ADVANCED NOISE ABATEMENT APPROACH ACTIVITIES AT NOTTINGHAM EAST MIDLANDS AIRPORT, UK

Tom G. Reynolds, University of Cambridge, Cambridge, UK
Liling Ren & John-Paul B. Clarke, Georgia Institute of Technology, Atlanta, GA, USA

Abstract

Advanced noise abatement approach procedures incorporating Continuous Descent Approach, Precision Area Navigation and Low Power/Low Drag elements have been developed for a regional UK airport in partnership between academia and key stakeholders. The procedures were designed for a wide variety of aircraft types and equipages using a combination of advanced academic research tools, industry simulators and stakeholder input. Interactions between airspace constraints and procedure design were found to be critical. Flight trials of the procedures have demonstrated significant environmental benefits compared to non-trial flights: 3-6 dBA peak noise reductions and 10-20% fuel burn/emissions reductions have been observed. However, the importance of aircraft automation level, air traffic control coordination and the need for effective environmental performance metrics have been highlighted.

Introduction

Environmental factors are becoming major constraints to air transportation system growth. With this in mind, the Silent Aircraft Initiative (SAI) was formed in 2003 by the Cambridge-MIT Institute (a collaboration between the University of Cambridge and the Massachusetts Institute of Technology (MIT)) with the goal of developing a conceptual design for a future ultra-low noise commercial aircraft. A novel component of SAI was a collaborative “Knowledge Integration Community” (KIC) with members drawn from key stakeholder groups (manufacturers, regulators, operators, Air Traffic Control (ATC), airports, community groups, etc.) who provided support and feedback on the emerging designs to ensure credibility and relevance to real-world issues. As part of the SAI effort, future low-noise operations concepts were developed and analysed, including slower, steeper and displaced threshold approaches [1]. In order to gain tangible, short-term benefits within the lifetime of the SAI project and to take full advantage of the collaborative nature of the KIC, a parallel activity was initiated to develop low noise approach procedures at a UK airport. This activity was coordinated by the SAI operations team but involved a large group of KIC partners. After an extensive review of suitable airports and discussions with KIC partners, Nottingham East Midlands Airport (NEMA) was chosen as the focus of the activity based on its suitability against a number of criteria, including ATC/airspace flexibility; wide mix of traffic and the airport’s pre-existing desire to implement such procedures. The objectives were to:

- Develop advanced low noise approach procedures for a range of aircraft types using advanced modelling and analysis research tools available within SAI.
- Conduct flight trials of the procedures to assess their environmental and operational performance under realistic conditions with a range of aircraft types.
- Explore benefits associated with academic and stakeholder collaboration in this field.

The activities associated with these objectives are documented in this paper. General low noise approach concepts are discussed, followed by the design and analysis of the specific procedures developed for NEMA. The flight trials results are discussed next, followed by a discussion of their wider implications and conclusions.

Low Noise Approach Concepts

Continuous Descent Approaches

Continuous Descent Approach (CDA) procedures are the most common noise abatement approach technique. They are designed to eliminate level segments present in conventional “step down” approaches, keeping aircraft at higher altitude and lower thrust for longer, thereby reducing noise impacts and reducing fuel burn and emissions. The basic concept is illustrated in Figure 1.

![Figure 1: Continuous Descent Approach Concept](image-url)
The term CDA has come to mean different things to different people, but an existing UK industry Code of Practice [2] states “an arrival is classified as a CDA if it contains, at or below an altitude of 6000 ft, no level flight or one phase of level flight not longer than 2.5 nm,...[where] level flight is interpreted as any segment of flight having a height change of not more than 50 ft over a track distance of 2 nm or more”. The suitability of this definition will be discussed in subsequent sections.

**Vectored and Area Navigation CDAs**

Two general types of CDA procedure can be defined: Vectored (V-CDA) and Area Navigation (RNAV-CDA), as illustrated in Figure 2.

![Figure 2: Conventional “Step Down” vs. Vectored and Area Navigation CDA Concepts](image)

The V-CDA can be used by most aircraft types at many airports, so has found widespread use. Air traffic controllers in the terminal area give heading vector commands to each aircraft just as they do with conventional step-down approaches and therefore retain a large amount of control flexibility. The vectors are tailored to each aircraft within the context of the wider traffic situation in order to optimize spacing and sequencing for best runway usage. Because the sequence and content of the clearances to each aircraft are slightly different, vectoring operations normally result in dispersed ground tracks with large areas around the airport exposed to some aircraft noise. Unlike conventional approaches, during a V-CDA the controller also estimates the track distance to be flown by an aircraft given the vectored path to be used and issues these estimates to flight crews at various points during the approach (e.g. at 30 nm and 20 nm to touchdown). The flight crew use the track distance estimates to determine the appropriate aircraft descent rate to try to achieve a CDA, either with rules of thumb or flight manual charts. Variants of the V-CDA have been operational at many UK airports (including NEMA) for many years with success in reducing noise and fuel burn. Initially it was common for track distance estimates to be quite inaccurate, particularly under-estimation by the controller [3] resulting in aircraft needing to level off and therefore reducing the effectiveness of the CDA at these times. Capacity could also be affected. However, as experience has grown with V-CDA techniques, high CDA compliance is possible (at least against the definition outlined above) with little or no capacity implications.

As aircraft technology has advanced, the accuracy of CDA achievement can now be improved by developing procedures that involve a pre-defined trajectory which can be programmed into area navigation (RNAV) equipment such as the Flight Management System (FMS). Because the track distance can be determined accurately with knowledge of the waypoints (WPs in Figure 2), descent rates can be optimized in the procedure design or by the FMS such that level segments can often be eliminated entirely (potentially allowing for a stricter definition of CDA) to gain the maximum environmental benefit. Additionally, because the lateral path is predetermined, aircraft fly down a narrow path whose width is determined by the Required Navigation Performance (RNP) standard of the procedure, also shown in Figure 2. This enables noise exposure to be limited to those regions, allowing procedure designers to locate ground tracks over lower-impact regions (e.g. busy roads or lower population densities) or to mitigate noise impacts in affected regions (e.g. through property sound insulation). However, because of their pre-determined nature, RNAV-CDA procedures must be designed to be robust to a wide range of aircraft behaviours and environmental conditions (especially wind). In addition, differing aircraft behaviours while flying an RNAV procedure, combined with the reduced scope for ATC tactical control, often leads to the use of larger separations between aircraft flying these procedures. This in turn can affect runway throughput, which is currently limiting the use of these procedures during peak demand periods.

**Low Speed and Low Power/Low Drag**

Airframe and engine sources contribute about equally to the overall aircraft noise levels on approach. Airframe noise comes from the undercarriage, high-lift devices, control surfaces, drag augmentation (e.g. speedbrakes) and the scattering of boundary layer turbulence at the trailing edges. Sound pressure level from these airframe sources has an intensity proportional to \( n \) (velocity)\(^n\) (where \( n \geq 5 \) depending on the source), while engine noise is related to the thrust level. These factors imply a number of different strategies for reducing noise during approach. Reducing airspeed to near final approach speed early during the approach reduces the airframe noise due to the (velocity)\(^n\) relationship. But lower approach speeds are also associated with the need for earlier deployment of high-lift and drag generating devices.
(additional airframe noise sources) and associated higher engine thrusts. This also has potentially negative implications from an ATC and throughput perspective. An alternative strategy is to use higher approach speeds early on during the approach. This keeps aircraft in clean aerodynamic configuration for as long as possible during the approach, delaying the deployment of slats and flaps and keeping the aircraft at low engine power during this time, i.e. a Low Power/Low Drag (LP/LD) approach. This technique does require the aircraft to be slowed to final approach speed at lower altitudes with more noise at these times compared to slowing down early, especially if speedbrakes are required. However, the LP/LD technique is generally preferred by ATC for low noise approaches.

“Ideal” Low Noise Approach Procedures

The “ideal” noise abatement approach procedure enables the entire descent and approach phase of flight to be flown as high as possible for as long as possible with no level segments, at flight idle engine thrust and with clean aerodynamic configuration for as long as possible. This involves a combination of the CDA, RNAV and LP/LD techniques described above. Practically, there is often a trade-off between some of the elements. For example, a CDA with zero level segments may require addition of thrust or speedbrakes under certain conditions which could lead to higher noise levels than an approach that involved a small level segment but did not require thrust or speedbreak usage (e.g. if the level segment is used for deceleration). Therefore, it is important to account for these issues in the design of the approach procedure to achieve lowest noise. In addition, the practicalities of controlled airspace limitations around a given airport and the different behaviors of aircraft types that must be accommodated in the design make such an ideal procedure challenging to achieve. These issues are demonstrated in the NEMA procedure design process that is the focus of the rest of this document.

NEMAX Procedure Design

General Design Philosophy

A set of P-RNAV (Precision Area Navigation corresponding largely to RNP-1) CDAs with Low Power/Low Drag elements were developed for NEMA’s runway 27. This runway was chosen because it is in use approximately 70% of the time. The starting point for the procedure designs were the requirements laid out in Eurocontrol and JAA standards [4,5] and the airport’s desire to contain the majority of trial aircraft within “approach zones” identified in prior airspace consultation exercises [6]. To achieve this objective, two trial procedures were developed that utilised waypoints to approximately mirror the lateral routes currently flown—see Figure 3. They were designated as “NEMAX” procedures, corresponding to the name of the common waypoint just prior to the final approach fix. The southerly approach (NEMAX1A) was designed to avoid the city of Leicester, while the northerly/westerly approach (NEMAX1B) was designed to avoid Derby and to minimise overflight of Nottingham. Additional waypoints were inserted where required to ensure aircraft remained within controlled airspace and to minimise population exposure to noise wherever possible. The entry points for the procedures corresponded to existing waypoints used by conventional standard terminal arrival routes.

Figure 3: NEMAX Trial Procedure Lateral Paths
New waypoints were named according to Eurocontrol convention, with major points (such as the intersection of the two procedures) assigned a unique five-letter name, and intermediate points named according to the last two letters of the ICAO airport code (EGNX), “N” or “S” depending on whether the procedure was from the north or south, and two digits corresponding to the approximate track distance remaining to touchdown. Vertical constraints were defined at each waypoint to achieve the best CDA profile possible across the aircraft types/equipages likely to be participating in the trial. This involved designing the procedures for the Airbus A319, Boeing 757, 767 and MD11 with various FMS technologies, as shown in Figure 4.

The vertical constraints were also required to ensure aircraft remained within controlled airspace at all times. Several of the NEMAX1A waypoints were required at the sector boundaries with vertical constraints to ensure airspace compliance, as shown in Figure 5. For example, an “at or above Flight Level 50” constraint was imposed at NXS17 to ensure aircraft were always at least 500 ft above the floor of controlled airspace in the upstream sector. Speed constraints were also used at select waypoints (e.g. 180 kts at NXS11), designed to achieve Low Power/Low Drag objectives across the aircraft types participating in the trial.

**Simulation Studies**

Following initial design, the procedures were refined using a variety of simulation tools. Evolutions of the procedure were mainly tested using the Tool for Analysis of Separation and Throughput (TASAT) [7] shown in Figure 6. Originally developed to support CDA trials in the US [8], it has been enhanced to reflect the wider range of aircraft involved in the NEMA activity.

![Figure 6: TASAT](image)

The central piece of TASAT is the fast-time aircraft simulator core which allows Airbus A319, Boeing 737, 757-200, 767-300 and 747-400 aircraft types to be modeled. The A319 model was added to support this trial, while the B747-400 was used as a surrogate for the MD11F in the absence of specific performance data for that type. The dynamics are based on actual aerodynamic and engine performance data provided by the manufacturers for each type. Three-axis and power setting control are assumed to be performed by the autopilot and autothrottle respectively, coupled to an FMS module which models basic RNAV functionalities. Before the execution of a test procedure, the FMS module builds the lateral (LNAV) flight path based on the waypoint locations and the vertical (VNAV) flight path based on any altitude/speed constraints at those waypoints in a similar fashion to the real FMS. The lateral turn anticipation is computed from projected aircraft speed at the turn, while the vertical flight path is computed through backward integration of the aircraft dynamics from the last altitude/speed constraint up to the entry fix. In the ideal case, an idle VNAV path is built from cruise to the final approach fix, giving maximum noise and fuel burn benefits. During the execution of the procedure, the FMS module continuously monitors the aircraft state relative to the computed LNAV and VNAV flight paths and supplies corrective inputs through the autopilot and autothrottle as required. However, as in the real world, the pilot assumes the responsibility of controlling the extension of flaps, landing gear and speed brakes. The operation of these elements are defined in the aircraft operations manual, and are modeled in the

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**Figure 4: Aircraft Types and Equipages Used for Procedure Design**

B757-200F, Honeywell Legacy FMS

B767-300F, Honeywell Pegasus FMS

MD11F, Honeywell Pegasus FMS

**Figure 5: NEMAX Controlled Airspace Interactions**

The following sections detail the simulation and analysis steps involved in the generation of the final procedures before submission to the regulator.
simulation through a pilot response delay to account for the variability induced by different pilots implementing the required actions at slightly different times. The model can be executed hundreds of times in fast-time with different aircraft types, weights, configurations and wind conditions in order to generate an ensemble of possible aircraft trajectories to analyse a procedure’s viability.

Multiple iterations of the NEMA candidate procedure designs were tested under a variety of environmental conditions. Wind cases involved speeds defined by the CAA wind spiral formula (i.e. Wind speed = (Altitude/1000) + 40 kts). Directions were defined as “worst case” direct head or tail winds along each leg of the procedure or “design case” where the wind direction was constantly from 270 degrees consistent with the prevailing conditions at NEMA when operating runway 27 approaches.

Based on the results from the simulator, procedure designs were refined and retested. For example, early procedure iterations had minimal vertical constraints, resulting in occasional unacceptable controlled airspace violations in some areas (see Figure 7: a violation around NXS17 is evident) where the FMS-calculated optimal vertical profile was too low. These violations were eliminated in subsequent designs, but suggested that the procedures may keep the aircraft higher than the ideal profile.

Results for the final NEMAX1A procedures under zero and design wind conditions are presented in Figure 8 and Figure 9. The ground track, vertical profile, engine fan speed (N1, an indicator of thrust) profile and indicated airspeed (IAS) profile are shown as a function of distance to the runway. The constraints at each waypoint location are also shown by black bars (if max/min constraints) or circles (if “at” constraints). The results suggested that the final procedure designs should perform well for all the types simulated. The vertical profiles all had zero level segments but were close to some constraints, especially at NXS17 & 22 in the NEMAX1A procedures for reasons identified above. Engine N1 results showed flight idle throughout much of the approach (as desired) prior to spool-up just before ILS intercept, although a few thrust spikes were predicted to occur under design wind conditions. Speed remained at quite high levels until late into the approach consistent with LP/LD. Other results (not shown) suggested flaps were stowed until just before 10 nm to the runway, also consistent with LP/LD, while speedbrake predictions indicated that some usage was to be expected. This is probably related to the procedures keeping aircraft higher than the ideal profile due to the airspace constraints, and the excess altitude was being lost using speedbrakes.

Design iterations were also tested in full-motion flight simulators for the A319 and B767 (use of TASAT for the other Boeing aircraft types was considered sufficient after its validation in other studies [8]). Simulator runs were performed under a variety of representative and extreme local pressure and wind conditions. The local pressure state is particularly important because the transition altitude from standard to local pressure occurs at
4,000 ft, partway through the procedures. In all cases the aircraft was able to fly the procedures, with minimal use of speedbrake and only occasional thrust spikes to maintain the vertical profile as discussed. Occasional level-offs were observed prior to some of the waypoints in NEMAX1A. Tweaks to the procedures were tested to eliminate these through increased vertical constraints at key waypoints and these results were fed into the final procedure design.

Navigation Infrastructure Assessment

In order to conduct P-RNAV operations, the navigation infrastructure around the airport needed to be validated to allow performance to RNP-1 standards. The navigational aids to be used during the trial were Distance Measuring Equipment (DMEs) (although GPS may be appropriate in the future). Coverage around NEMA was examined by Lockheed Martin/Stasys using Eurocontrol’s DEMETER simulator and RNAV Flight Check analysis tool. These use a DME location and terrain database to determine coverage in a given location. Results indicated the worst case coverage occurs at 2000 ft AMSL (the lowest level of the procedures) but still provides limited redundancy for large areas around NEMA, even at this low level (see Figure 10). At the expected minimum altitudes of aircraft flying the trial procedures, redundancy is available on both procedures.

The following trial data was collected:

- Radar: latitude; longitude; transponder altitude (from all flights)
- Flight Data Recorder (FDR): INS latitude; INS longitude; altitude; airspeed; Mach; heading; pitch; roll; wind speed/direction; engine fan speed (N1); fuel flow; flap/speedbrake/gear position (from about 50% of flights)
- Noise monitor data: peak noise from fixed monitors at key locations (from some flights)
- Pilot/controller reports (from some flights)

Data for baseline (non-trial) flights from random times in the trial period was also collected to allow changes with trial flights to be assessed.

Lateral Flight Track Analysis

Radar ground tracks for the aircraft that flew the trial procedures are presented in Figure 11.
These show that the lateral dispersion around the centre-line of the procedures was very low for all types (less than ±0.5 nm dispersion) which is well within the P-RNAV limits of ±1 nm. These ground tracks also illustrate that not all trial procedures were flown in their entirety via VELAG and TEKRU; some aircraft were initially under conventional vector control by ATC before joining the procedure at intermediate waypoints.

Because B757 and MD11 flights conducting NEMAX1A procedures dominated the trials, these will be the focus of subsequent analyses. Radar ground tracks for NEMAX1A and baseline arrivals are shown in Figure 12. The tight concentrations of the lateral tracks for the trial flights are again evident, especially in comparison to the much more dispersed ground tracks of the conventionally vectored baseline arrivals. Despite this dispersion, the baseline traffic is still largely contained within the approach zones. Similar baseline tracks were seen with the MD11s.

MD11 trial flights are also shown. The increased capability of the vertical automation in the MD11’s Pegasus FMS allows their pilots to fly the vertical profile in full FMS-managed mode throughout, resulting in the much more consistent vertical profiles. The MD11 trial flights achieved even better CDA performance, with average level segments of only 0.3 nm/flight below 9000 ft compared to 3.9 nm/flight for the MD11 baselines.

**Vertical Profile Analysis**

A comparison of the vertical profiles for the trial and baseline flights is made in Figure 13. The swathe of B757 NEMAX1A flights are generally higher than the baseline flights, illustrating the trial procedure is tending to keep aircraft higher. The relatively large amount of variation in the vertical profiles of the B757 trial aircraft are consistent with the less advanced technology in the vertical automation capability of the Legacy FMS present in the B757’s of the operator concerned, requiring the vertical profile to be flown in a combination of automatic VNAV and V/S (Vertical Speed) modes. V/S mode requires pilot intervention through the autopilot mode control panel. Different behaviours result from different intervention times and commanded vertical speeds by different pilots. Despite this variability, the trial flights still contain considerably fewer and shorter level flight segments compared to the baseline flights: an average of 1.6 nm/flight below 9000 ft for the trial flights compared to 6.0 nm/flight below 9000 ft for the baseline.

The upper profiles of Figure 14 reinforce that the B757 trial flights are being kept higher for longer than the baseline prior to ILS intercept, although the variability in the trial flights is quite high for reasons discussed. The lower profiles show that, although the variability is significantly reduced in the MD11, the average profiles of the B757 and MD11 trial flights are very similar. This indicates that the B757 pilots are flying a similar average vertical profile through the mixed VNAV
& V/S mode as the full VNAV mode of the MD11. The profiles also illustrate that the trial flights have shorter tracks (and therefore spending less time) below 9000 ft, with an average of 33 nm track distance below 9000 ft for the trial flights compared to 37 nm for the baseline.

**Speed Profile Analysis**

The average airspeed for the B757 trial and baseline flights are shown in Figure 15.

![Figure 15: B757 Average Airspeed Profiles](image)

These profiles illustrate that the trial speed are very close to the baseline (with lower variability) until approximately 15 nm to the runway, but are slightly lower from then until ILS intercept. This period of lower trial speed probably resulted from the speed constraint at NXS11 being too low. However, this lower speed corresponds to the period when the aircraft is higher than the optimal profile and therefore lower speed was being traded off for higher altitude in this region. This behaviour is not ideal from a low power/low drag perspective and this is an interesting area for trial procedure refinement. Similar behaviours were seen in the MD11 data.

**Engine N1 Analysis**

The NEMAX1A and baseline B757 engine N1 behaviour is shown in Figure 16.

![Figure 16: B757 Average N1 Profiles](image)

There is significant variability, but the trial flights have average N1 lower than the baseline outside 30 nm and 10-5 nm to the runway. On average both types of approach are close to flight idle (approx. 40%) prior to the ILS. This is not unexpected given that many of the baseline flights should still be V-CDAs.

**Noise Analysis**

Noise predictions were made by inputting the trajectory data into industry-standard noise codes. Wyle Laboratories’ NMSim takes inputs of aircraft trajectories in the form of latitude, longitude, altitude, heading angle, flight path angle, speed, power, roll angle and terrain features to calculate ground noise footprints and time histories for different metrics. This model was used to predict the noise impacts of the procedures, which were then validated using noise measurements from monitors positioned near NXS11, 17 and 22 as shown in Figure 17. This shows the NMSim peak noise (LAmx) footprint for the average B757 NEMAX1A approach and shows good correlation with the monitor field measurements for that type.

![Figure 17: Noise Prediction & Monitor Data](image)

Because the baseline flights had dispersed ground tracks, it was difficult to get field measurements from fixed monitors. Therefore, the validated NMSim noise predictions were used to calculate the noise impacts of the average baseline trajectory for each aircraft type and hence calculate the noise difference between the trial and baseline flights at various locations: see Figure 18.

![Figure 18: NMSim Noise Analysis](image)

These results show reductions of 3-6 dBA peak noise for both aircraft types when flying the NEMAX1A procedure compared to baseline,
values identical to those observed in the Louisville P-RNAV CDA trials in the US [8].

Additional noise analysis was conducted using the FAA’s Integrated Noise Model (INM v6.2). This was used to compare the peak noise contour areas and population impacts for the NEMAX1A and a representation of the baseline procedures, as shown in Figure 19. This illustrates that the dispersed ground tracks associated with the baseline operations produce peak noise contours with much larger areas compared to those associated with the concentrated trial procedures, at least for contours ≤65 dBA. The number of people exposed to noise of these peak values is therefore much larger in the baseline case. Of course, concentrated ground tracks mean that those people who are within a given contour may be exposed to a greater number of flights compared to the same contour with dispersed ground tracks, but this is the fundamental distinction between dispersed and concentrated policies.

![Figure 19: INM Noise Analysis](image)

**Fuel Burn & Emissions Analysis**

Fuel burn impacts operator costs and emissions production, so was of interest in this trial. The FDR fuel flow data allowed fuel usage for the aircraft types to be compared between the trial and baseline flights: average fuel used below 10,000 ft is given in Figure 15.

![Figure 20: Fuel Burn Analysis](image)

The generally lower thrust and shorter flight times below 10,000 ft with the trial procedures leads to significant fuel savings of around 10% for each type compared to the baseline flights. Note that, although the CDA performance of the MD11 trial flights was superior to that of the B757, the baseline MD11 flights also had better CDA performance than the B757 baselines, and hence the net savings with the trial procedures are about the same for both types.

Emissions production can be calculated using ICAO “emissions indices” [9] for different pollutants from which production can be calculated by multiplying the “time-in-mode” in a given flight phase with the index of the pollutant of interest. The Boeing Method 2 (BM2) methodology [10] is coded into TASAT which was used with the trial data to calculate emissions production for various pollutants. The analysis showed that the NOx, CO2, H2O and SOx emissions production were all reduced with the trial flights by similar amounts to the fuel burn. HC and CO emissions were similar or slightly higher in the trial flights, consistent with the slightly increased production of these species at lower thrust settings.

**Discussion**

The environmental performance of the trial flights is seen to be superior compared to the baseline flights against a number of environmental metrics (CDA performance, peak noise, fuel burn and emissions production). The CDA performance from these trials is summarized in Figure 21 and has implications for the appropriateness of the Code of Practice definition of the CDA presented earlier. Performances of the baseline and trial flights against this definition are presented in Table 2.

![Figure 21: CDA Performance Summary](image)

**Table 2: CDA Performance Metrics**

<table>
<thead>
<tr>
<th>Type &amp; Procedure</th>
<th>Current CDA definition performance</th>
<th>Stricter CDA definition performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>B757 Baseline</td>
<td>65%</td>
<td>10%</td>
</tr>
<tr>
<td>B757 NEMAX1A</td>
<td>87%</td>
<td>52%</td>
</tr>
<tr>
<td>MD11 Baseline</td>
<td>81%</td>
<td>23%</td>
</tr>
<tr>
<td>MD11 NEMAX1A</td>
<td>100%</td>
<td>90%</td>
</tr>
</tbody>
</table>

The performance of the baseline flights are 65% and 81% for the B757 and MD11 respectively, despite the presence of an average of 6.0 nm and
3.9 nm of level flight below 9000 ft. In order to quantify the benefits of more advanced CDAs, the NEMAX1A results were also tested against a stricter CDA definition: an arrival was considered an “advanced CDA” if it contained, at or below 9000 ft, no level flight or one phase of level flight not longer than 1 nm. Performance against this definition is also given in Table 2. The baseline flights performance falls to 10% (B757) and 23% (MD11), while those for the NEMAX1A trials are 52% (B757) and 90% (MD11). This provides a much better reflection of the relative CDA performance of the observed behaviours. Although the industry definition of CDA was originally developed for use in the confined airspace of the London terminal area, these results suggest that additional, stricter definitions should also be used to better quantify CDA performance.

The pilot and controller report forms also gave interesting insights into the performance of the trial procedures. Many comments provided positive feedback of the operational performance of the procedures, while others pointed to areas for refinement. The non-ideal nature of the vertical profile (as established during the development due to airspace constraints) was noted as having a potential adverse impact on workload. The need for enhanced ATC coordination was also flagged and this is a critical issue if environmental benefits are to be maximized by flying procedures from as high as possible (although these trials were specifically designed to have no effect on upstream ATC). Finally, one controller commented on the difficulty sequencing non-trial flights behind a trial flight. This highlights the need to assess the aggregate environmental performance across multiple approaches so that benefits from advanced “green” procedures are not achieved at the expense of worse environmental performance from other approaches being used concurrently.

**Conclusions**

Advanced noise abatement procedures have been successfully developed and introduced at Nottingham East Midlands Airport in a true collaborative partnership between academia and wider stakeholders. Flight trials of the procedures indicate aircraft are being kept higher, with less level flight and lower thrust leading to reduced noise, fuel burn and emissions production. Some interesting pointers for further work have been highlighted, in terms of the interaction between aircraft automation capability, airspace constraints and procedure design; the need for enhanced ATC coordination if environmental benefits and capacity are to be maximized; and the need for effective individual and aggregate traffic environmental performance metrics to be developed.

**References**


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**Key Words**

Environment, Noise Abatement, Continuous Descent Approaches, P-RNAV, Noise, Fuel Burn, Emissions.

**Biographies**

Tom G. Reynolds is a senior research associate at the University of Cambridge’s Institute for Aviation and the Environment. He obtained his Ph.D. in Aerospace Systems from MIT’s International Center for Air Transportation in 2004, has an S.M. in Aeronautics & Astronautics from MIT and a B.Eng. in Aeronautical Engineering from the University of Bristol.

Liling Ren is a research engineer in the Air Transportation Laboratory at the Georgia Institute of Technology researching air traffic management and the environmental impact of aviation. He earned his Sc.D. in Aerospace Systems from MIT in 2006. He holds an M.S. and a B.S. in Aerospace Engineering from Beijing University of Aeronautics and Astronautics.

John-Paul B. Clarke is an associate professor in the School of Aerospace Engineering and direct or of the Air Transportation Laboratory at the Georgia Institute of Technology. His research and teaching address issues of optimization and robustness in aircraft and airline operations, air traffic management and the environmental impact of aviation. He received his S.B., S.M. and Sc.D. from MIT and was a faculty member there prior to moving to Georgia Tech.