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NOISE ABATEMENT PROCEDURES ENABLED BY ADVANCED AIRCRAFT AND AIR TRAFFIC CONTROL TECHNOLOGIES

J.-P. Clarke

Massachusetts Institute of Technology (MIT), Room E10-122, 77 Massachusetts Avenue, 02139,
Cambridge, MA, United States Of America

Tel.: 617-253-0904 / Fax: 617-253-4196 / Email: johnpaul@mit.edu

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ABSTRACT

Advanced noise abatement procedures have been shown to be an effective means of reducing the impact of noise on communities surrounding airports, and thus remove or reduce the barriers that the environmental impact of aircraft operations may pose to the continued growth of aviation. The primary obstacle to the implementation of these procedures is the inability of humans to manually maintain the precise sequencing and spacing necessary to maximize takeoff and landing rates in heavy traffic. This paper presents the results of work done to define the noise abatement procedures enabled by advanced aircraft and air traffic control technologies, to quantify the benefits of these procedures, and to develop the automation infrastructure required for implementation of these procedures in heavy traffic. Specifically, the benefits of advanced noise abatement procedures and the CRIST framework for integrating advanced noise abatement procedures into the air traffic control system, are presented.

1 - INTRODUCTION

The impact of aircraft noise in residential communities limits the number of aircraft operations that may be performed at airports and prevents expansion of airport facilities. Most airports in the United States and other developed countries have either noise curfews that restrict the hours during which all or certain types of aircraft may operate, or preferential runway assignments during certain times of the day to limit the noise impact in residential areas. Although significant reductions in source noise have been achieved through the use of advanced engine technology and improved engine design, we have now entered a period of diminishing returns with respect to source noise reductions.

Advanced noise abatement procedures can reduce the impact of noise on communities surrounding airports and thus remove or reduce the barriers that the environmental impact of aircraft operations may pose to the continued growth of aviation. To implement these noise abatement procedures in heavy traffic without sacrificing airport throughput, controllers must precisely sequence and space aircraft with varying performance characteristics. Ultimately, they will be limited by their inability to manually maintain the precise sequencing and spacing required for maximum throughput and safety. Thus, there is a need for automation and decision aids to assist air traffic controllers in maintaining maximum throughput while executing procedures that are robust to parameters such as wind, and pilot and aircraft performance.

This paper presents the results of work done to define the noise abatement procedures enabled by advanced aircraft and air traffic control technologies, to quantify the benefits of these procedures, and to develop the automation infrastructure required for implementation of these procedures in heavy traffic. The benefits of advanced noise abatement procedures are presented in first part of the paper. The CRIST (Cost, Revenue, Information, Strategy and Tactics) framework for integrating advanced noise abatement procedures into the air traffic control system is presented in the second part of the paper.

2 - BENEFITS OF ADVANCED NOISE ABATEMENT PROCEDURES

Recent advances in guidance and navigation technology have given the cockpit crew unprecedented capabilities under Instrument Flight Rules (IFR). Random Area Navigation (RNAV) allows pilots to create trajectories using a series of straight-line segments between arbitrary reference points or waypoints. The Global Positioning System (GPS) provides accurate position estimates at any location around the world. In combination, these capabilities provide the flexibility required for incorporating noise as a major constraint in the design of all weather flight procedures.

For example, aircraft using heading guidance during noise abatement departure procedures are restricted to a single turn [FAA 1976]. Thus, the effectiveness of these procedures is limited to airports where there are broad areas of low population density. This restriction can be eliminated if RNAV and GPS are used to provide flight guidance since flight paths can be tailored to low populated regions using as many straight-line segments as needed. Similarly, aircraft using the Instrument Landing System (ILS) for approach guidance are required to intercept the ILS glide slope from below and consequently are forced to spend considerable amounts of time maneuvering at low altitude. The close proximity to the ground combined with the higher thrust required for level flight with flaps extended produces significant noise impact on those communities along the approach path. With RNAV and GPS, virtual descent points can be created to reduce noise impact by allowing aircraft to intercept a virtual slide slope at higher altitudes and descend along a 3° approach flight path with thrust set to idle. In both cases, the improved navigational precision provided by RNAV and GPS also allows aircraft to closely follow the assigned flight tracks, eliminating any noise impact that arises when aircraft are unable to stay on assigned track using the existing navigation system.

Noise abatement procedures enabled by RNAV and GPS have been demonstrated to significantly reduce the noise impact in communities around airports [Clarke and Hansman, 1997]. In a case study of approaches to runway 13L at John F. Kennedy International Airport (JFK) in New York City, the ILS approach was compared to a 3° decelerating approach that was designed to have a similar ground track to ILS approach. Figure 1 compares the noise impact of the ILS and 3° decelerating approach. As the figure illustrates, the decelerating approach eliminates the noise impact created by the low altitude vectoring and turning required during the ILS approach.

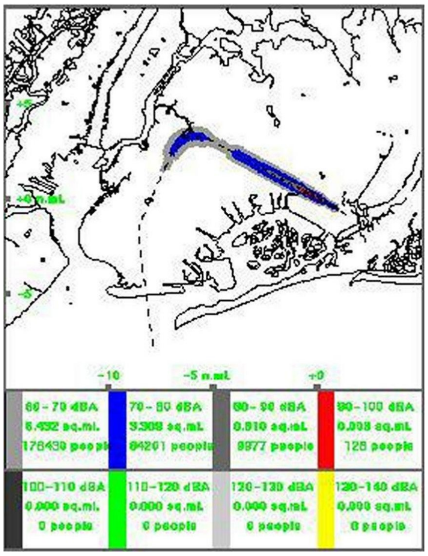

Figure 1(a): Noise impact of ILS.

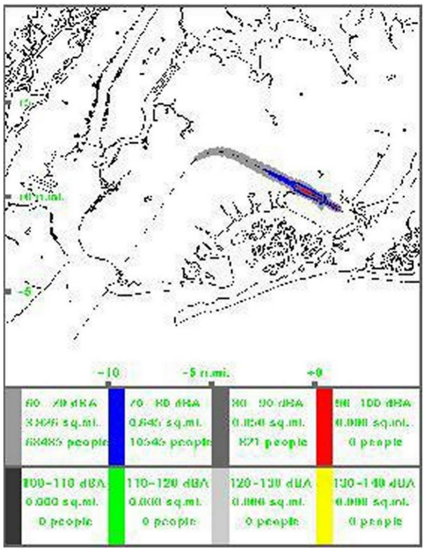

Figure 1(b): 3° decelerating approach to runway 13L at JFK.

Figure 2 shows a comparison of the population impacted by peak noise greater than 60 dBA during the ILS approach and the 3° decelerating approach. As the figure shows, the 3° decelerating approach reduced the noise impact by 68%. Similar levels of approach noise reduction (in terms of the percentage change in impacted area) were also observed in a case study of approaches to Schiphol Airport in Amsterdam, The Netherlands for the 737-300 and the 747-400 [Kirk and Clarke, 1997].

3 - TECHNOLOGICAL CHALLENGE

While the benefits of advanced noise abatement procedures have been recognized, the presence of humans in the air traffic control loop limits implementation.

One example of the limitations human place on air traffic control is the inability of air traffic controllers to manually maintain the precise sequencing and spacing required for maximum throughput and safety in heavy traffic. During existing approach operations, air traffic controllers often maintain all the air-

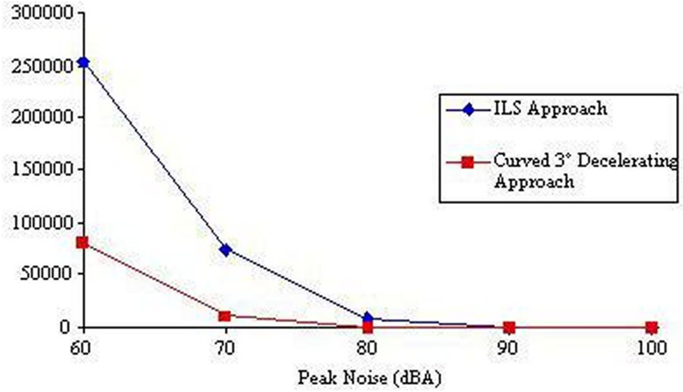

Figure 2: Noise reduction enabled by 3° decelerating approach to runway 13L at JFK.

craft under their control at a common speed to reduce the surveillance needed to assure separation i.e. they use speed as a surrogate for constant monitoring of aircraft separation. This is accomplished by simultaneously fixing the common speed and the required separation when the aircraft are being merged. Once these two values have been fixed, the separation is automatically maintained provided each pilot maintains his/her speed. During a decelerating approach however, it is not possible to maintain all the aircraft at the same speed as the aircraft are decelerating at different rates based on their weight, performance characteristics and atmospheric conditions. Thus, the separation between aircraft on a common path will not be constant and the surveillance requirement will be greater than the surveillance requirement for existing procedures.

Consider a pair of aircraft that are part of an arrival stream. In the case where the lead aircraft in a pairing is decelerating at a faster rate than the trailing aircraft, a separation buffer must be added at the start of the procedure to ensure that the separation minimum is not violated during the procedure. This does not affect capacity as the buffer is eliminated at the end of the procedure and the separation will therefore be at the minimum. In the case where the lead aircraft is decelerating at a slower rate than the trailing aircraft, the separation between the aircraft increases during the procedure. Thus, if the separation can not be below the minimum at any point during the approach, capacity will be reduced since the separation at the end of the procedure will be greater that the minimum. One way to compensate for the increase in separation between aircraft is to separate the aircraft laterally and design a converging procedure where the rate of lateral convergence is equal to or slightly less than the rate of longitudinal divergence. During such a procedure, the separation of the aircraft would be expected to remain constant. Therefore, if the separation at the start of the procedure were equal to the minimum separation then the separation at the end of the approach would be equal to or nearly equal to the minimum separation.

4 - CRIST FRAMEWORK

In the most generic sense, engineered systems may be described by their CRIST – Cost, Revenue, Information, Strategy and Tactics. Specifically the performance of any system is characterized by the cost of operation, which is measured in terms of the inputs to the system and/or the negative outputs of the system, and the revenue from operation, which is measured in term of the positive outputs of the system. The operation and control of that system is characterized by the information that is required for operation, and the balance between strategy and tactics that is employed during operation.

Ultimately, strategic control can only be employed when the current state of the system is known and the behavior of the system is understood well enough that future performance may be predicted. Thus, it is the quality and quantity of information available for state estimation and prediction that determines the appropriate strategic control and tactical control.

In the air traffic control context, the cost of operation is equal to the sum of the resources necessary to operate the system and the negative outputs of operations such as the environmental impact. Similarly, the revenue from operation is the positive outputs of the system such as the number of aircraft handled per unit time – throughput. The control, and ultimately the performance of the air traffic control system, is determined by the information available about the environment and the aircraft, and the ability to predict the future trajectory of all the aircraft in the system. It is within the CRIST framework that the problem of integrating advanced noise abatement procedures into the air traffic control system is examined.

5 - ROLE OF AUTOMATION

As discussed above, humans have difficulty monitoring and predicting the separation between aircraft that are decelerating at different rates. Thus, tactical control would be difficult in such a situation. The CRIST framework suggests that the appropriate solution for the system would be to increase the quality and quantity of information available so that strategic control may be employed. This may be accomplished through automation tools and decision aids that take as inputs the improved state estimates enabled by GPS, predict the future states of all the aircraft using 4D trajectory prediction and then generates conflict free trajectories that require minimal intervention by humans. Once these trajectories are generated, the precise guidance and navigation capabilities of RNAV and GPS can then be used for strategic control of all the aircraft while simultaneously assuring precise trajectory following. Therefore the integration of noise abatement procedures into the air traffic control system must leverage the guidance and navigation capabilities of RNAV and GPS through air traffic control automation.

The future of air traffic control will be largely shaped by the development of automated systems such as the Center TRACON Automation System (CTAS), a suite of automation aids developed for controlling traffic in the terminal area. In its prototype operation at Dallas-Forth Worth Airport, CTAS has shown promising results in term of increasing arrival throughput. The Passive Final Approach Spacing Tool (pFAST), one the four main modules of CTAS, increased the arrival rate by 13% without imposing additional workload on air traffic controllers. Active-FAST, an updated version of pFAST that uses predicted aircraft flight paths to perform sequencing and spacing, is in its design stage. Passive-FAST, however, does not consider noise abatement procedures in the mix of procedures that is considers. The implementation of Active-FAST presents an opportunity for the introduction of advanced noise abatement procedures into the air traffic control system.

6 - CASE STUDY

The following case study illustrates the move to strategic operation and control – within the CRIST framework – that is enabled by improved aircraft and air traffic control capabilities. The case study assumes that two aircraft, a 737-300 and a 747-400, are performing 3° decelerating approaches. The speed profiles of both aircraft are illustrated in Figure 3. As the figure shows, the aircraft do not have similar speed profiles during the approach, thus if the aircraft were required to be on a common path (as is the case during current procedures), the separation of the aircraft would change during the procedure.

The requirement that aircraft follow a common path can be relaxed or modified however, if the aircraft is equipped with advanced guidance and navigation systems and air traffic controllers have the appropriate automation tools. Figure 4 shows a potential merging scenario for the two aircraft described above. The 737-300 and 747-400 are initially at points C and D respectively, on approach to the same runway. It is assumed that the 737 aircraft is trailing behind the 747 aircraft at a distance l and the lateral separation between the parallel tracks is such that the horizontal separation is equal to the minimum separation. The aircraft are to be merged at point A, a distance $\mathrm{d_A}$ from the runway threshold, and the track joining the parallel tracks is at an angle θ as shown. From the airspace design perspective, the parameters of the merging procedure l, $\mathrm{d_A}$ and θ are design parameters that airspace designers may use to increase the level of strategic control and thereby increase capacity while easing the workload of the controllers.

Figure 5 illustrates interrelation of the design parameters if a separation distance of 5 nautical miles is to be enforced throughout the approach. As the figure shows, the merge angle θ is a function of the distance from the merge point to threshold and the initial trailing distance.

For example, if the aircraft were required to transition from a 3 nautical mile separation in the terminal area to a 5 nautical mile separation during the final approach, the merge angle would be approximately equal to 20 degrees. This type of transition is common in air traffic control, thus designing procedures that enable the transitions without the intense tactical control currently required during merging is move toward strategic control.

7 - SUMMARY

Noise abatement procedures provide an effective means of achieving further reductions in the impact of aircraft noise in communities surrounding airports. Use of noise abatement procedures, however, has been limited by guidance and navigation considerations. Existing guidance and navigation systems, such as the Instrument Landing System (ILS), utilize ground-based beacons, which, because they provide coverage over a limited area, limit the types of noise abatement procedures that may be employed.

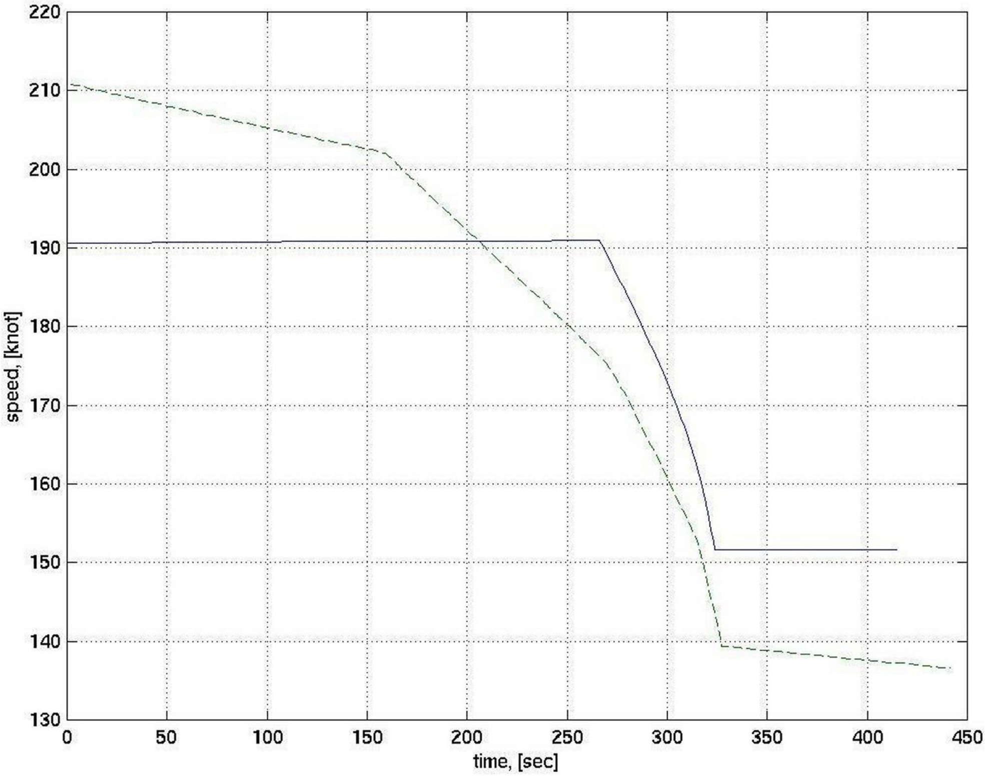

Figure 3: Speed profile of 737-300 (dash line) and 747-400 (solid line) during 3° decelerating approach.

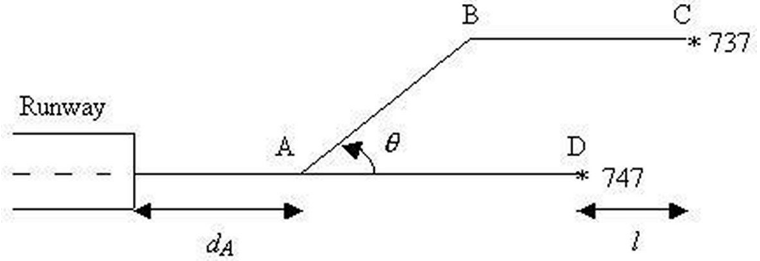

Figure 4: Potential merging scenario for 737-300 and 747-400.

Advanced flight guidance technologies such as Area Navigation (RNAV) utilizing the Global Positioning System (GPS) enable more flexible approach and departure procedures that reduce noise exposure to the most sensitive areas.

The primary obstacle to the implementation of these procedures remains the inability of humans to manually maintain the precise sequencing and spacing required for maximum takeoff and landing rates in heavy traffic. Introduction of automation that predicts the performance and noise impact of aircraft, and uses this information to assist the controller in determining and maintaining the appropriate sequencing and spacing is critical to the successful utilization of noise abatement procedures.

Strategic control can only be employed when the current state of the system is known and the behavior of the system is understood well enough that future performance may be predicted. Thus, it is the quality and quantity of information available for state estimation and prediction that determines the appropriate strategic control and tactical control. In this case, the CRIST framework suggests that the appropriate solution for the system would be to increase the quality and quantity of information available so that strategic control may be employed. Therefore the integration of noise abatement procedures into the air traffic control system must leverage the guidance and navigation capabilities of RNAV and GPS through air traffic control automation.

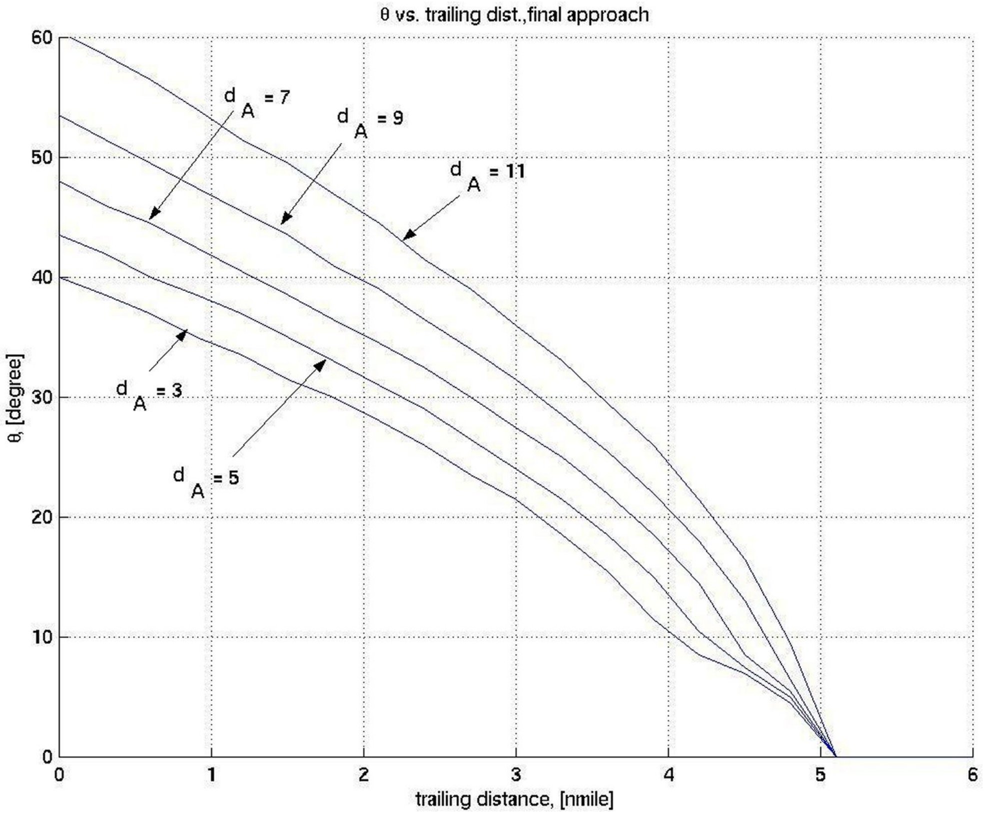

Figure 5: Interrelation of design parameters for a 5 nautical mile separation.

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