9-12 AUGUST 2015
inter.noise 2015
SAN FRANCISCO, CALIFORNIA USA

Noise computation for future urban air traffic systems

Michael Arntzen[a)]
Roalt Aalmoes
Environment & Policy support department, NLR
Anthony Fokkerweg 2, 1059 CM, Amsterdam, the Netherlands

Frank Bussink
Cockpit & Flight Operations, NLR
Anthony Fokkerweg 2, 1059 CM, Amsterdam, the Netherlands

Emmanuel Sunil
Jacco Hoekstra
Communication, Navigation, Surveillance/Air Traffic Management, TU Delft
Kluyverweg 1, 2629 HS, Delft, the Netherlands

The development of Personal aerial vehicles and unmanned aerial vehicles are expected to have a considerable influence on the development of future airspace design around large cities. In the Metropolis project, four different concepts for airspace design are assessed for a (metropolitan) city of the future. The different noise impact on the ground is addressed in this paper. The noise model is based on the maximum allowable source noise levels as proposed by the Federal Aviation Authority, as actual noise data from the considered aircraft is not available. Transmission loss has been modelled using Noise-Power-Distance relations from the Integrated Noise Model. The resulting noise model shows remarkable different noise footprints between the four concepts and between different traffic patterns, which included both converging and diverging flows. The layered airspace structure provided the lowest noise impact on the ground.

[a)] Email: Michael.arntzen@nlr.nl, also affiliated with the Aircraft Noise & Climate Effects group of the TU Delft.

1 INTRODUCTION

The popularity and availability of Unmanned and Personal Aerial Vehicles (UAVs and PAVs) has increased in the past years. Furthermore, these means of transportation have been proposed as alternatives for road traffic and may become more common in a future air transportation system. This leads to the question if the airspace can accommodate a large number of these flying vehicles safely. Within the Metropolis project (EU FP7) four different airspace structure concepts were designed and put to the test in rather extreme traffic densities [1]. Each concept uses a Self-Separation system to allow each vehicle execute conflict detection and resolution, i.e. safe flight. However, the different airspace concepts generate, even with the same source and destinations for the traffic, very different movements in the air.

The first concept is the ‘Full Mix’ (FM) concept, which uses an unstructured airspace. Each individual vehicle is allowed to find its own path towards its destination. This can be a very efficient structure since each vehicle is allowed to fly a direct path between the origin and destination. Aircraft are also allowed to fly at their optimum altitude.

The second concept is the ‘Layered’ (LAY) concept and can be regarded as an extension of the hemispheric rules [2]. The LAY concept creates horizontal layers (300 ft. high) of airspace in which flights are only allowed in a particular direction separated by 45 degrees of heading, i.e. layer 1 from 0-45 degree, layer 2 from 45-90 degrees, etcetera. See figure 1 (left) for an illustration of this concept. Thus, aircraft have to base their altitude (and also efficiency) based on their heading. However, within each layer the aircraft are headed in the same direction which theoretically leads to fewer conflicts.

The third concept is the ‘Zonal’ concept (ZON). Within the ZON concept there are multiple rings, similar to city-rings allowing road traffic nowadays, around the city center of Metropolis. On these rings the traffic is allowed either to travel either a clockwise or anti-clockwise direction. There are inbound and outbound radials that lead traffic from and to the rings. The altitude of the vehicles is chosen by the vehicles themselves. See figure 1 (middle) for an illustration of this concept.

The final, fourth concept, is the ‘Tubes’ concept (TUB). Within the TUB concept, the vehicles are assigned a 4-D tube in which they have to fly to reach their destination. The tubes at the same altitude do not intersect except at nodes, in which aircraft are allowed to travel in vertical and horizontal direction. In TUB all aircraft are a-priori de-conflicted by ground automation. See figure 1 (right) for an illustration of this concept.

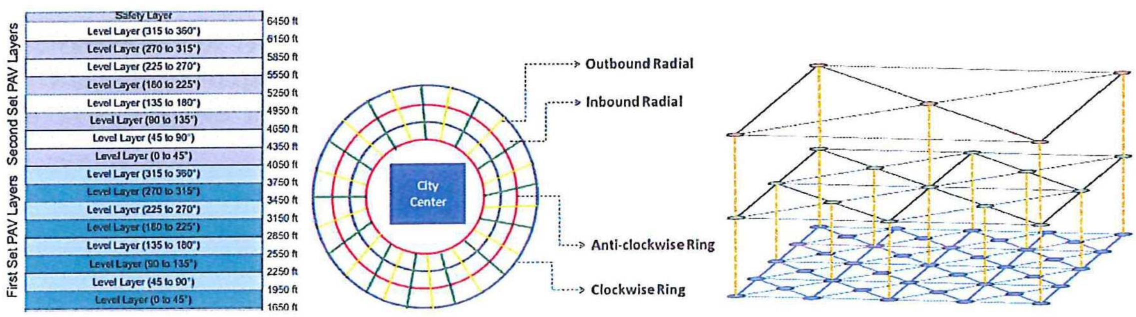

Fig. 1 - Impressions of the LAY concept (left), the ZON concept (middle) and TUB concept (right).

Hence, airspace concepts range from unstructured FM via LAY and ZON to the most structured TUB concept. Besides safety [3] and efficiency related parameters, as part of the environmental impact study, the noise impact was also considered. To calculate the noise level on the ground, information about the source noise level of each aircraft and associated propagation transmission loss is necessary. This information and noise calculations are typically implemented with noise assessment models such as the Integrated Noise Model (INM) [4].

The Metropolis vehicles are not integrated in INM. Hence, a dedicated analysis was executed (similar to the approach of INM) to assess the noise impact. The resulting model should not be considered to predict the exact absolute noise levels of these futuristic scenarios due to constraints on available information. However, it does provide an indication of the differences in noise impact of the four airspace design concepts. This paper highlights the results from the noise study of the Metropolis project.

2 STUDY SETUP

2.1 Traffic

The simulated Metropolis area was based on present-day Paris, i.e. 40x40 nautical miles. While traffic was simulated for the entire area, environmental metrics were logged for a smaller 'experimental area' of 448 NM^2. The actual traffic was simulated using the Traffic Manager (TMX) software from the NLR [5]. To simulate some of the 'real-world' intricacies, some random parameters such as wind and rogue aircraft (aircraft that did not conform to the airspace routing) were added.

Different day-time periods and traffic densities have been simulated in the Metropolis project. The traffic pattern for morning, lunch and evening flights were severely different due to traffic headed to the city center (morning) or the other way around (evening). PAV traffic densities were also varied from low (2625 movements), medium (3375 movements), high (4125 movements) to ultra (4875 movements). These movements are averaged instantaneous traffic volumes. The UAV traffic volume per hour can be considered (roughly) as half of the reported PAV values.

The Metropolis project considered four vehicles, one UAV and three PAVs. The UAV is projected to be 2 meter in diameter and capable of carrying up to five average-sized packages for delivery of goods. Only the three PAVs were taken into account for the current noise analysis and were one (heavy) tilt-rotor vehicle, considered to be an alternative to a bus, and two light-weight 'flying cars', considered to be alternatives to either a car or a motorcycle. UAV movements are expected to occur only for short-ranges and where, consequently, in all four concepts allowed to operate by the FM 'rules'. Hence, the UAVs trajectories were similar for all four concepts and are thus ignored in assessing the four concepts.

The individual trajectories of each flight were analyzed and sorted. Parts of the flight trajectory below 1650ft were ignored: below that altitude the aircraft are landing or taking-off and are ignoring the airspace design concept rules. Therefore, it does not make a difference for the evaluation of these concepts if these movements are removed from the comparison.

Figure 2 shows the simulated topology of the aircraft trajectories. The FM and LAY concept show rather similar trajectories, although notice that for the LAY concept the aircraft tend to fly at a higher altitude. The TUB concept shows a rather different structure, individual tubes can be picked out. The ZON concept show the circular arcs that aircraft fly on the clockwise and anti-clockwise rings.

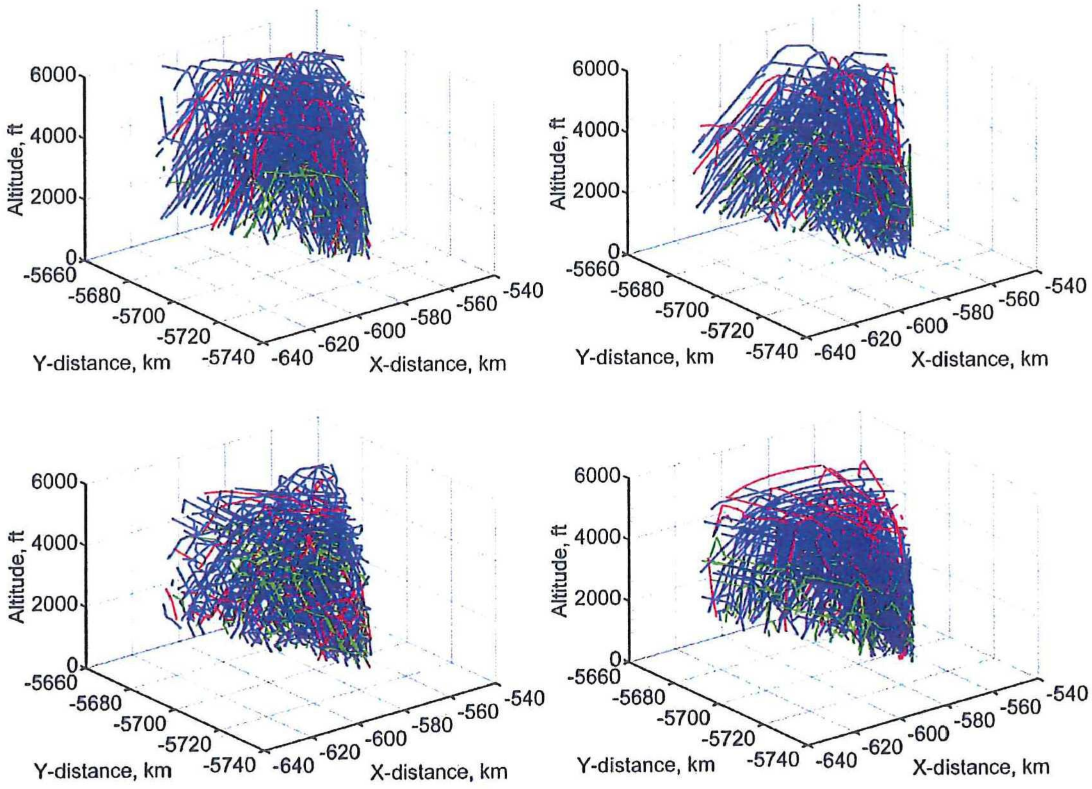

Fig. 2 - The individual trajectories plotted for the four concepts. (FM: upper left, LAY: upper right, TUB: lower left and ZON, lower right; Red: tiltrotor, Blue and Green are flying cars)

2.2 Source Noise Levels

The source noise levels for the considered vehicles are unknown or not disclosed by their manufacturers. Hence, the FAA regulation [5, fig K4] for certification of tiltrotor aircraft was used to indicate the maximum allowable source noise level for the three aircraft. These sound levels depend on the maximum take-off weight of the aircraft. Consequently, the tiltrotor had higher source noise level (9-10 dB) than the two 'flying cars'.

These certification noise values are prescribed in the EPNdB noise metric. However, for our analysis the LAmax noise metric needs to be known and implied that a conversion was necessary. Hence, the certification values were converted to LAmax by using the difference in EPNdB and LAmax as found in INM's Noise-Power-Distance (NPD) relations.

2.3 Propagation Transmission Loss

Noise levels decay as a function of distance during propagation by a transmission loss. Such a transmission loss is in INM inherently included in the NPD relations. A similar approach was created for the current analysis by adopting the noise decay trend from existing NPD relations. The tiltrotor used the NPD trend from a heavy (S-76) helicopter whereas the 'flying cars' were given the NPD trend belonging to a small aircraft (DA-20). The source noise dependency of each aircraft on thrust was not modeled due to uncertainty regarding the aircraft noise production and a lack of data. Hence, the maximum allowed source noise from certification was thus taken, i.e. a worst case scenario. The noise impact is calculated for the ground-level, not the city high-rise (flat ground), to reduce the complexity in the calculations.

2.3 Noise Metrics

Three noise metrics were assessed:

1. Time in specific altitude band
2. Number Above 55 dB(A) contour (N55)
3. LDEN noise footprints and contour area (70 LDEN)

The first, time based, metric provides an assessment of the differences in time spend at specific altitudes. The idea is that whilst the aircraft is at a higher altitude, the nuisance on the ground is minimized.

The N55 metric provides an indication on how audible the flyover events are. If the sound on the ground (LAmax) is more than 55 dB(A), the individual aircraft is assumed to be audible. Although higher values as limit could have been chosen, the 55 dB(A) limit is selected to balance a lower city background noise level and tonality that these aircraft (especially tiltrotors/propellers) are expected to exhibit. Contours are drawn for 400 events, i.e. 400 events where the noise level exceeded 55 dB(A), and the corresponding contour area is assessed.

The LDEN is a noise metric measuring the cumulative effect of each individual flight passing through the experimental area. An LDEN footprint visualizes differences between the concepts and daytime periods. The day-evening-night multiplier of the LDEN metric is set to equal (day-time) events to allow a fair comparison between the time periods.

3 RESULTS & DISCUSSION

Results were examined for the different periods in the simulation: Morning, Lunch (middle of the day), and Evening. Figure 3 shows the resulting footprints for the morning scenario in case of the ultimate traffic density.

The difference between the four concepts shown in Figure 3 is remarkable. The FM and LAY concept show a similar noise footprint pattern whereas the TUB and ZON concept show a footprint that is very different. In the TUB concept, the individual tubes can be picked out in the noise footprint whereas in the ZON footprint the circular arcs and radials are distinguishable.

The noise footprint of the TUB concept lacks the distinctive high intensity at the origin (city center) but spreads noise more evenly. Since the number of flights accommodated by the TUB concept is lower than the others, due to capacity constraints, its results are not further analyzed in detail here because such a comparison is unfair.

Differences between the FM and LAY concept include the lack of the high intensity area at the origin in the LAY concept. This can be caused by aircraft that need to ascend/descend quicker, compared to the FM concept, to reach a particular altitude/heading layer combination. This results in aircraft that fly at higher altitudes in the layer concept than in the FM concept and thus a reduced noise level at ground level. This also shows in the time metric results later in this section.During lunch-time in the scenario, the characteristics of each concept are retained. It seems that the only (slight) difference is that noise is reduced further away from the city center. Due to the small deviations, the figures for the lunch-time characteristics are not presented in this document. Figure 4 illustrates the results for the evening.

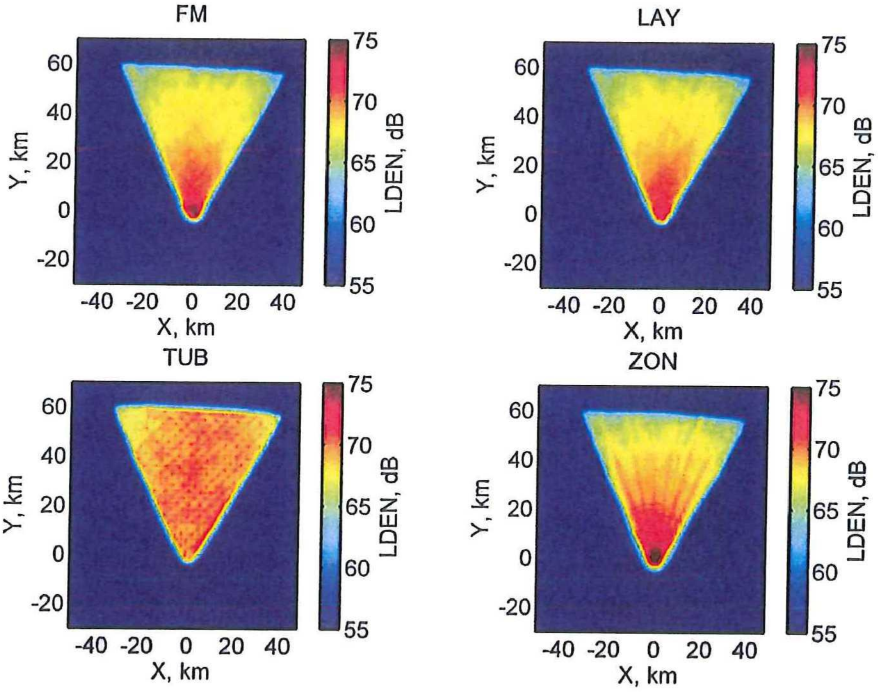

Fig. 3 - The LDEN footprints for the four airspace concepts for the morning (ultimate traffic density) scenario.

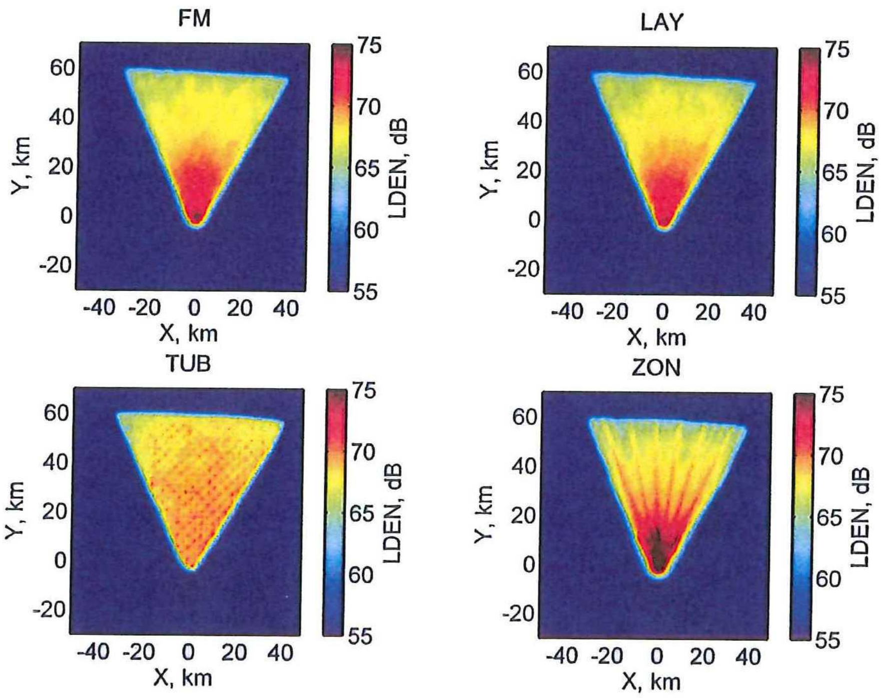

Fig. 4 - The LDEN footprints for the four airspace concepts for the evening (ultimate traffic density) scenario.

If examined more closely, there are differences between the morning (Figure 3) and evening scenario (Figure 4). The noise footprints of the FM and LAY concept show that more noise is present further away from the city. The LAY concept shows as well a small focus of noise near the city center.

However, the largest difference can be found for the ZON concept. The radials are more 'lit up' in the noise footprint, indicating higher noise levels that also extend to the edge of the experiment area. Moreover, the noise level is higher near the city center.

In essence, there are differences between the morning, lunch or evening scenario. The largest differences can be found between the morning and evening scenario but the characteristic noise footprint of each concept does not change dramatically during the time of the day. This is also observed for lower traffic densities, which was not included here for brevity.

To quantify all the noise metrics, the N55 and LDEN footprints were converted into contours depicting a specific value, i.e. a contour where N55 equals 400 events and the 70 LDEN contour. The area enclosed by such a contour can be compared between the concepts. Such results are shown in table 1 for low and ultimate traffic densities.

Table 1: A quantification of the contour areas for N55 and LDEN and the time spend below 2000 ft. and above 4000 ft.

			N55 - 400	70 LDEN	t <2000 ft.	t >4000 ft.
	Concept	**Density**	km^2	km^2	hours	hours
Morning	FM	Low	24	0	142	209
	LAY	Low	3	0	125	317
	TUB	Low	0	1	295	236
	ZON	Low	190	56	107	248
Morning	FM	Ult	477	229	290	387
	LAY	Ult	417	207	251	572
	TUB	*Ult*	*176*	*685*	*644*	*345*
	ZON	Ult	968	389	240	461
Evening	FM	Low	106	5	143	210
	LAY	Low	66	0	128	323
	TUB	*Low*	*0*	*0*	*207*	*169*
	ZON	Low	228	79	110	222
Evening	FM	Ult	525	352	308	419
	LAY	Ult	464	304	290	616
	TUB	*Ult*	*3*	*75*	*524*	*285*
	ZON	Ult	821	481	335	514

Table 1 illustrates the results of the different concepts. Results for lunch time, medium and high densities have been left out for the sake of brevity. Furthermore, notice that the majority of the TUB concept has been greyed out. This is due to the fact that the amount of flights used in that concept was too low due to capacity constraints. As a result, these particular scenarios cannot be used in a comparison since the resulting noise impact is much lower.

There are several interesting observations resulting from table 1, amongst others:

- The contour area of the N55 and LDEN metric of the LAY concept is the lowest (a smaller noise impact) for all daytime periods and densities if the TUB concept is ignored.
- The differences between the contour area for the FM and LAY concept are reduced for a higher traffic density.
- It is noticed that the LAY concept spends less time below 2000 ft. and more time above 4000 ft. This is beneficial for noise impact since noise impact on the ground is lower at higher altitudes. (this explains why the LAY contours are smaller than the FM ones)
- The ZON concept spends, for the majority of occasions, the least time below 2000 ft. but also exhibits, quite contradicting, the largest LDEN and N55 contour.

It should be noted that in the current analysis, the ZON concept accommodated more flights (7% more) than the FM and LAY concept. This difference is not large enough to explain the larger contour area found of the ZON concept compared to the FM or LAY.

4 CONCLUSIONS

The current noise methodology is based on the regulatory limitation for tiltrotor noise to predict the source noise levels. As such, the absolute levels are likely to be off compared to the case when these vehicles would actually fly. However, it does allow evaluating differences that may be expected for the airspace design concept.

Based on the LDEN footprints shown in figures 3 and 4 it is concluded that the spreading of the total amount of sound is different between the airspace concepts. The FM and LAY concept spread the noise impact very similar and show higher intensities near the busy origin (Metropolis center). Quite different is the footprint of the TUB concept that shows a very uniform spreading of noise over the grid. The ZON concept is again different as it shows higher sound intensities along the radials and circular arcs limiting the zones. In that sense, the ZON concept could be useful to dispense sound in particular areas of Metropolis.

Based on the observations of table 1 it becomes clear that the LAY concept offers the smallest contour areas. The reported differences between the FM and LAY concept become smaller for higher traffic intensity. The fact that the LAY concept offers smaller noise contours than the FM concept can be associated with the fact that less time is being spent below 2000 ft. The TUB concept could not be quantified extensively due to the lower number of flights accommodated by that airspace concept. It remains unknown what the absolute noise levels would be if the same amount of traffic could have been accommodated. The ZON concept shows that, despite the least time spend below 2000 ft., that its contour areas is larger than that of the FM and LAY concept.

Hence, the TUB and ZON concept exhibit characteristic footprints that are either uniformly spread (TUB) or condensed along radials and arcs (ZON). Footprints resulting from the LAY and FM concept are very similar. Based on the absolute size of the noise contours it is concluded that the LAY concept provides the lowest noise impact on the ground of the current Metropolis city.

5 ACKNOWLEDGEMENTS

This research received funding from the Seventh Framework Programme of the European Commission under grant number 341508 (Metropolis).

From the Metropolis project, the authors would like to thank Oliver Schneider, and Stefan Kern (both DLR), professor Daniel Delahaye, Georges Mykoniatis, and Andrija Vidosavljevic (all from ENAC), Joost Ellerbroek (TU Delft), and Dennis Nieuwenhuisen, Marieke Suijkerbuijk, and Pim van Leeuwen (all NLR) for their contribution for concept and scenario definition, and the simulation tracks that are used in the noise calculations.

6 REFERENCES

1. *Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities*, 'E. Sunil, J. Hoekstra, J. Ellerbroek, F. Bussink, D. Nieuwenhuisen, A. Vidosavljevic, S. Kern, 11th USA/Europe ATM R&D seminar (ATM 2015).

2. *Rules of the air*, ICAO, Annex 2, July 2005.

3. *A conceptual third party risk model for personal and unmanned aerial vehicles*, R. Aalmoes, Y.S. Cheung, E. Sunil, J. Hoekstra, F. Bussink, ICUAS15, 6-9 June, Denver USA, 2015.

4. *Integrated Noise Model (INM) Version 7.0 Technical Manual*, FAA-AEE-08-01, January 2008.

5. *Traffic manager: a flexible desktop simulation tool enabling future ATM research*, F. Bussink, J. Hoekstra, B. Heesbeen, Digital Avionics Systems Conference (DASC), 2005, vol 1. P 3-B.

6. *Noise Certification Standards for Tiltrotors*, FAA- 2013-00111, 78 FR 1133, January 2013. (https://federalregister.gov/a/2013-00111)