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ANALYSIS OF THE INFLUENCE OF HIGH-LIFT DEVICES RETRACTION IN TAKE-OFF NOISE OF A GIVEN AIRCRAFT THROUGH TRAJECTORY OPTIMIZATION

Pedro Alberto Godinho Ciloni
Pedro Paglione
Instituto Tecnologico de Aeronáutica – ITA – Praça Marechal Eduardo Gomes, 50 – Vila das Acácias – CEP: 12228-900 – São José dos Campos – SP - Brazil
e-mails pedrociloni@gmail.com, paglione@ita.br

Abstract. *On the past decades, based on complaints from communities living near airports, aircraft noise has become an issue for airlines and aircraft manufacturers. It is known that during take-off, most of the aircraft noise comes from the engines. That means that less thrust, higher altitude or both together would reduce the aircraft take-off noise. To achieve this noise reduction without changing the aircraft, a combination of high-lift devices retraction and thrust reduction must be done. Part 36 does not allow aerodynamic configuration changes during noise certification, although thrust reduction is allowed. The purpose of this work is to study the benefits that would arise from retracting flaps and slats together with a thrust reduction in order to reduce the aircraft take-off noise. The study is done using trajectory optimization and the results are compared to a reference trajectory in order to quantify the noise reduction. Reductions in noise of the order of 1dB are achieved and shown in the results.*

Keywords: *Aircraft noise, trajectory optimization, high-lift devices.*

1. INTRODUCTION

Noise pollution caused by aircrafts in airports and its surroundings has been worrying aeronautical authorities for more than 50 years and has become more and more an issue to airlines and airliners. From a technological development point of view, much work on noise level reduction have been done. The improvement on engine technology is probably the most important player on aircraft noise reduction so far, although aviation regulating bodies has played an important role in restricting more and more the requirements in aircraft noise certification.

Performance requirements for take-off noise certification do not allow changes in the aerodynamic configuration, i.e., flaps and slats must remain on the same position from the runway length to the end of the climb. The non-efficient aerodynamics during this procedure degrades the aircraft climb performance in such a way that the noise measured by the ground microphone could be lower if flaps and slats were retracted, because the over flight noise would be done in a higher altitude. Besides that, a better aerodynamic efficiency due to high-lift devices retraction would enable a greater thrust reduction at the end of the climb.

The purpose of this work is to investigate the advantages in retracting high-lift devices during the take-off procedure from an over flight noise point of view. The study is done through the use of optimization of the aircraft take-off and climb trajectory, aiming an augmentation of the distance from the ground microphone while flying over it, together with a thrust cutback procedure, seeking a noise level reduction. The aerodynamic (drag polars) and engine (thrust deck) models used in the present work were developed for an academic aircraft project (Ciloni, 2011). The noise model is semi-empirical (Kroo and Alonso, 2011) and its inputs are just the aircraft distance from the microphone, the size of the engines and the thrust reduction.

2. REFERENCE TRAJECTORY AND THRUST CUTBACK DEFINITIONS

Take-off noise certification is based on a reference trajectory which is calculated according to some technical orientations and limitations imposed by FAA through Part 36 (FAA Part 36, 2011). This trajectory is determined by the manufacturer aiming to reduce noise. It is important to emphasize that Part 36 does not require flight tests for noise requirement compliance, in such a way that the manufacturer demonstrate the noise performance of its aircraft through simulations. However, in order to obtain the aircraft noise model, some flight tests are in generally made to build a noise data bank based on speed and altitude of the aircraft.

Atmospheric data is obtained considering an ISA+10°C atmosphere, at sea level, with relative humidity of 70% and no wind. Take-off must consider using full available thrust from the beginning of the runway length to the end of the climb with all engines operating. Reference speed for the take-off trajectory is the operational climb speed chosen by the manufacturer for normal operation. This speed must be higher than V_2 + 10 knots (5.14 m/s) but not higher than V_2 + 20 knots (10.28 m/s). V_2 is the speed at which the aircraft lowest point reaches 35 ft (10.67 m) with one of the engines not operating. The take-off configuration must be chosen by the manufacturer and must be kept unchanged during all the take-off procedure. Take-off configuration means not only flaps and slats position, but also the gravity center position and the configuration of systems that may affect the aircraft noise and performance. Landing gears must be retracted, which means the reference trajectory must take into account a landing gear retracting time. The aircraft weight must be considered the maximum take-off weight for which the noise certification is required. The Part 36 reference trajectory is shown at Fig. 1.

Thrust cutback means a thrust reduction. The reference trajectory may or may not consider a thrust cutback, according to the manufacturer's will. When a thrust cutback is required, the take-off is done just as explained above, and climb is done at the reference thrust gradient until the moment of thrust levers retraction. From this point on, a new climb gradient is established at the new reduced thrust and kept until the end of the noise calculation. As explained earlier in this section, the take-off configuration does not change even after the thrust cutback. The thrust cutback must allow a 4% climb gradient with all engines operating or a steady level flight with one engine not operating, which one is the most restrictive.

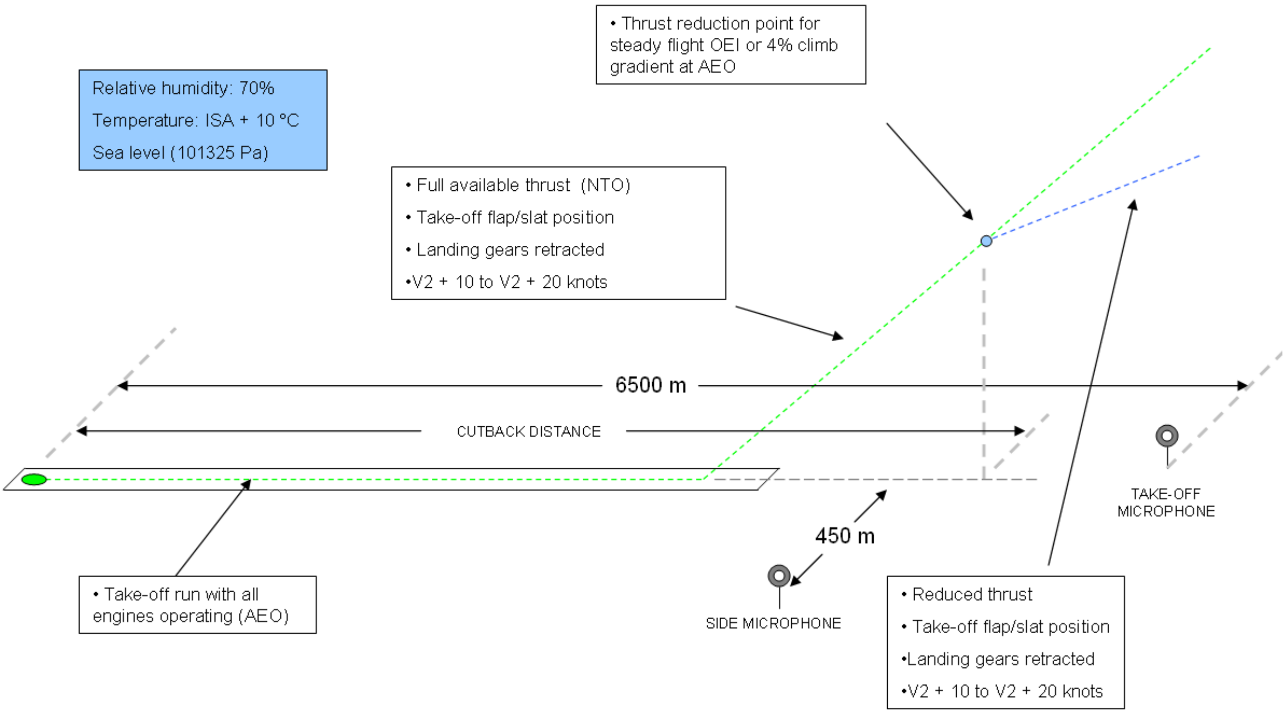

Figure 1. Part 36 take-off reference trajectory and thrust cutback.

3. OPTIMIZATION

With the purpose of optimizing the aircraft climb, a computational code was generated in order to simulate the climb according to Part 36 requirements. Since the purpose of this work is to study the advantages of high-lift devices retraction, an alternative trajectory was proposed as shown on Fig. 2 and implemented in the code. Only one initial position of flaps and slats will be analyzed and a thrust cut back is considered to occur at the end of the climb.

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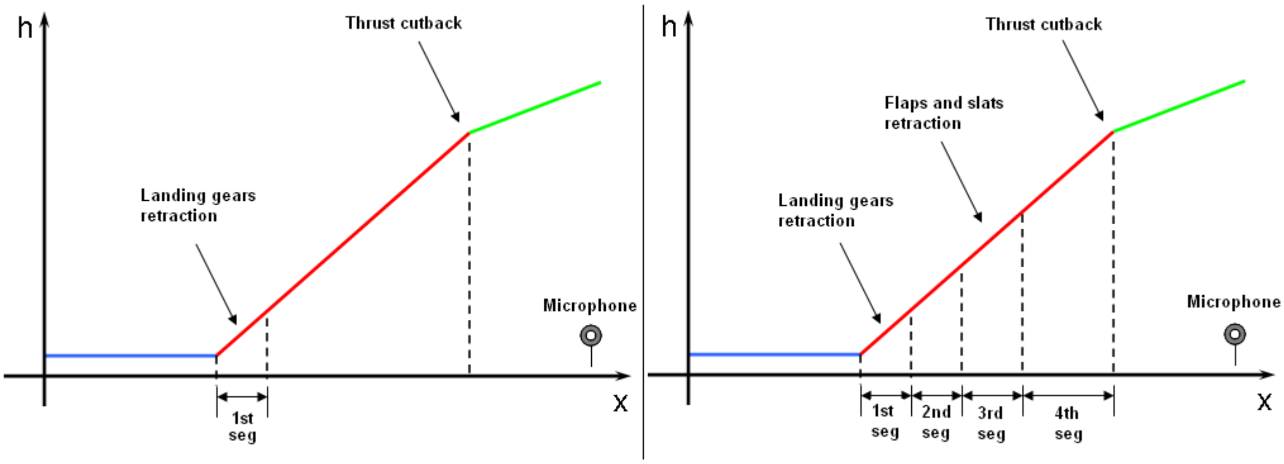

Figure 2. Comparison between the Part 36 climb trajectory (left hand side) and the proposed climb trajectory (right hand side).

The Part 36 climb is done at a constant calibrated airspeed. Instead of that, the proposed trajectory climb is done at a constant climb gradient. The climb is still divided into 4 segments in such a way that each one of them can be traversed at a different climb gradient, being the speed a function of the chosen climb gradient. The aircraft is considered to be a punctual and steady mass and the trajectory is considered to take place only on a longitudinal plan. Mass changes due to fuel consumption are not considered because they do not affect significantly this analysis. Based on the proposed trajectory shown above, the optimization will be made through the variables shown in Tab. 1. The climb gradient higher limit was set up to 27% because this is the most high value of gradient flown by airlines in generally. Higher values are possible, but may cause discomfort to passengers.

Table 1. Variables to be used in the trajectory optimization

Variable	**Lower limit**	**Higher limit**
Increase of speed on the 4th segment on a straight level flight	0 KTAS = 0 m/s	25 KTAS = 12.86 m/s
Climb gradient on 1st segment	0 %	27 %
Climb gradient on 2nd segment	0 %	27 %
Climb gradient on 3rd segment	0 %	27 %
Climb gradient on 4th segment	0 %	27 %

The optimization method chosen is the Genetic Algorithm (MOGA) because of its robustness and also because it avoids convergence to local minimum. The trajectory code was developed in Matlab® and the optimization was made through modeFRONTIER®. The trajectory throughout the entire take-off and climb is determined from numerical integration of the differential motion equations, derived from Newton's second law. The equations of the flight phase are shown below, as well as a figure showing the forces acting on the aircraft during flight. It is important to emphasize that during ground phase and rotating phase some additional forces appear beside the ones shown here. Those additional forces are taken into account in the computational code built.

$$T.\cos(\alpha) - D - W.\sin(\gamma) = \frac{W}{g}\frac{dV}{dt} \tag{1}$$

$$T.\sin(\alpha) + L - W.\cos(\gamma) = \frac{W}{g}V\frac{d\gamma}{dt} \tag{2}$$

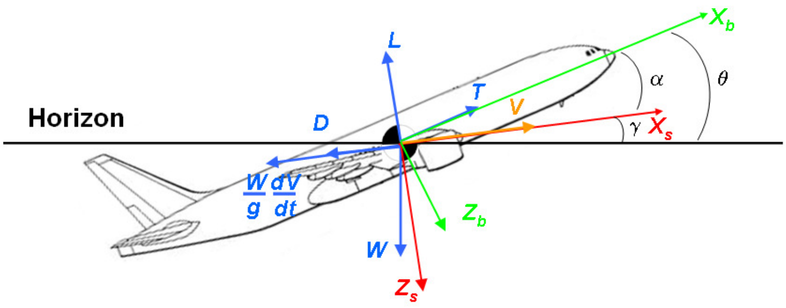

Figure 3. Forces acting on the aircraft during flight

The noise model is semi-empirical, easy to implement and can be found at the Stanford University website. The thrust cutback is executed according to Part 36 proceedings. The objective of the optimization is to find out a balance between how much to climb and how much to accelerate the aircraft, i.e., determine where to "spend the energy" arising from the engines, obtaining as less noise as possible. It is important to observe that the higher the altitude, the lower the noise, but as the aircraft accelerates, the thrust reduction can also be greater, reducing noise as well, so answering what is best, climbing or accelerating is not trivial. The thrust reduction is made according to a "measurement cone" as shown in Fig. 4. By the time the aircraft crosses the cone, the thrust is reduced to the lowest possible value to maintain steady level flight. The cone is defined based on the thrust cutback at a Part 36 reference trajectory and the position of the take-off noise measurement microphone.

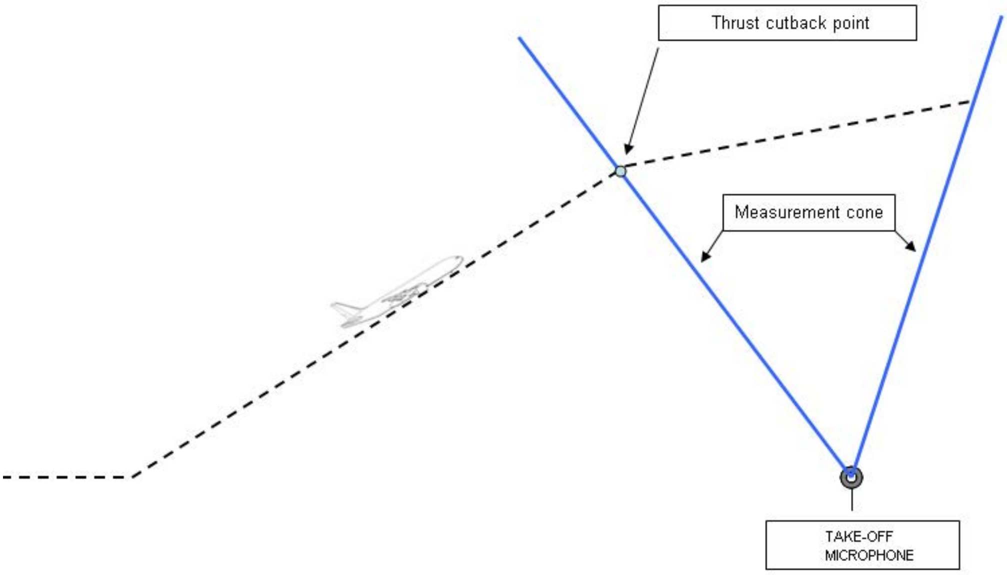

Figure 4. Measurement cone used to bound the thrust reduction point

4. RESULTS

The optimization results show a considerable improvement on the aircraft take-off noise. Results also prove that it is better to use the engines energy to climb than to accelerate more and have a larger thrust cutback. Figure 5 summarizes the results into a single 3D graphic. Each red dot in the graphic is a case from the optimization. The projections of those points into each of the 3 planes are shown as blue dots in order to visualize the effects of two parameters separately. It is possible to observe the concentration of points on a region, which means the optimizer considered that region as optimum and focused on decreasing the aircraft noise there. The acronym EPNdB is the effective perceived noise level (EPNL) in decibels (dB).

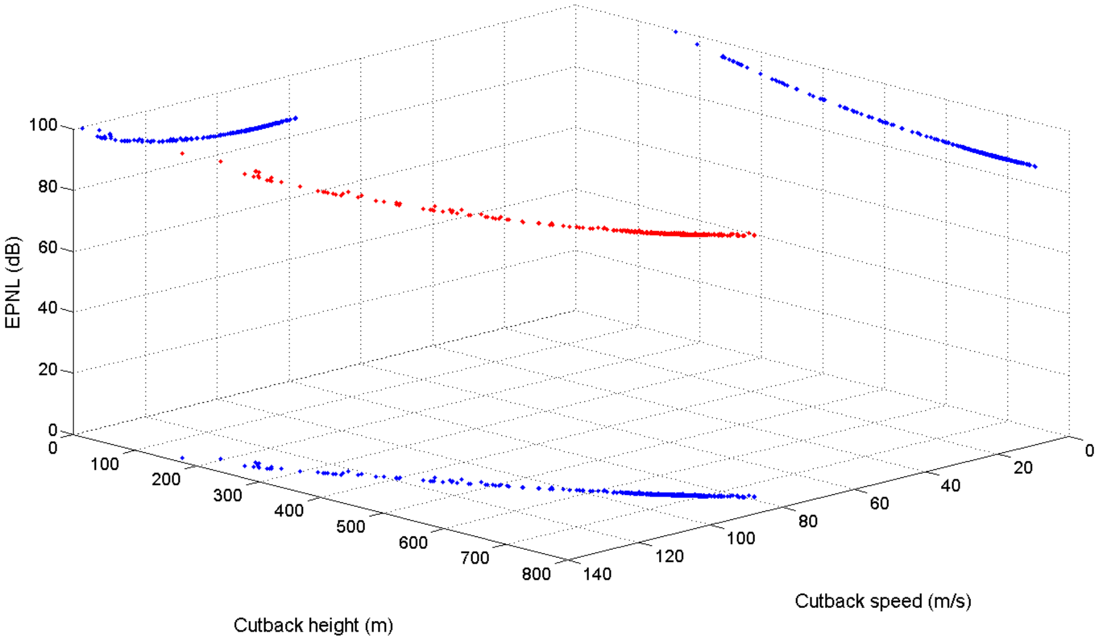

Figure 5. Effect of cutback speed and cutback height on the aircraft effective perceived noise level (EPNL)

Figure 6 shows in more details one of the planes of the 3D graphic shown in Fig. 5. A Paretto frontier can be clearly seen on this graphic. More than that, an optimum individual occurs at about 685 meters of cutback height, although there are several others close to it. The parameters of the optimum individual are shown in Tab 2.

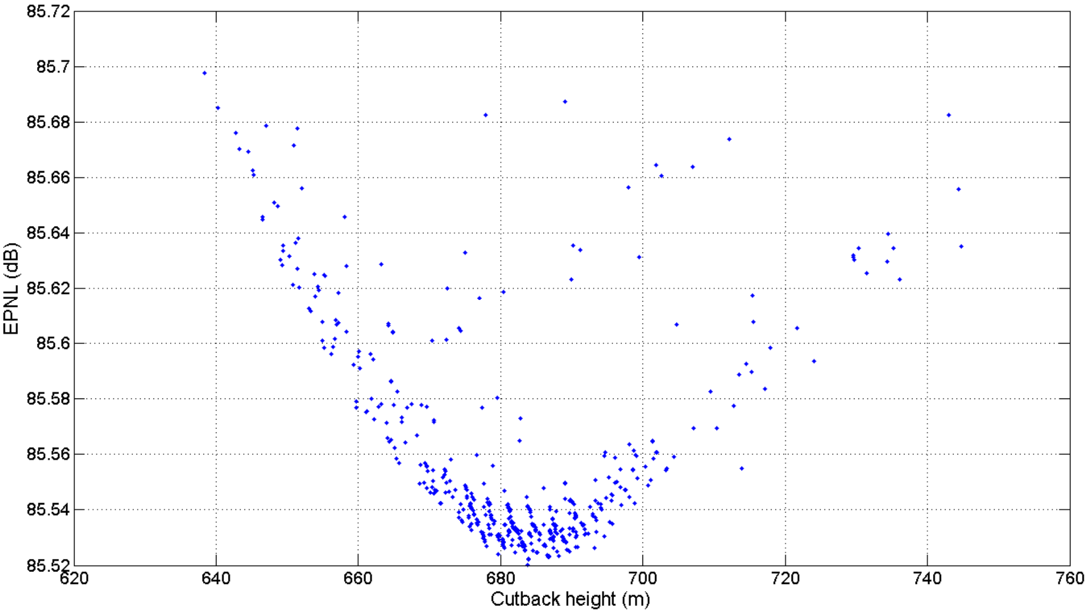

Figure 6. Effect of cutback height on the aircraft effective perceived noise level (EPNL)

Table 2. Optimization variables values of the most silent trajectory obtained

Variable	Value
Increase of speed on the 4th segment on a straight level flight	13 KTAS = 6.69 m/s
Climb gradient on 1st segment	20 %

Climb gradient on 2nd segment	0 %
Climb gradient on 3rd segment	2.5 %
Climb gradient on 4th segment	27 %
EPNL obtained	**85.52 dB**

The EPNL obtained for the optimum individual is of 85.52 dB. For a comparison matter, the EPNL obtained with this numerical model for the Part 36 reference trajectory shown in Fig. 2 is of 86.90 dB, which means the optimum trajectory reduced 1.38 dB in the aircraft take-off noise. An interesting comparison that can be done is that of the reference trajectory with the optimum trajectory. This comparison is on Fig. 7, showing that at 6500 meters of horizontal distance, which is the position of the take-off noise measurement microphone, the aircraft is higher at the optimum trajectory than at the Part 36 reference trajectory, i.e., the aircraft is more far from the microphone at the optimized trajectory, which means the noise is lower. The thrust cutback is also higher at optimum trajectory because the aircraft gets at the cutback point flying faster than at the reference trajectory, allowing it to reduce more the thrust.

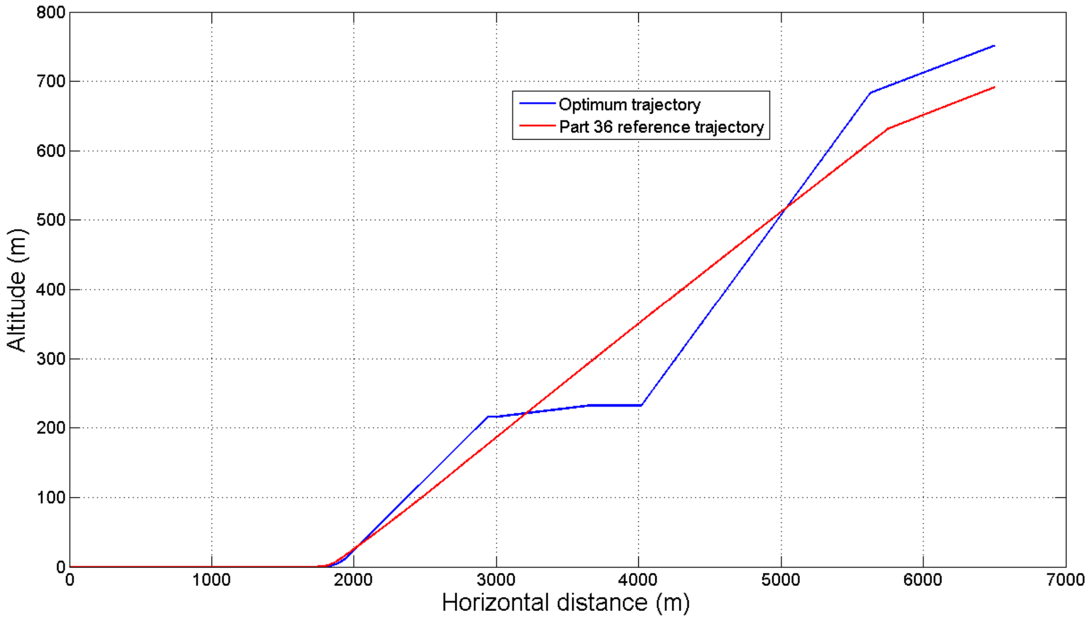

Figure 7. Comparison between the optimum trajectory obtained and the Part 36 reference trajectory

5. FINAL COMMENTS

The optimization showed the potential of retracting high-lift devices in reducing noise. The optimizer finds out the best combination between climbing and accelerating, i.e., it seeks the aircraft to get at the thrust cutback cone flying faster, but still keeping the altitude not to low, otherwise the aircraft would be too close to the microphone and noise would not be reduced. The main direct responsible for the noise reduction is the thrust cutback. The noise model used here does not take into account the time of exposition to the aircraft noise. If a more complex model was used, maybe the thrust cutback point could also be optimized, reducing the noise even more.

There are already some airports around the world that charge fees from the airlines for the noise its aircrafts make during the operations, like the Frankfurt airport, in Germany. Although it is not allowed to do the procedures shown here for certification purposes, during daily operation airlines may optimize its aircrafts trajectories, reduce the noise and pay less fees.

6. REFERENCES

Kroo, I. and Alonso, J., “Aircraft Design: Synthesis and Analysis” – Course Notes – Noise. 10 Jul. 2011 <adg.stanford/aa241>..

Ciloni, P.A.G., 2011. *Otimização de Trajetória de Decolagem com recolhimento de Dispositivos Hipersustentadores Visando Ruído Mínimo*. M.E. thesis, Instituto Tecnológico de Aeronáutica, São José dos Campos.

FAA, 2011, Federal Aviation Regulations Part 36 – “Noise Standards: Aircraft Type and Airworthiness Certification”. Federal Aviation Administration (FAA), USA.

7. RESPONSIBILITY NOTICE

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