be collected for all 95 of the MAGENTA airports. A baseline schedule of operations, as provided in the Global Regional Environmental Aviation Tradeoff (GREAT) tool, provides the operations by origin and destination pair, the aircraft operating the route, the distance of the route, and the total number of times per year the operations occur, and is therefore appropriate for generating generic runways [18]. The operational data in GREAT uses, as a baseline, the 2006 Fleet and Operations Module (FOM) [19]. While the operational data is largely based in operations counts by aircraft type, the geometric variables are of a different constitution. The geometric variables are relatively undefined, and are not particularly tabulated in any one place. Therefore, the raw geometric data has to be identified, gathered, and organized manually. The relevant geometric data includes the runway layout for each airport and a representative contour for each airport.

A. Generic Runways

While other variables such as the trip distance distribution of the flights at an airport, or the time of day of the flights are important to the overall noise response, the most significant contributors are assumed to be the total

number of operations, and the types of aircraft that fly in a given schedule along with the distribution of operations across those aircraft. While grouping could be performed on the operational volume and aircraft distribution together, it is useful to further de-couple these characteristics. For example, while two airports may have similar aircraft distributions by percentage, the number of operations could differ by an order of magnitude, which would negatively impact the ability to provide a representative set of operational characteristics. Therefore, the 95 airports must first be grouped by the total number of operations, which can then be followed by a more targeted grouping by aircraft distribution.

Another issue is the definition of aircraft types. Analyzing the distribution of flights with respect to specific equipment flying at a given airport would be infeasible, as there are 452 unique aircraft in the entire set of operations at the 95 sample airports. To handle this issue, the seat class designations, listed in Table 1, will be utilized to simplify the aircraft distribution. The consequent assumption is that each seat class can be reasonably represented by a single vehicle and that only one vehicle per seat class is necessary to create significant groupings. The operational dataset contains vehicles ranging from seat class 2 to seat class 9.

Table 1: Seat class definitions [13].

Seat Class	Pax Range
1	1-19
2	20-50
3	51-99
4	100-150
5	151-210
6	211-300
7	301-400
8	401-500
9	501-600
10	601+

Statistical K-Means clustering, designed to identify groups sharing similar features, will be utilized in the grouping process, providing the most desirable mathematical characteristics to segment the operational data. "K-means is a prototype-based, partitional clustering technique that attempts to find a user-specified number of clusters represented by their centroids." [20] Using the mean operational volumes and seat class distributions of the centroid within each group, ANGIM flight schedules representing generic runways can be created.

Test 1: Baseline Verification

The first test of the generic runways is to verify the mathematical formulation. This test will be accomplished by running the baseline operations through ANGIM for a single-runway, cross-flow airport configuration, thus removing any bias due to geometric effects. All flights for a given seat class in the actual operational schedules will be flown by the chosen representative aircraft, to remove any bias error caused by using a representative aircraft to serve as a proxy for each seat class group. The generic runway flight schedules will also be run through ANGIM under the same conditions. The actual and predicted total areas will be collected for the 95 airports as well as for each grouping.

Test 2: Robustness to Aircraft Variability

The second test consists of comparing the generic runway predictions to the actual operational schedules at the MAGENTA 95 airports, with operations flown by the 452 unique aircraft specified in the schedule. This test introduces the variability of the aircraft fleet. It is important to maintain consistency in the face of aircraft variability to ensure that introduction of new aircraft or retirement of current aircraft does not diminish the mathematical theory on which the generic runways are based. While this may introduce significant bias error due to the ability of the representative aircraft to characterize the specific aircraft in the schedule by seat class, the generic runways can be calibrated by perturbing operational volume.

Test 3: Robustness to Forecast Variability

The final examination of the generic runways tests their ability to scale with a change in forecast. Since the generic runways are intended to serve for long-term fleet-level noise predictions, they must be capable of scaling with a forecast as it evolves or changes over time. To test this capability, the 95 airport baseline schedules will be varied using scaling factors that vary by seat class from 0.5 to 2. These will be derived from a Design of Experiments (DOE) of 100 cases of four composite Beta distributions, samples of which can be seen in Figure 1.

Each of these cases essentially represents a possible future operational schedule. Once applied to the baseline operations, each case will be modeled for each of the 95 airports. The calibrated generic runways will similarly be varied parametrically, and used to predict the fleet-level noise for each of the 100 operational conditions examined.
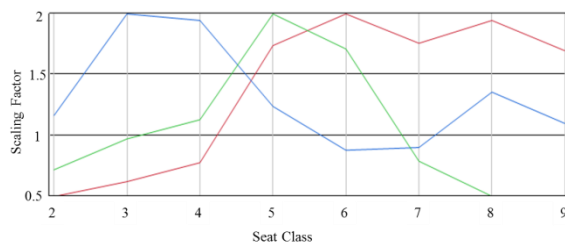

Figure 1: Composite beta distributions used to scale flights by seat class.

B. Generic Infrastructures

The process for geometric variables must necessarily differ because the data types are entirely dissimilar to those of the operational characteristics. The geometric characteristics considered at this stage are simply the number of runways, the relative orientation of the runways, and a representative noise contour. In many cases, however, the actual runway layout will not map directly to how an airport is actually operated, or how the resulting noise contour appears. Similarly, some runways are so close to each other that they do not produce separate definable contours, therefore behaving as one runway with respect to the contour geometry. This situation leads to the introduction of a

third geometry defined as the effective runways. Effective runways refer to the runway layout modified by the appearance of the resulting contour, basically re-structuring the original layout to represent, in a reduced form, a layout that would produce such a contour. A common example is two parallel runways such as those shown in Figure 2 [21], [22]. The contour shape essentially advises how the actual configuration can be simplified into more basic parts. By reducing the uniqueness in this fashion, the variety of airport geometries can be reduced to a few simple sets that can be observed and classified. The goal of generic infrastructures is to capture the interplay of the multi-runway airport configurations and their effect on the overall trends of such a contour. Therefore, it is not entirely imperative that each airport geometry is faithfully represented by a generic infrastructure, but rather that the emergent trends in the general class of airport contour geometries are captured.
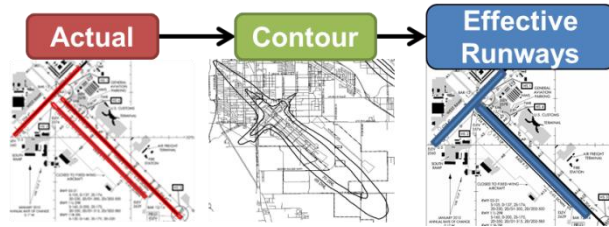

Figure 2: Using layout and contour map to derive effective runways [21], [22].

Test 4: Baseline Comparison

The first generic infrastructure evaluation will consist of comparing the generic infrastructure area predictions to the total 65 dB DNL contour areas of the actual unique infrastructures for the MAGENTA 95, as run through ANGIM. To ensure there is no bias due to operations, a fixed flight schedule will be applied to all generic and actual airports. Other assumptions include that all runway lengths will be assumed to be 2 nautical miles, to conform to the ANGIM assumptions. As with the generic runway test, all configurations will be run in cross-flow, removing any geometric bias caused by the difference between approach and departure operations. Similar to the generic runway validations, the generic infrastructure groups will also be tracked independently and analyzed for deficiencies and opportunities for calibration.

Test 5: Robustness Assessment

While operations can vary greatly over time, the infrastructures of airports change with much less frequency and variability. Capacity-related expansions, in fact, are limited to additions of parallel runways [23]. Instead, the robustness of the generic infrastructures refers to the ability for the generated set to represent, on average, the diversity that potentially exists in the current and future set of airport infrastructures. Furthermore, the robustness assessment must serve as a confirmation that no other significant geometries are contained within the observed

generic infrastructures, thus providing another form of calibration. The experiments will involve using a Latin Hypercube (LH) DOE to vary the relevant geometric parameters. The number of runways and therefore the specific geometric variables will differ between the different generic classes, and thus the variables and their ranges will be unique to each generic class and consequent experiment. All flights will operate in cross-flow on all runways, eliminating any geometric differences between approach and departure operations. An example of the geometric variables that will be examined for a potential generic airport infrastructure is shown in Figure 3. As can be seen, one runway will always remain as a fixed reference runway. The experiment will track the relationship between the 65 dB DNL contour areas to changes in the geometric characteristics, and examine the results for evidence that the configuration is sufficiently homogeneous. If a sub-category emerges, this category will be included in the generic classes.
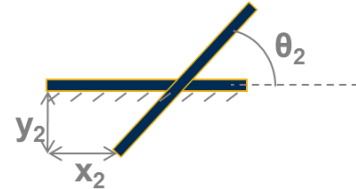

Figure 3: Runway configuration in terms of geometric variables.

Calibration

Based on the baseline validation and the robustness assessments, the observed baseline generic infrastructures can be calibrated to better represent the average geometries within each class. Using the trends observed from the robustness assessment, the behavior of the contour area with respect to the variables can be leveraged to adjust the geometric definitions of the generic infrastructures to better represent the sample set.

C. Test 6: Generic Airports Validation

The final assessment of the operational and geometric groupings is to map the two into a set of generic airports. The 65 dB DNL contour area for all 95 airports will be tracked, along with the distribution of the error. Shapes will also be qualitatively compared, to ensure that no geometric re-classifications are required. For example, if two runways are closely spaced but operations are relatively low, they may in fact not behave as a single effective runway or vice versa.

IV. Implementation

The activities defined in the approach were carried out under the assumptions stated. Any relevant discussions regarding the results will be provided as necessary.

A.   Generic Runways

Grouping

K-Means statistical clustering was utilized for the operational volume groupings. The clustering provides the user with the option of selecting the total number of groups. Based on several trial runs, a total of three volume categories, Small, Medium, and Large, were chosen, and are summarized in Figure 4. These categories are chosen to sufficiently articulate the operations volume space to ensure that aircraft distribution groupings are within the same general airport size.
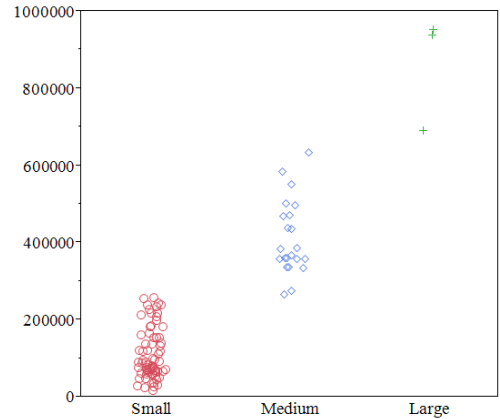

Figure 4: Volume clustering of the 95 airports.

Once the operational volume groups were created, the distribution of flights by seat class were analyzed. Based on trial analysis, it was found that six generic runways would likely provide a total number of generic airports between ¼ - ⅓ of the 95 total airports. This kind of reduction of the airport space would be significant for rapid fleet-level modeling purposes. The six generic runway configurations defined consist of two Small (S1 and S2), two Medium (M1 and M2), and two Large (L1 and L2). An example of the clustered distributions for Small airports by seat class is depicted in Figure 5. Similar groupings were created for the Medium and Large airports. The generic runways were then created by averaging the total number of operations of the airports represented, averaging the seat class distributions and assigning the operations to the

Figure 5: Small airport clustered seat class flight distribution.

representative aircraft. The stage length distributions of flights were also averaged from the actual schedules of the airports within each generic runway (GR) group. A summary of the generic runway distributions are listed in Table 2. Fractional operations are a function of the mathematical averaging.
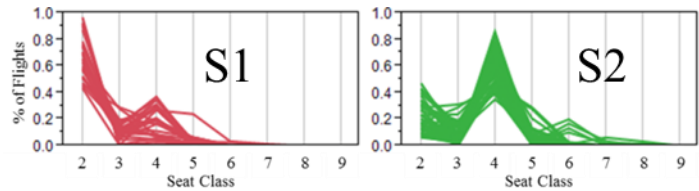
Table 2: Summary of generic runways including airports represented, operations per day, and seat class distribution.

GR	# of Airports	Ops/Day	%SC2	%SC3	%SC4	%SC5	%SC6	%SC7	%SC8	%SC9
S1	29	250.29	66.67	11.52	18.28	3.11	0.34	0.07	0.02	0.00
S2	41	345.44	23.49	9.29	57.58	7.14	2.01	0.35	0.14	0.01
M1	12	1162.81	50.91	10.64	21.55	12.62	3.37	0.66	0.23	0.03
M2	10	1091.78	23.41	6.60	47.22	15.88	5.34	1.29	0.24	0.03
L1	1	2571.33	40.28	16.19	28.59	9.40	3.88	1.34	0.30	0.04
L2	2	2253.03	30.65	8.00	46.10	10.87	4.08	0.26	0.04	0.00

While some generic runways have relatively sparse membership, it is important to recall that these generic runways must be able to account for changes to the operational landscape, as well as potentially account for airports outside the baseline sample set utilized to create the groups.

Test 1: Baseline Verification

The first test consisted of comparing the generic runways to the unique 95 airport operations using only the representative aircraft in both the actual and generic runway flight schedules, which isolates the observed error as much as possible to only the precision error caused by the statistical groupings, listed in Table 3.

Table 3: Baseline verification results comparing total and GR specific 65 dB DNL contour area error.

GR	GR Area (nmi^2)	# of Airports	Pred.Area (nmi^2)	Actual Area (nmi^2)	Error (nmi^2)	% Error
S1	0.52	29	15.08	13.84	1.24	8.96
S2	0.82	41	33.62	34.01	-0.39	-1.15
M1	1.83	12	21.96	21.91	0.05	0.23
M2	2.25	10	22.5	22.56	-0.06	-0.27
L1	3.98	1	3.98	3.89	0.09	2.31
L2	3.94	2	7.88	7.84	0.04	0.51
Totals		**95**	**105.02**	**104.05**	**0.97**	**0.93**

The results show that the theory behind the generic runways is behaving as expected, with error below 1% in total. Within the groups, absolute error is also helpful to analyze, because the total groups and their areas can vary in magnitude, and relative error can occasionally misrepresent the apparent error, as is the case with S1.

Test 2: Robustness to Aircraft Variability

The generic runways were next compared to the 95 actual aircraft schedules, utilizing the unique aircraft designated in the flight schedules. This test introduces diversity within the aircraft fleet, forcing the generic runways to predict behavior in the face of fleet variability. To account for some of this variability, a calibration is applied by perturbing the generic runway operations total to better approximate the airports within each group. The results are listed in Table 4 .

Table 4: Comparison of calibrated generic runways to the 95 actual airport schedules allowing for aircraft variability.

GR	GR Area (nmi^2)	# of Airports	Pred.Area (nmi^2)	Actual Area (nmi^2)	Error (nmi^2)	% Error
S1	0.51	29	14.79	14.7	0.09	0.61
S2	0.91	41	37.31	37.1	0.21	0.57
M1	1.9	12	22.8	22.97	-0.17	-0.74
M2	2.32	10	23.2	23.22	-0.02	-0.09
L1	4.34	1	4.34	4.34	0.00	0.00
L2	5.49	2	10.98	11.02	-0.04	-0.36
Totals		**95**	**113.42**	**113.35**	**0.07**	**0.06**

Test 3: Robustness to Forecast Variability

The final evaluation of generic runways is to test their ability to scale with the operational landscape in a large number of potential situations. For this purpose, the actual 95 airport operations were varied using composite beta distributions, applied through a scaling factor on the total number of flights by seat class. Each case essentially represents a different potential change to the operational landscape. The generic runways are then scaled parametrically by seat class using the same scaling factors, and the ability of generic runways to retain their accuracy can thus be examined. The success of the test is measured by the clustering of the error about zero. Furthermore, the correlation of change in total operations and operations by seat class must be relatively low, as any error trend with respect to changing seat class operations would be troublesome for predicting future flight operational scenarios. The results are shown in Figure 6, with density ellipses use to aid in the visualization of the correlation. As can be seen in the results, the distribution of the error is clustered about zero, and there is insignificant correlation with respect to changes in total operations, and operations by seat class for all except seat class 2. It was found, in this case, that the representative aircraft selected was much louder than most aircraft in that seat class, and therefore the error with respect to changes in seat class 2 operations cause a correlation with predictive error. Nonetheless, the correlation is relatively minor, and it is expected that replacing the representative aircraft with a more appropriate vehicle in the future would erase the correlation. Removing cases in which seat class 2 operations are at the extreme confirms this likelihood as it results in more reasonable correlation for total error as can be seen in Table 5. Therefore, the generic runways can be considered to be robust to a varying flight schedule, demonstrating the ability to retain accuracy under such circumstances.
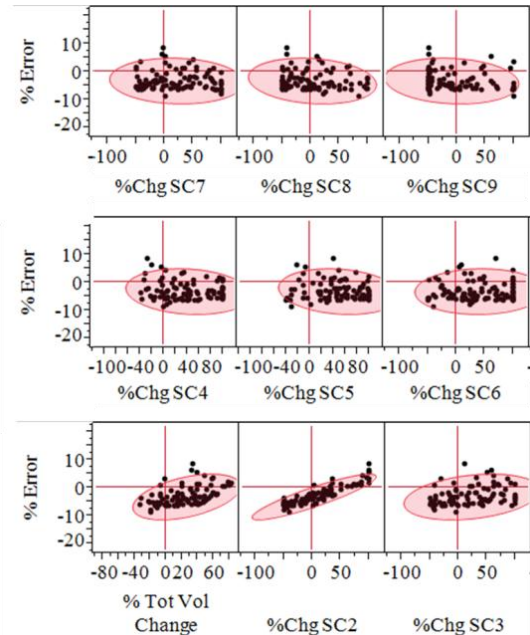

Figure 6: Relative error versus relative change in total operations and change in operations by seat class.

Table 5: Correlations with respect to predictive error by total operations and by seat class.

% Change in Volume	Error Correlation	Error Correlation (extreme SC2 cases removed)
Total Operations	0.46	0.26
SC3	0.30	0.09
SC4	-0.14	-0.17
SC5	-0.17	-0.14
SC6	0.04	0.18
SC7	-0.07	0.18
SC8	-0.17	-0.00
SC9	-0.12	-0.30

B.   Generic Infrastructures

Grouping

The infrastructures derived from observation of the compiled geometric database suggests at minimum, seven basic geometric categories: Single, Parallel, Intersecting, Parallel-Intersecting, Parallel-Single, Parallel-Intersecting-Single, and Triple Intersecting. They are qualitatively characterized by the examples in Figure 7.
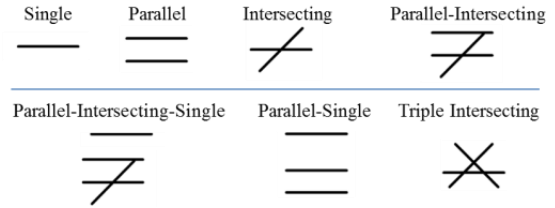

Figure 7: Preliminary observed generic infrastructures.

The creation of these generic infrastructures was based on the observation of actual runway geometries as well as contour geometries, used to infer effective geometries. Using these general categories, a baseline assessment can be conducted.

Test 4: Baseline Comparison

The baseline generic infrastructures were run through ANGIM and compared to the actual unique configurations of the MAGENTA 95 also run through ANGIM. A fixed flight schedule was used for both sets to remove any bias due to operations. The baseline comparison results are listed in Table 6.

Table 6: Comparison of baseline generic infrastructures of in-group and total 65 dB DNL contour area.

Infrastructure	Apts.	True Area (nmi^2)	Pred. Area (nmi^2)	Error (nmi^2)	% Error
Single	16	26.30	25.28	-1.02	-3.88
Parallel	9	18.30	17.28	-1.02	-5.57
Intersecting	34	63.55	61.25	-2.3	-3.62
Parallel-Intersecting	28	63.35	60.9	-2.45	-3.87
Parallel-Intersecting-Single	2	2.44	2.33	-0.11	-4.51
Parallel-Single	1	2.19	2.15	-0.04	-1.83
Triple Intersecting	5	11.30	11.76	0.46	4.07
Sum	**95**	**188.23**	**180.95**	**-7.28**	**-3.87**

The total area estimate is relatively accurate (for example, assuming single-runway geometries for all airports would result in approximately 38 nmi^2 of total error), but the error within the geometries still suggests certain room for improvement. Due to the infrastructural uniqueness of two airports, which will be discussed later, the predictions for these were provided using super-positions of the generic infrastructures. Once robustness assessments are completed, calibration activities can be performed to improve the error of the baseline infrastructures.

Test 5: Robustness Assessment

The robustness assessments of the generic infrastructures were performed on the fundamental geometries, except for the Single runway infrastructure. The Single runway airport infrastructure is trivial, since no variation is possible, and is really an extreme case of the Parallel configuration. The other geometries can be created by superimposing the fundamental geometries without further runway intersections, and are therefore also trivial cases. The variables examined for each fundamental geometry were the cartesian position of the left runway-end and the rotation about that end if applicable. The ranges used for the DOE are listed in Table 7.

Table 7: Geometric variable ranges for infrastructure robustness assessments.

GI	X_2 (nmi)	Y_2 (nmi)	θ_2 (deg)	X_3 (nmi)	Y_3 (nmi)	θ_3 (deg)
Parallel	-1.25 – 1.25	0 – 1.6	N/A	N/A	N/A	N/A
Intersecting	0.3 – 5.3	-1.5 – 1.5	0 – 180	N/A	N/A	N/A
Parallel-Intersecting	-1.25 – 1.25	0 – 1.6	0.3 – 5.3	-1.5 – 1.5	0 – 180	-1.25 – 1.25
Triple Intersecting	-1.5 – 1	-1.5 – 1.5	15 – 75	1 – 3.5	-1.5 – 1.5	105 – 165

These were varied, using fixed operations and the resulting contours were calculated through ANGIM. The results were evaluated to identify any relevant sub-categories and to uncover trends between the variables. A subset of the analysis can be seen in Figure 8, where the Parallel, Intersecting, and Parallel-Intersecting geometry results were used to observe the effect of the geometric variables on the airport 65 dB DNL contour area. Based on the lack of segmentation as a function of the geometric variables in Figure 8, no other significant geometries were identified. The trends identified, however, will be very valuable to tune the baseline configurations.
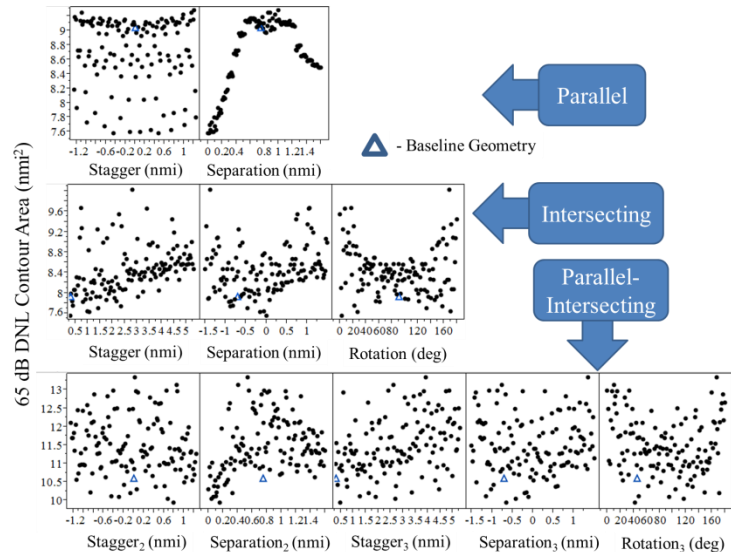

Figure 8: Trends on 65 dB DNL contour area with respect to geometric variables for various generic infrastructures.

Calibration

Having completed the baseline analysis, and examined the effect of the various geometric varibles, the information from both can be utilized to perform calibration. The baseline analysis, visualized in Figure 9, can be used to determine the required direction of calibration, while the robustness assesments can be used to provide the

method of calibration. The baseline analysis shows that the Intersecting, Parallel-Intersecting, and Parallel-Intersecting-Single have the most significant opportunities for calibration, because the generic infrastructure is furthest from the center of the distribution of represented airports as shown in Figure 9. These infrastructures can be tuned by perturbing the geometric variables examined for the robustness assessment, using the observed trends to converge on an appropriate geometry. A particularly useful calibration is the Single geometry, which was originally defined as one runway, whereas some of the
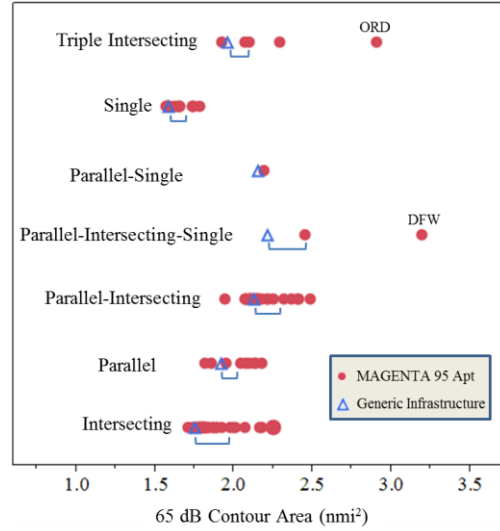

Figure 9: Initial distribution of actual in-group 65 dB DNL contour area.

actual geometries classified as Single have parallel runways with non-zero, but minimal separation. This situation suggests that in fact a sub-geometry does exist, but that instead of introducing a new infrastructure, the Single geometry can be adjusted to an effective single, modeled by a closely separated parallel runway set. The outlier airport for the Parallel-Intersecting-Single and the Triple Intersecting respectively are Dallas Fort Worth (DFW) and Chicago O'Hare (ORD), which were mentioned earlier due to their infrastructural uniqueness. The former is best represented by a combination of Parallel-Intersecting and Intersecting, while the latter is essentially constructed of two Triple Intersecting geometries, as can be seen in Figure 10. These airports are of primary importance due to their operational volume, and may warrant individual treatment from a generic infrastructure standpoint. The final tuned generic infrastructure results can be seen in Table 8. By tuning the geometries with the knowledge gained from the robustness assessment, the generic infrastructure error has been reduced significantly.
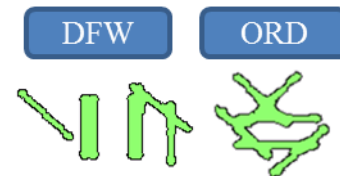

Figure 10: DFW and ORD may require specific infrastructure treatment.

Table 8: Calibrated generic infrastructure in-group and total 65 dB DNL contour area comparisons.

Infrastructure	Apts.	True Area (nmi^2)	Pred. Area (nmi^2)	Error (nmi^2)	% Error
Single	16	26.30	26.20	0.10	0.39
Parallel	9	18.30	19.30	-1.00	-5.44
Intersecting	34	63.55	64.80	-1.25	-1.97
Parallel-Intersecting	28	63.35	61.57	1.78	2.81
Parallel-Intersecting-Single	2	2.44	2.36	0.08	3.16
Parallel-Single	1	2.19	2.15	0.04	2.05
Triple Intersecting	5	11.30	12.36	-1.06	-9.34
Sum	**95**	**188.23**	**188.73**	**0.50**	**0.27**

C. Test 6: Generic Airports Validation

Finally, the generic runways and generic infrastructures can be combined to yield the total set of generic airports. The combination led to a total of 21 generic airports, less than a quarter of the original sample set. If specific infrastructures are used for DFW and ORD, the total number remains unchanged, since they are also fairly unique from an operational perspective. The final evaluation thus consists of validating the ability for the generic airports to predict the in-group and total fleet-level 65 dB DNL contour area of the 95 MAGENTA airports using the actual operations, unique aircraft, and actual infrastructure geometries. This test also allows for examination of the enabling assumption of decoupling operational and geometric characteristics along the lines of magnitude and shape. The summary of the total fleet-level estimate results are listed in Table 9 and the distribution of the absolute errors for all generic airport groups can be seen in Figure 11. As can be seen, the total area is well predicted, and the error is evenly distributed about zero. While the in-group error is also acceptable, there may be further opportunities for calibration. It is important to recall that calibration must be done at the generic runway or generic infrastructure level, however, as the relatively low amount of variability within these types will provide significantly increased computation speed. On the other hand, if calibration is done at the generic airport level, the simplicity in combining a handful of types will be somewhat compromised. While this would still result in a significant savings, it would not fully exploit the potential gains.
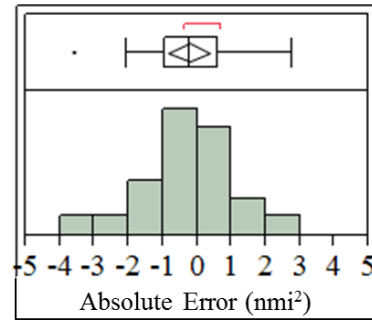
Table 9: Summary of prediction error for generic airports.

Pred. Area (nmi^2)	Actual Area (nmi^2)	Error (nmi^2)	% Error
144.86	149.47	-4.68	-3.13

Figure 11: Absolute error distribution for generic airport groupings.

V. Conclusions and Future Work

The research presented above demonstrates the approach and implementation required to create a set of generic airports in support of a generic framework for environmental aviation analysis. These generic airports can be used to infer noise-specific trends about airports, by simply analyzing the generic version, saving runtime in early fleet-level airport noise analyses. Generic airports were constructed by decoupling the operational and geometric characteristics into generic runways and generic infrastructures respectively. Generic runways were created using operational data to group airports by total operations, and seat class distribution of flights. Generic runways were

then verified to ensure that the mathematical model behaved as expected, and were validated with respect to fleet diversity and variation in operational scenarios. The generic runways demonstrated that they can predict the fleet-level 65 dB DNL contour area of the 95 sample airports, as well as preserving trends and accuracy in the face of a changing operational landscape. Generic infrastructures, on the other hand, were created by gathering geometric data, such as actual runway layout, and resulting contour geometries to create reduced 'effective' geometries. These effective geomtries were then qualitatively categorized to yield seven generic infrastructures. Baseline generic infrastructures were used to examine the direction required for calibration, while a configuration robustness assessment was utilized to define the mode of calibration. Calibration was then performed and the evaluation was executed to demonstrate the ability of generic infrastructures to predict the fleet-level 65 dB DNL contour of the 95 sample airports successfully. Twenty-one generic airports were then constructed by joining the two components, and similarly shown to provide accurate in-group and total predictions of the 65 dB DNL contours for the 95 sample airports. Regardless of whether or not a detailed or rapid-simplified model is being utilized, quartering the preparation, runtime, and analysis requirements is a significant improvement that enables more fleet-level analysis, leading to more informed decisions. By examining the generic classes presented here, a significant amount of insight can be gained on the unique airports, before there is any need to perform a detailed specific analysis, allowing computational and time resources to be allocated with greater confidence and efficiency.

While a successful preliminary set of generic airports was presented here, there are still opportunities for further research in this area. For example, the variables utilized for grouping were relatively limited in number, and the cost-benefit of including more detailed variables could be examined with respect to the total number of final generic airports (resulting in a loss of computational efficiency) versus the increased precision and robustness of the final set. With respect to generic infrastructures, more quantitative methods could be employed to provide a less subjective approach to the categorization of airport geometries. An objective categorization of the grouping variables may yield a more robust and internally consistent result. Finally, while a currently available set of aircraft noise models was used, an improved set can now be obtained with the most recent release of AEDT, and these noise responses should be utilized to provide a more concrete assessment of the groupings presented here. The current grids also led to the definition of a representative vehicle for seat class 2 that was overpredicted the seat class 2 operations as they were scaled away from thebaseline. A future assessment must replace the seat class 2 representative vehicle with a more appropriate selection.

Acknowledgements

Student Biography

Mr. Bernardo received his Bachelor of Science in Mechanical Engineering from the University of Pittsburgh in the spring of 2008. He then went on to join the Aerospace Systems Design Laboratory at the Georgia Institute of Technology. He received his Masters of Aerospace Engineering from there in December 2009. He is now a Ph.D. candidate at Georgia Tech and recently received the FAA DOT Student of Year Award for 2012. Mr. Bernardo's research focuses on developing a rapid fleet-level noise prediction methodology, including new metrics for describing airport contours, and generic classifications of airports with respect to noise. His goal is to create and demonstrate a methodology to better investigate fleet-level noise early in the technology selection process, allowing decision makers to better select and invest between options for further development.

References

[1]   Carbon Mitigation Initiative, "Carbon Mitigation Initiative: Annual Report 2009", Princeton University, New Jersey, 2010, p.72.

[2]   Passchier-Vermeer, W., and Passchier, W. F., "Noise Exposure and Public Health," *Environmental Health Perspective;* Vol.108, Supplement 1, 2000, pp. 123-131.

[3]   Mestre, V., "Effects of Aircraft Noise: Research Update on Selected Topics: A Synthesis of Airport Practice," ACRP Synthesis 9, Transportation Research Board, Washington, D.C., 2008.

[4]   Manci, K. M., Gladwin, D. N., Villella, R., Cavendish, M., "Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: A Literature Synthesis," National Ecology Research Center, U.S. Department of the Interior Fish and Wildlife Service, Jun. 1988, URL: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA201966&Location=U2&doc=GetTRDoc.pdf.

[5] Takemoto, P., "Fact Sheet – Next Generation Air Transportation System", Federal Aviation Administration Press Release, Washington, DC, May. 2010, URL: http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=10261.

[6] G Skalecky, J., "CLEEN Planned Solicitation," FAA Office of Environment and Energy, *CLEEN Market Research Conference*, Washington, DC, May. 2008, URL: http://www.faa.gov/news/conferences_events/2008_market_research_conference/materials/media/CLEENPlannedSolicitatio n.pdf .

[7] Aeronautics Science and Technology Subcommittee, "Biennial Update: National Aeronautics Research and Development Plan," Committee on Technology: National Science and Technology Council, Feb. 2010, URL: http://www.whitehouse.gov/sites/default/files/microsites/ostp/aero-rdplan-2010.pdf.

[8] Del Rosario, R., Wahls, R., Follen, G., Madavan, N., "Subsonic Fixed Wing Project," *Fundamental Aeronautics Program 2011 Technical Conference,* Cleveland, OH, Mar. 2011, URL: http://www.aeronautics.nasa.gov/pdf/subsonic_fixedwing.pdf.

[9] Bernardo, J. E., Kirby, M., Mavris, D. N., "Development of a Generic Fleet-Level Noise Methodology," AIAA, *50th AIAA Aerospace Sciences Meeting and Exhibit Including the New Horizons Forum and Aerospace Exposition*, AIAA- 2012-339, Nashville, TN, Jan. 9-12, 2012.

[10] Tetzloff, I. J., Crossley, W. A., "An Allocation Approach to Investigate New Aircraft Concepts and Technologies on Fleet-Level Metrics," *9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO),* AIAA 2009-6979, Hilton Head, South Carolina, 2009.

[11] Becker, K., "A Methodology to Enable Rapid Evaluation of Aviation Environmental Impacts and Aircraft Technologies," Ph.D. Dissertation, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA, 2011.

[12] Federal Aviation Administration, "Aviation Environmental Design Tool (AEDT)", FAA, URL: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/aedt/.

[13] Isley, S., Kirby, M., "A Comparison of Aircraft Retirement and Fuel Efficiency Policy Instruments: A Modified Fleet and Operations Module Approach," *7th Annual Joseph A. Hartman Student Paper Competition*, Sept. 2010.

[14] Ottl, G., and Bock, P., "An Approach to Airport Categorization – Category Definition and Quantification for Air Traffic Related Simulation Purposes," *Journal of Aerospace Operations 1*, pp. 155-170, IOS Press, 2012.

[15] Bock, P., Schinwald, C., "Airport Capacity Impact of New Aircraft Concepts: How to Manage Airport Diversity and Individuality," CEAS Aeronautics Journal 2: 3-10, 2011.

[16] Kish, C., "An Estimate of the Global Impact of Commercial Aviation Noise," Master's Thesis, Massachusetts Institute of Technology, Jun., 2008.

[17] FAA, "Environmental Tool Suite Frequently Asked Questions," URL: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/toolsfaq/, Jul., 2012.

[18] Bernardo, J., Kirby, M., Pfaender, H., Mavris, D., "CO_2 Emission Metrics for Commercial Aircraft Certification: A National Airspace System Perspective: A PATNER Project 30 Findings Report," Partnership for AiR Transportation Noise and Emissions Reduction, An FAA/NASA/Transport Canada-sponsored Center of Excellence, Report No. PARTNER-COE-2012-002, Mar. 2012.

[19] Kirby, M., Becker, K., Isley, S., Burdette, G., Mavris, D., "Development of an Interactive Capability to Trade Off New Technologies and Future Aircraft to Reduce Aviation Environmental Impacts," ICAS 2010-4.10.2-645, 2010.

[20] Pang-Ning Tan, Michael Steinbach, and Vipin Kumar, *Introduction to Data Mining*. 1st edn (Boston: Pearson Addison Wesley, 2006), pp. xxi, p. 769.

[21] Boeing, "Airport Noise and Emissions Regulations: Tucson International Airport," http://www.boeing.com/commercial/noise/tucson.html , accessed Dec. 18, 2012.

[22] AirNav, "KTUS: Tucson International Airport, Tucson, Arizona, USA," http://www.airnav.com/airport/KTUS, accessed Dec. 18, 2012.

[23] Federal Aviation Administration, "Airport Design," Advisory Circular, AC 150/5300-13, U.S. Department of Transportation, Sep. 29, 1989.