REVIEW
OF
NOISE ABATEMENT PROCEDURE RESEARCH & DEVELOPMENT AND IMPLEMENTATION RESULTS

DISCUSSION OF SURVEY RESULTS

Approved by the Secretary General
and published under his authority

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International Civil Aviation Organization

1. INTRODUCTION

1.1 This document summarizes Noise Abatement Procedure (NAP) Research and Development (R&D) projects undertaken by various parties, including universities, regulatory agencies, manufacturers, air carriers and airports. The summaries are a result of a survey questionnaire that was distributed to contact persons for NAP R&D. As such, they should be viewed as a snapshot of the efforts being undertaken at this time. Some of these summaries report preliminary measured results of work already in progress, while others report predictions of anticipated environmental impact improvements. While the reported benefits for Continuous Descent Arrivals (CDA), in particular, show promise, some of the results have been achieved in unique operating environments with single operators using similar aircraft types with advanced navigation equipment. It will take incorporation of flight, airspace, and ATC procedure changes and improvements in aircraft equipage on a wide-spread basis, adopted by the pilots, air carriers, Air Navigation Service Providers and airport operators for these benefits to be fully realized.

2. REVIEW OF ESTABLISHED PRACTICES

2.1 Noise abatement operational procedures are being employed today to provide noise relief to communities around airports from both arriving and departing aircraft. PANS-OPS, Volume 1, contains guidance for the development of a maximum of two noise abatement departure procedures (NADP's) designed generally to mitigate noise either close in (NADP 1) to the airport, or further out (NADP 2) along the departure path. Appendix B of this report contains a list of current NADP's in use by air carriers for a wide range of aircraft types.

2.2 Noise abatement operational procedures in use today can be broken down into three broad categories:

Noise abatement flight procedures

- Continuous Descent Arrival (CDA)
- Noise Abatement Departure Procedures (NADP)
- Modified approach angles, staggered, or displaced landing thresholds
- Low power/low drag approach profiles
- Minimum use of reverse thrust after landing

Spatial management

- Noise preferred arrival and departure routes
- Flight track dispersion or concentration
- Noise preferred runways

Ground management

- Hush houses and engine run up management (location/aircraft orientation, time of day, maximum thrust level)

- APU management

- Taxi and queue management

- Towing

- Taxi power control (Taxi with less than all engines operating)

2.3 Although noise abatement procedures may have quantifiable environmental benefits, effective implementation may be difficult: procedures must be developed, tested, and evaluated for benefits and ATC impacts; approved and accepted by the airport and the ANSP (Air Navigation Service Provider); and adopted by the airlines and other airport users. The PANS-OPS allows a maximum of two different takeoff procedures to be implemented by an airline. The Air Carrier Survey shown in Appendix B reports how different airlines are applying the close-in and distant noise abatement departure procedure criteria to seventeen different airplane types. The criteria specify minimum altitudes for thrust reduction and flap retraction, but otherwise give operators considerable latitude to develop their own profile designs. For any noise abatement operating procedure to be adopted, it needs to be demonstrated that with appropriate crew training, it does not compromise safety and that ATC can accommodate the procedure with minimal or no impact to airport capacity or controller workload.

2.4 There are numerous system constraints that prevent or hinder the implementation of noise abatement procedures in general, and Continuous Descent Arrivals in particular. They include:

- Lack of harmonising guidance - As noted above, PANS-OPS establishes minimum altitudes for aircraft configuration change and thrust reduction within an NADP, but leaves development of specific aircraft profiles to the operator. Appendix B illustrates the diversity of aircraft procedures. These variations make the quantification of noise and emissions benefits very difficult and drive the requirement for very sophisticated modelling to determine the effects of the different profiles. With respect to CDA, there is no single definition of the procedure, nor is there a commonly agreed methodology or toolset for assessing the benefits.

- Capacity requirements – Airport and airspace capacity may be adversely impacted by noise abatement procedures, particularly during high demand periods. It may be impractical to use noise preferred runways or flight procedures like CDA if they generate unacceptable levels of delay and congestion. Delay and congestion contribute directly to incremental noise and emission impacts.

- Airport/ground equipment – Hush houses and other airport infrastructure items which may contribute to noise and emission improvements require space and funding, which may not be available at all locations.

- Aircraft equipage – Many aircraft do not yet have sophisticated flight management systems, data link, or the data base capacity necessary to optimize arrival and departure noise abatement procedures.

- Pilot and air traffic controller acceptance - Noise abatement procedures often increase pilot and controller workload and introduce non-standard or more complex procedures. Variations in optimum aircraft performance may make it difficult for controllers to efficiently sequence and space traffic, thus making them reluctant to embrace CDA procedures in other than light traffic periods.

- Lack of skills, training, and awareness – Effective implementation of noise abatement procedures requires a collaboration among airports, ANSP's, and aircraft operators. Absent this collaboration and coordination, it is unlikely that procedures will gain regular use. Ideally procedures will be incorporated into the standard operating procedures for both flight crews and controllers, and thereby be included in job function and training.

- Economic constraints – Evaluation and implementation of noise abatement procedures, upgrade of aircraft or airport navigation equipment, and construction or installation of noise mitigating airport infrastructure require financial resources that may not be available. These economic constraints may delay or prevent the full environmental benefits from being realized.

- Lack or poor quality of information – Although there is a wealth of information and guidance available from a variety of governmental and commercial sources, some parties may be unaware of its existence, or how to access it.

- Airport configuration and local community characteristics – In many locations where noise and emissions problems are most acute, airports have little room to expand their land mass or modify their operations or layout to reduce environmental impacts. Similarly, adjacent communities may be well- established with no compatible land uses where arrivals or departures could be directed to minimize noise on surrounding residential areas.

- Terrain and obstacles – Likewise, terrain or manmade obstacles around airports may severely limit ATC, airport, and aircraft operator opportunities to safely and economically implement many simple and effective noise abatement procedures.

- Trade off between noise and emissions – Although CDA procedures appear to provide both noise and emissions benefits, other noise abatement procedures have the potential or do in fact increase emissions. In cases where noise abatement flight tracks, preferred runways, noise displaced landing thresholds, and other procedures increase flight path miles or taxi distance, they will proportionately increase fuel burn and emissions.

2.5 The noise abatement operational procedures described above can make a measurable contribution to reducing noise levels in the vicinity of airports. The magnitude and scope of the reductions, as well as the specific procedures to be used to achieve them should be determined through a comprehensive noise study. The study should also include an analysis of emissions impacts and fuel burn, as these variables may be affected by procedure changes both in the air and on the ground. The aircraft operators and ANSP should be parties to the study to ensure the safety and feasibility of the procedures and to take advantage of their technical expertise. The environmental benefits of some operational procedures are straightforward and easy to visualize: preferential runways or flight tracks move aircraft away from more noise sensitive locales. Conversely, the benefits assessments for NADP's and CDA procedures are extremely complex and may require detailed modelling in order to be well understood. It is imperative that accurate aircraft operating data and specific operator flight procedures are applied as input to the noise and emissions models and that impacts on airport and airspace capacity be analyzed. It is worth repeating that some noise abatement operational procedures may increase emissions or derogate airport capacity while providing significant noise relief. Appropriate consideration of all potential environmental impacts is essential, particularly as priorities change and procedures evolve or come up for review.

3. IMPLEMENTATION OF NAP - NEAR TERM SOLUTIONS (SYNTHESIS OF COLLECTED R&D/IMPLEMENTATION SUMMARIES)

3.1 The majority of Noise Abatement Procedure R&D centers on techniques for reducing arrival and approach noise. The exceptions contained in this report are the European SOURDINE II project and the Japan R&D project which look into the environmental impact of Noise Abatement Departure Procedures. Arrival techniques, especially CDA (Continuous Descent Arrival) have attracted much interest within the aviation community in the last several years with most of the current work focused on CDA demonstrations at selected airports with individual air carriers. CDA's have the potential for reducing noise, emissions and fuel burn, but these benefits must be quantified while demonstrating Air Traffic Control compatibility and assessing capacity impact in order to be adopted on a broad scale. Variations in aircraft performance and complex airspace structures have limited widespread CDA implementation. Researchers are working on automation tools and minimum aircraft equipage to reduce the pilot and controller workload associated with the procedures.

3.2 Existing and potential operational enablers - These enablers facilitate the effective implementation of Noise Abatement Procedures.

- Top level commitment and leadership – The development, evaluation, coordination and implementation of sophisticated noise abatement procedures require strong leadership and commitments from all stakeholders to ensure success. The definition of success for each stakeholder should be established in advance.

- Collaborative environmental management – planning by stakeholders – As international agreements on environmental goals evolve, it is imperative that all stakeholders participate in the planning process and understand the complex interactions among competing interests.

- Harmonized guidance – Aviation is inherently international in scope. The promulgation of harmonized guidance from states on noise abatement operational procedures and emissions impacts provides the foundation for broad and effective implementation.

- Standardized and accurate monitoring and modelling information – Standardized technical analysis and modelling of noise abatement procedures, including impacts on fuel burn and emissions, form the basis for rational decision-making and procedure/program selection.

- Training and awareness – Sensitivity to the environmental impacts of aviation should be established through training and the incorporation of environmental "best practices" in standard operating procedures. In many instances, corporate or operator goals and environmental goals can be aligned (e.g., reduced fuel consumption).

- Dissemination of requirements – adequate communication – These elements form the foundation for training and awareness and are essential for effective procedure selection and implementation.

- Expertise and skills – Effective implementation of noise abatement procedures depends upon a collaboration of knowledgeable and technically competent stakeholders from a variety of disciplines, including representatives from communities and local governments around the airport.

- Adequate resources and technology – In order to insure effective implementation of noise abatement operational procedures, adequate resources to support development, analysis, modelling, implementation, training and education must be available. Sophisticated technology may be required on participating aircraft (satellite based Flight Management Systems) and in the ground ATM infrastructure (sequencing and spacing software) to realize fully the comprehensive environmental benefits.

- Standardized ATM framework (e.g., state approval of P-RNAV) – Harmonization of ANSP airspace, procedure and regulatory requirements, and standards facilitates the development and implementation of effective noise abatement operational procedures. It also significantly increases the likelihood of aircraft operator cooperation and participation.

3.3 As one leg of the Balanced Approach, noise abatement operational procedures have shown a substantial environmental benefit. Further optimization and development of new operational procedures show a promise of additional benefits. The R&D projects reported in this paper show predictions and/or measurements of the following environmental benefits:

— 3 to 12 dB noise reduction, and 8% to 36% reduction in noise contour areas on approach;

— 2 to 9 dB noise reduction and 23% to 42% reduction in noise contour areas on departure;

— As much as 35% reductions in CO_2, HC and NO_x and 50 to 1000 pound fuel savings per landing; and

— 90 to 630 kg CO_2 and 60 to 440 pound fuel savings per departure.

There is a clear incentive for conducting further R&D on noise abatement procedures, combining the efforts of universities, regulatory agencies, manufacturers, air carriers and airports to minimize the impact aviation has on the environment. This is especially true for CDA's, where reductions in noise come with reductions in emissions *and* fuel burn.

3.4 Many of the R&D projects involve arrival techniques. Because some of these techniques are relatively new and/or not universally adopted, much of the focus is on pilot and ATC workload, and capacity integration. To facilitate acceptance and mitigate pilot workload, flight deck systems are being developed to help the pilots manage the aircraft and communicate with ATC. The demonstrations of these procedures are aimed at developing ATC procedures, communications and procedure integration to mitigate capacity impact.

3.5 The reported R&D projects are either stand alone endeavours or a part of broader research programs. While most of the reported projects are in progress or have been completed, the time frames of the studies range from 2001 to as far out as 2011. There are indications of new R&D projects to continue the development of the techniques, technologies, and ATC integration of CDA's, as well as new R&D into developing and optimizing noise abatement departure procedures.

4. CONCLUSIONS

4.1 Noise abatement procedures form one leg of the Balanced Approach; and as such, continued development and optimization of operational procedures are essential for minimizing the environmental impact of aviation. Operational procedures can often be implemented with the existing fleet and have the potential to make an immediate improvement in the environmental impact of aviation. As described in some of the projects contained in this report, the predicted and measured improvements to noise, emissions and fuel burn can be substantial. Continuing R&D must work to optimize procedures, determine the technologies needed and identify pathways to facilitate acceptance by airports, air carriers, pilots, ANSP's, and communities around airports.

A SURVEY REPORT ON CURRENT AIR CARRIER NADP (NOISE ABATEMENT DEPARTURE PROCEDURES)

BACKGROUND

4.2 Modelling the aero-profiles resulting from specific departure procedures produces the data necessary to assess departure noise and engine emissions. Accurate modelling of an aircraft departure begins with the selection of a takeoff weight, takeoff thrust, flap setting, temperature, and airport elevation. In addition, management of the aircraft configuration and thrust during the initial climb must be specified. The initial climb is characterized by segments of constant speed climb, acceleration, and flap retraction along with an initial thrust reduction from takeoff power.

4.3 The sequence of the initial climb segments is prescribed by the air carrier and can vary, not only by carrier, but also by airport and aircraft type. Having no single source of reference for the details of operational departure procedures has presented problems for similar modelling efforts and the procedures provided by a few air carriers, while valid, could not be considered as representative of the industry.

4.4 To create a detailed reference source for departure procedures, a questionnaire was developed and forwarded to an extensive list of air carriers. To encourage a response, the air carriers were given an overview of the work being conducted by both CAEP WG2 and SAE A-21 citing the importance that the modelling be representative of actual operations.

5. SURVEY RESULTS

5.1 Paragraph 3.0 shows the results of the questionnaire forwarded to the air carriers requesting detailed information regarding reduced takeoff thrust application, takeoff flap selection, and a detailed description of their respective departure procedures. The following carriers responded to the questionnaire:

American Airlines	United Air Lines	Delta Air Lines	US Airways
Northwest Airlines	KLM	All Nippon	Qantas
Lufthansa	UPS	British Airways	Japan Air Lines
Alitalia	ABX Air	DAS Air	LuxAir

Monarch	Air France	Continental Airlines

5.2 The number of aircraft represented in the survey is approximately 3,850.

6. AIR CARRIER SURVEY RESULTS

TAKEOFF THRUST SUMMARY

The vast majority of survey participants reported the use of reduced thrust takeoffs, applying either de-rated thrust or assumed temperature methodology.

TAKEOFF FLAP SUMMARY

The following reflects the most common reported takeoff flap settings:

AIRCRAFT	FLAP SETTING
A300	15
A310	15 & 20
A319	CONF 1+F & CONF 2
A320	CONF 1+F & CONF 2
A321	CONF 1+F & CONF 2
A330	CONF 1+F & CONF 2
A340	CONF 1+F & CONF 2
B737	05 & 01 & 15
B747	10 & 20
B757	15 & 05
B767	05 & 15
B777	05 & 15 & 20
MD11	25 & 20
MD80	11
MD90	11
DC8	15 & 18
DC9	05 & 01
DC10	20
EMB14	09
F100	05 & 15

DEPARTURE PROCEDURE SUMMARY

Notes:

- Target climb speeds are given as V2 plus, no attempt was made to specify the actual target speed as it is accepted that the segment is flown to the manufacturer's specified safety speed.

- The initial power reduction is simply given as climb power although some reported the use of de-rated climb power.

- Some air carriers publish more than one departure procedure for each fleet type.

Aircraft: A319, A320, B737, B747, B757, B767, B777
Profile 1
- Takeoff Power and Flaps Climbing at V2 plus to 800' AFE
- At 800' Set Climb Power
- Constant Speed Climb to 1500' AFE
- At 1500', Reduce Pitch, Accelerate and Retract Flaps on Schedule
- Constant Speed Climb to 3,000' AFE
- At 3000', Accelerate to 250 kts.
- Constant Speed Climb to 10,000'

Aircraft: B737, MD90
Profile 2
- Takeoff Power and Flaps Climbing at V2 plus to 800' AFE
- At 800', Set Climb Power
- Constant Speed Climb to 2500' AFE
- At 2500', Accelerate to 250 kts While Retracting Flaps on Schedule
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: A319, A320, B737, B747, B757, B767, B777
Profile 3
- Takeoff Power and Flaps Climbing at V2 plus to 800' AFE
- At 800', Reduce Pitch, Accelerate and Retract Flaps on Schedule, Following Initial Flap Retraction (B747 Flap 5; B777 Flap 1), Set Climb Thrust
- Constant Speed Climb to 3000' AFE
- At 3000' Accelerate to 250 kts
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: B747, B767, B777
Profile 4
- Takeoff Power and Flaps Climbing at V2 plus to 800' AFE
- At 800', Reduce Pitch, Set Climb Power, Accelerate and Retract Flaps on Schedule
- Constant Speed Climb to 3000' AFE
- At 3000' Accelerate to 250 kts
- Constant Speed Climb to 10,000'

Aircraft: A300, A319, A320, A321, A330, B737, B747, B757, B767, B777, MD80, MD90
Profile 5
- Takeoff Power and Flaps Climbing at V2 plus to 1000' AFE
- At 1000' AFE, Set Climb Power, Reduce Pitch, Accelerate and Retract Flaps on Schedule
- Constant Speed Climb to 2500' AFE
- At 2500' AFE, Accelerate to 250 kts.
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: MD80, B737, B757, B767, B777
Profile 6
- Takeoff Power and Flaps Climbing at V2 plus to 1000' AFE
- At 1000', Set Climb Power
- Constant Speed Climb at V2 plus to 2500' AFE
- At 2500', Reduce Pitch, Accelerate and Retract Flaps on Schedule
- Accelerate to 250 kts
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: B757, B767, B777
Profile 7
- Takeoff Power and Flaps Climbing at V2 plus to 1000' AFE
- At 1000', Reduce Pitch, Accelerate and Retract Flaps on Schedule
- Set Climb Thrust
- At 3000', Accelerate to 250 kts
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: B737
Profile 8
- Takeoff Power and Flaps Climbing at V2 plus to 1000' AFE
- At 1000', Reduce Pitch, Accelerate and Retract Flaps on Schedule
- At Clean Speed, Set Minimum Power (1.2% Gradient)
- Constant Speed Climb to 2500' AFE
- At 2500', Accelerate to 250 kts
- Constant Speed Climb at 250 kts to 10,000'

Aircraft: B737
Profile 9
- Takeoff Power and Flaps Climbing at V2 plus to 1000' AFE
- At 1000', Set Minimum Power (1.2% Gradient)
- Constant Speed Climb to 2500' AFE
- At 2500', Reduce Pitch, Accelerate to 250 kts while Retracting Flaps on Schedule

Aircraft: A320, A321, B747, B767, B777
Profile 10

- Takeoff Power and Flaps Climbing at V2 plus to 1000’ AFE
- At 1000’, Accelerate and Retract Flaps on Schedule
- At 1500’ AFE, Set Climb Power, Accelerate to 250 kts
- Constant Speed Climb at 250 kts to 10,000’

Aircraft: A300, A319, A320, A321, A330, A340, B767, B777, MD11, MD80
Profile 11

- Takeoff Power and Flaps Climbing at V2 plus to 1500’ AFE
- At 1500’, Set Climb Power, Reduce Pitch, Accelerate to Greater of Clean Speed or 250 kts While Retracting Flaps on Schedule
- Constant Speed Climb at 250 kts to 10,000’

Aircraft: A300, A319, A320, A321, A330, A340, B737, B747, B757, B767, B777, DC10, MD11, MD80, EMB145
Profile 12

- Takeoff Power and Flaps Climbing at V2 plus to 1500’ AFE
- At 1500’, Set Climb Power
- Constant Speed Climb to 3000’ AFE
- At 3000’, Accelerate to 250 kts while Retracting Flaps on Schedule
- Constant Speed Climb at 250 kts to 10,000’

Aircraft: B777
Profile 13

- Takeoff Power and Flaps Climbing at V2 plus to 1500’ AFE
- At 1000’, Set Climb Power
- Constant Speed Climb to 3000’ AFE
- At 3000’, Accelerate to 250 kts while Retracting Flaps on Schedule
- Constant Speed Climb at 250 kts to 10,000’

Aircraft: B777
Profile 14

- Takeoff Power and Flaps Climbing at V2 plus to 1000’ AFE
- At 1000’, Set Climb Power, Reduce Pitch, Accelerate to Greater of Clean Speed or 250 kts While Retracting Flaps on Schedule
- Constant Speed Climb at 250 kts to 10,000’

APPENDIX C

A SURVEY COLLECTED FROM PRINCIPAL CONTACTS FOR NAP R&D

SURVEY RESULTS FOR NAP RESEARCH AND DEVELOPMENT

6.1 To collect information on NAP R&D and implementation projects, a questionnaire was developed and distributed to aviation industry coordinators and contact persons. Information and survey results obtained from Europe, United States and Japan are contained in this appendix.

APPENDIX C-1: SUMMARY CONTINUOUS DESCENT ARRIVAL AT LOUISVILLE INT'L AIRPORT (SDF) UNDER THE PARTNERSHIP FOR AIR TRANSPORTATION NOISE AND EMISSIONS REDUCTION (PARTNER)

Contact details:

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Project name:
Project 4: Continuous Descent Arrival at Louisville Int'l Airport (SDF) under the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER), a Federal Aviation Administration Center of Excellence (COE) for Aircraft Noise and Aviation Emissions Mitigation.

Sponsoring organization(s):
Federal Aviation Administration

Scope and Objectives of the project: (e.g. improving understanding, developing new techniques, enhancing implementation of existing capabilities, harmonisation etc?)
Comprehensive R&D demonstrations for the near term implementation of CDA in the USA. Initial CDA (approval and) launch planned at SDF by Fall 06. Other demonstration planning on-going at LAX and ATL.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Arrival or Departure Procedure}
Environmental mitigation of noise & emissions and fuel savings using Continuous Descent Arrival (CDA) procedures.

Project time frame, duration:
PARTNER Project since 2001 to present. Strategically, proposed for 2011, when COE becomes an independent entity.

Level of maturity and expected timeframe/lifespan for implementation of procedure/solution:
Basic CDA is available for operators/users to pursue airport specific design tailoring in order to demonstrate and file an FAA application for new procedure approval.

Order of magnitude of expected benefits (give scale of applicability- state, region, global):

- **Noise:** **@ 7.5-15 nm: up to 6dB noise reduction**
  Lower per aircraft noise levels
  Impact concentrated in narrow corridors
- **Emissions:** **CO below 3,000 ft reduced by 12.7% (B-767) and 20.1% (B-757)**
  HC below 3,000 ft reduced by 11.0% (B-767) and 25.1% (B-757)
  NOx below 3,000 ft reduced by 34.3% (B-767) and 34.4% (B-757)
- **Fuel burn:** **@ SDF: (B767) 350lbs/flt saved; (B757) 100 lbs/flt saved**
- **Other** (e.g. alternative mitigation cost reduction, constraint alleviation etc.)

Disbenefits or other considerations:
{Capacity, etc.}
Demonstrated for night time low traffic operations at Louisville airport for 2 aircraft types within UPS fleet.

Prerequisites:

- **Technical equipment {aircraft, airport, air-ground communication}:**
  Low traffic condition airport, aircraft with FMS, operator to work voluntarily with PARTNER/FAA design team.

- **Method of introduction in existing fleet and airport operations:**
  Applicable as Special" procedures with FAA.
- **Cost** (development cost and/or total for implementation):
  Interested operator shares cost with FAA.
- **Training {air traffic controllers, pilots}:**
  Pilots and ATC.
- **Acceptance {air traffic controllers, pilots}:**
  Must be demonstrated within the region locally.
- **Safety/Risk assessment:**
  No risks encountered during demos.
- **Other:**
  N/A

How will the outcome be used or implemented (e.g. formal Agencies involved or specific regulatory implications?)
CDA airport projects are being planned in collaboration with the FAA and the PARTNER COE- CDA Design Team.

Example of implementation:
PARTNER team collaboratively designed and demonstrated CDA and filed for "Special" procedure with FAA approval to utilize CDA at Louisville (SDF) airport. Anticipate FAA approval by Fall FY06.

Formal references:
J.-P. B. Clarke, N. T. Ho, L. Ren, J. A. Brown, K. R. Elmer, K.-O. Tong, and J. K. Wat, "Continuous Descent Arrival: Design and Flight Test for Louisville International Airport," AIAA Journal of Aircraft, Vol. 41, No. 5, pp. 1054-1066, September-October 2004.

J.-P. Clarke, D. Bennett, K. Elmer, J. Firth, R. Hilb, N. Ho, S. Johnson, S. Lau, L. Ren, D.Senechal, N. Sizov, R. Slattery, K.-O. Tong, J. Walton, A. Willgruber, and D. Williams, "Development, design, and flight test evaluation of a continuous descent Arrival procedure for nighttime operation at Louisville International Airport," PARTNER Center of Excellence Report PARTNER-COE-2006-002, 9 January 2006.

PARTNER website:
http://web.mit.edu/aeroastro/www/partner/projects/proj4.htm

APPENDIX C-2: ADVANCED ARRIVAL TECHNIQUES AT SCHIPHOL AMSTERDAM AIRPORT

Project name: Advanced Arrival Techniques at Schiphol Amsterdam Airport

Sponsoring organization(s): LVNL (Dutch Air Traffic Control), Boeing BCA, Boeing Phantom works

Scope/Objective of the research: Demonstrate capabilities of modern airplanes. The Advanced Arrival Techniques, as studied in the Advanced Arrival & Departure Techniques (AADT) project, focuses on the improvement of predictability in traffic behaviour during arrival for both pilots and controllers, by using aircraft-derived information from the flight deck in the ground ATM system. The predictability improvement is essential to allow continuous descent arrivals to be flown in peak hours. Today, continuous descent approaches can be flown by single flights accurately and efficiently, resulting in a significant reduction in noise and engine exhaust emissions, as well as fuel burn savings. As the number of continuously descending flight towards a landing runway increases, however, the Air Traffic Controller's job becomes increasingly more difficult because altitude separation is no longer available to ensure a safe, orderly and expeditious flow of traffic. In the current operation this problem is overcome by introducing a higher landing (time) interval between aircraft to account for the poor controller predictability of the aircraft flight path and speed. This in turn results in reduced airport capacity that forces CDA operations to be flown during night time only. However, predictability for controllers can be significantly improved when using information available on board of the aircraft.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Approach or Departure Procedure}

Investigate ability of local Air Traffic systems to communicate and predict airplane positioning
The trial objectives that have been defined in preparation of the trial are defined and agreed in [Ref. test plan]. The trial objective is to:

Conduct an in service operational trial repeatable Top Of Descent (TOD) Continuous Descent Arrival (CDA) procedure to support the following analyses in order to provide recommendations for strategy development:

Assessment of use of aircraft derived data to improve the predictability of the ATM system:

Assessment of airlines satisfaction with procedure and operating cost impact;

Assessment of crew satisfaction with procedure and workload impact;

Assessment of controllers' satisfaction with procedure workload; and

Assessment of the environmental impact (fuel burn, noise and emissions).

Level of maturity or expected timeframe for completion: April 2006 completed

Order of magnitude of expected benefits:
- **Noise:** 6 to 12 dBA

- **Emissions:** Currently under study - Unknown
- **Fuel Savings:** 50-1000 lbm of fuel

Disbenefits or other considerations:
Capacity impact:
The flight paths require precise flying through the Flight Management Computer (FMC) calculated routing. If the airplane crew is offered a different routing by ATC after the top of descent, the integrity of the CDA could be compromised because the FMC would be constrained to calculate a new optimal flight path. The pilot would take over at that point and could require changing speeds, adding engine power, or levelling off at lower altitudes. All these factors increase noise and fuel burn. Predicting airplane position and time is an absolute criterion for CDA's to be able to operate at times of high traffic volume. Using absolute standard arrival routes from top of descent is a critical element in pursuing CDA's for high traffic situations.

Prerequisites:
- **Technical equipment {aircraft and airport};** 737NG, MD-11 aircraft participated in trial. Amsterdam Schiphol airport ATC

- **Method of introduction in existing fleet;**

- **Cost;**

- **Acceptance {controllers, pilots};** Good
  In the low-density, night environment, the modified procedures were successful in that they did not increase controller workload and they permitted aircraft to descend optimally. Further success was realized in the way that the new procedures were introduced to the controllers and to the pilots at minimum cost.

- **Safety/Risk assessment**: Low risk

Example of implementation:

Formal references:

Research Report Advanced Arrival Techniques – Using aircraft capabilities to improve arrivals. D/R&D/005/026 version 1.0 dated 19 January 2006.

In-service Demonstration Test Plan Advanced Arrival Techniques. Version 0.4 dated 23 September, 2005.

APPENDIX C-3: LOUISVILLE (SDF) CONTINUOUS DESCENT ARRIVAL

Project name: SDF (Louisville) Continuous Descent Arrival

Sponsoring organization(s): Boeing, MIT, FAA, UPS, NASA, SDF (Noise Abatement Procedure Working Group)

Scope/Objective of the research: The primary objective of the design work was to come up with operational FMS based CDA procedures for opposite facing runways, 17R and 35L that begin at cruise altitude, may be used in daily operation, and did not have FMS issues identified in a previous (2002) flight tests. The purpose of conducting the demonstration flight test was to validate new design tools, demonstrate the robustness and consistency of the procedure, affirm the acceptability from both pilots and controllers, and to further validate noise, emissions, fuel burn and time savings that previous analysis and testing have shown.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Approach or Departure Procedure}:
The demonstration was conducted with the last 12 westerly arrivals between 1 to 2 AM local time. The flight tests were successfully completed with 125 aircraft participated over 10-nights. 123 aircraft performed as (or close to) expected. 2 aircraft were vectored (due to lower initial separation) and 1 aircraft unable to participate. Noise data was collected on 9 of the 10 nights; a late switch in direction of operation prevented noise measurement team moving to other side of airport. Louisville TRACON successfully mixed CDA and non-CDA aircraft on one night. The noise measurements were generally of high quality and matched predicted levels made with the flight data that was collected. Five weeks worth of flight data was collected and used to make noise predictions for the CDA test flights and flights during the following three weeks.

Level of maturity or expected timeframe for completion:
UPS is in the process of applying for special RNAV procedure for late night operations.

Order of magnitude of expected benefits:

- **Noise:** Reduced noise contour area by up to 33%
- **Emissions:** NOX, CO, and HC emissions were also reduced by up to 35
- **Fuel burn:** Flight time savings of a few minutes and fuel savings of 100 to 300 lbs were realized

Disbenefits or other considerations:
{capacity, etc.}
Capacity was not adversely affected, due to late night /single carrier, low cross traffic operations.

Prerequisites:
Technical equipment {aircraft and airport}: 757 and 767 aircraft arriving at SDF.

- **Method of introduction in existing fleet:**
  UPS will modify RNAV's which will be more efficient for implementation for the same 12 westerly arrival flights at night. ADS-B may be used to improve initial separation requirement.

- **Cost:**

- **Acceptance {controllers, pilots}:**
  Pilot acceptance of procedure was overwhelmingly positive while the controllers saw no issues.

- **Safety/Risk assessment:**

Example of implementation:
UPS has implemented this method for night time arrival at Sacramento Mather airport (one to two flights per night).

Formal references:
"Development, Design, and Flight Test Evaluation of a Continuous Descent Approach Procedure for Night time Operation at Louisville International Airport," FAA COE PARTNER CDA Development Team, 2005.

APPENDIX C-4: San Francisco (SFO) OCEANIC TAILORED ARRIVAL TRIAL

Project name: SFO Oceanic Tailored Arrival Trial

Sponsoring organization(s): NASA-Ames and Boeing

Scope/Objective of the research:

Phase 1. Basic OTA:

- Basic OTA is equivalent to a "Continuous Descent Approach" (CDA).
- Assess noise impact, fuel burn, and pilot and controller workload.
- If successful, basic OTA may become standard Bay Area approach
- procedure.

Phase 2. OTA with speed schedule:

- Basic OTA, with cruise and descent speeds modified by EDA.
- Assess ability to predictably modify an aircraft's trajectory using a clearance suggested by an advanced air traffic control tool.
- First step towards more efficient ATC operations.

Phase 3. OTA with "Required Time of Arrival" (RTA):

- Basic OTA, with aircraft assigned an arrival time at a low altitude waypoint.
- Assess effectiveness of aircraft adjusting speed to arrive at scheduled time.
- Aircraft technology may be useful for air-ground schedule coordination.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Approach or Departure Procedure}
There are a number of key components of the Tailored Arrivals end state system. They are:

1. Continuous Descent Approach Procedures - Fuel efficient, reduced noise flight profiles adaptable to a specific airspace.

2. ATC Flow Management Tool (NASA's Traffic Management Advisor, TMA) - Controls flows and sequencing into the terminal area to maximize throughput during high density operations. The flow management tool specifies Required-Time-of-Arrival (RTA) for each aircraft at specified points (e.g., a meter fix) and specifies the necessary delay for each aircraft to reach the desired RTA.

3. ATC Descent Tool (NASA's En Route Descent Advisor, EDA) - Derives precise, conflict free "tailored" 4D trajectory for each aircraft to meet its RTA with the best possible descent profile for the aircraft.

4. CPDLC - Controller to Pilot Data Link to: (a) provide an efficient mechanism for uplinking complex trajectory data to the flight deck; (b) provide a mechanism for downlinking critical aircraft parameters to maximize accuracy of the TMA / EDA aircraft trajectory model; and (c) provide an efficient mechanism for uplinking critical data (e.g., up-to-date wind data) to support optimal precision in aircraft compliance with the desired 4D trajectory.

5. FMS – Aircraft automation to accurately guide the aircraft along the desired 4D trajectory.

Level of maturity or expected timeframe for completion:
Phase 1 trail period is June – December, 2006.

Order of magnitude of expected benefits:

- **Noise:** 3 – 6 dB
- **Emissions:** Reduction due to reduced flight time
- **Fuel burn:** A few hundred pounds/flight

Disbenefits or other considerations:
{Capacity, etc.}
The trial will be conducted during low density operations.

Prerequisites:
Technical equipment {aircraft and airport}; FANS equipped aircraft (777, 747, and MD11) at SFO and OAK:

- **Method of introduction in existing fleet;**

- **Cost;**

- **Acceptance {controllers, pilots};** Oakland Center, TRACON, United, and possibly Fedex are participating

- **Safety/Risk assessment:**

Example of implementation:

Formal references:

APPENDIX C-5: Santa Ana (SNA)/Long Beach (LGB) TAILORED ARRIVALS

Project name: SNA/LGB Tailored Arrivals

Sponsoring organization(s): Boeing

Scope/Objective of the research: The purpose of this task is to work with airport operators and authorities to design and conduct an in-service flight demonstration of a tailored arrival / continuous descent arrival procedures for John Wayne and Long Beach airports.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Approach or Departure Procedure}
The goals for these procedures are to improve operational efficiency, save fuel, and reduce environmental impacts such as noise and emissions. The unique features of this particular project are to develop and test low density day time arrival procedures by flight demonstrations. These two airports have night time curfews and have common initial arrival fixes. Identify problem areas and required ground tools necessary for future implementation in the complex blend of commercial, regional, and general aviation traffic that exists in Southern California.

Level of maturity or expected timeframe for completion:
Perform demonstrations on carrier revenue fights in 2006 and 2007.

Order of magnitude of expected benefits:
- **Noise:** 3 – 6 dB
- **Emissions:** Reduction due to reduced flight time
- **Fuel burn:** A few hundred pounds/flight

Disbenefits or other considerations:
{capacity, etc.}
Capacity is not addressed in this demonstration**.**

Prerequisites:
Technical equipment {aircraft and airport}; 737, 737NG, A320, 757, 767 arriving at SNA, LGB

- **Method of introduction in existing fleet;**
- **Cost;**
- **Acceptance {controllers, pilots};**
- **Safety/Risk assessment:**

Example of implementation:

Formal references:

APPENDIX C-6: SOURDINE II PROJECT

Contact details:

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Project name:

SOURDINE-II Study on the optimisation of procedures for decreasing the impact of noise II

Sponsoring organization(s):

The Sourdine II consortium included Airbus France, Eurocontrol Experimental Centre, AENA, INECO, Isdefe, SICTA and NLR (Co-ordinator). The project was part of the European 5th framework programme, financed 50% by DG-TREN.
The consortium was supported by an expert panel (not funded), which provided feedback during procedure definition and at intermediate phases of the assessments.

Scope <u>and</u> Objectives of the project: (e.g. improving understanding, developing new techniques, enhancing implementation of existing capabilities, harmonisation etc?)

The Sourdine II project is the follow-up project of the 4th Framework Programme Sourdine. Sourdine provided an inventory of noise abatement procedures and associated noise reduction potential. It also identified operational and technical bottlenecks with regard to implementation, such as constraints of the current ATM system, current operating procedures and hand-on experience of experts as well as lack of enabling technology in this field.

The objectives of Sourdine II were set at the development of new procedures and supporting technology:

- Development of new advanced and innovative environmental friendly approach and departure procedures, based on the results from the Sourdine I project.

- An accepted implementation plan by all involved stakeholders to be able to migrate from the current situation to advanced environmentally friendly approach and departure procedures. This avoids the need to develop specific local solutions to a European problem.

- Development of enabling technology to achieve the successful introduction of the selected departure and approach procedures, such as ATC controller tools and cockpit monitoring tools

- Achievements consist of quantified results for each procedure in terms of safety, capacity and environmental benefits, as well as associated costs or benefits. Objective evaluation of these issues is performed by comparing controller and pilot workloads during baseline scenarios, i.e. current day, with future procedures.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Arrival or Departure Procedure}

Five arrival procedure have been evaluated in the project:
- Procedure I: baseline stepped approach
- Procedure II: CDA with fixed 2° descent
- Procedure III: CDA combining a fixed 2° CDA descent with an increased (4°) final glide slope
- Procedure IV and V: CDA featuring steep constant speed segment at resp. intermediate and landing configuration

Three departure procedures were evaluated:
- Procedure I: Baseline ICAO A
- Procedure II: Optimised Close-in procedure
- Procedure III: Optimised Distant procedure

The Sourdine II terms of reference focused on procedures for medium and long-term implementation. The conclusions of the initial Sourdine project clearly indicated that the introduction of new noise friendly operating procedures can only be successful provided the current airport capacity and safety levels are not negatively affected. Therefore, the objectives of Sourdine II have been set at a broad assessment of newly developed procedures and supporting technology, with respect to noise, safety, capacity, user acceptance (both Pilot and Air-Traffic controller), emissions and cost benefit.

Project time frame, duration:

Project timeframe: 2001 to 2005; duration 45 months.

Level of maturity and expected timeframe/lifespan for implementation of procedure/solution:

The project has shown that the Sourdine II departure procedures are found to be currently implementable, while the arrivals should follow a stepped implementation. It is expected that procedure II can be implemented in large airports, (in low traffic density situations), procedure V in medium airports and procedure III in small airports. Procedure IV should be further assessed for maintenance evaluation, feasibility and acceptance by the users.The implementation has been divided into three main steps characterised by defining an iterative improvement cycle:

1. The stepped approach begins with the current situation by taking full advantage of existing technology.

2. The less intrusive procedures can be implemented in the short-term in a busy traffic ATM system.

3. The more intrusive procedures can be implemented in the short term in low density traffic.

It is recommended to perform flight trials to get detailed feedback on aircraft performance as well as pilot and controller acceptability from hands-on experience. Results from these flight trials can support additional assessments like performed in this project to reach the ultimate goal: continuous descent approaches during peak-hour operations at major European airports while maintaining or even improving capacity and safety.

Order of magnitude of expected benefits:

Noise benefits have been assessed for the different procedures on airport scale for Paris CDG, Madrid Barajas, Amsterdam and Naples airports. Noise results were obtained in terms of 55, 60 and 65 Ldn contours. Comparisons between the baseline approach and different CDA procedures indicated contour reductions of up to 8 % (55Ldn) for Procedure II and up to 36% (60Ldn) for Procedure III. During the assessment it was concluded that the baseline procedure selected for all airport was in fact significantly less noise than actual procedures at the different airports.

For departures, the optimised Close-in provided a 23% (maximum) reduction of the 65Ldn contour compared to the ICAO A baseline whereas the Distant procedure resulted in 55Ldn contour reductions of up to 42% compared to baseline.

Preliminary emissions predictions were performed be it at a limited scale and can be found in the reference indicated below.

Disbenefits or other considerations:
{Capacity, etc.}

Capacity reduction; according to fast time results:

ARRIVAL CAPACITY					
Airport	Baseline	NAP II	NAP III	NAP IV	NAP V
Madrid	78-80	70-72	70-72	68-70	72-74
Paris-CDG	81-83	80-82	80-82	x	80-81
Amsterdam	72-74	69-71	x	59-61	66-68
Naples	31-33	30-32	x	28-30	30-32

In Real Time simulations, controllers stated that this procedure could be used in real operation with an expected capacity of 30-32 arrivals per runway per hour, compared with today's peak-hour capacity of 33-36. This number could be increased once controllers get more hands-on experience concerning the "new" speed profiles and aircraft performance.

Departures: no disbenefits expected.

Prerequisites:

- **Technical equipment {aircraft, airport, air-ground communication}:**

  ATM: RNAV routes, Arrival Manager and Ghosting tool for the merging of traffic
  Cockpit: indication of configuration change points on navigation display, FMS/Engine control adaptation for NADP thrust management

- **Method of introduction in existing fleet and airport operations:**
  Start at low density (night time operations), build up experience.

- **Cost** (development cost and/or total for implementation):
  -

- **Training {air traffic controllers, pilots}:**
  Pilots and ATC

- **Acceptance {air traffic controllers, pilots}:**
  Procedure II has the highest acceptability of both pilots and Air Traffic Controllers.

- **Safety/Risk assessment:**
  An initial high-level safety evaluation identified some safety issues for the four approach procedures for which solutions are required. Possible speed excess situations were identified for the CDA procedures II and III. Concerning procedure III, the increased final glide slope is a non-standard operation and potentially leads to higher workload and in combination with CDA could have an accrued risk of speed excess. This operation requires special analysis in relation to acceptance and to obstacle clearance surfaces. Concerning procedures IV and V, the steep intermediate approach segment and glideslope interception from above, were identified as safety issues (potential consequences of a glideslope undershoot and an unstabilised approach). Potential flight path control problems, which could lead to an increased workload and an unstabilised approach in case the path is too shallow were also identified. With regard to the two departure procedures are speed control problems at low power setting at OEI climb thrust were identified.

- **Other:**
  N/A

How will the outcome be used or implemented (e.g. formal Agencies involved or specific regulatory implications?)
Project results are widely communicated with Airports, Airlines and ANSP's and serve as a basis for procedures in European research projects like AWIATOR, SILENCER and OPTIMAL.

Example of implementation:

-

Formal references:
http://www.sourdine.org

APPENDIX C-7: SUMMARY OF NOISE ABATEMENT OPERATING PROCEDURE IN JAPAN

Project name:
Fundamental research on aircraft performance relevant to noise abatement departure procedures

Sponsoring organization(s):
Japan Civil Aviation Bureau

Scope/Objective of the research:
Define the difference with regard to noise and emission between NADP's in PANS-OPS and the noise abatement departure procedure mainly adopted in Japan, i.e. steepest climb.

Summary description of project:
{Include i) Driver, if not noise/emissions, ii) Approach or Departure Procedure}
Steepest climb departure procedure is one of the variations of NADP-1, and is most effective to confine the noise impact within the small area around the airport. NADP-2 has a distant crossover point to become quieter than NADP-1 or steepest climb, and is most effective to bring down fuel consumption.

Level of maturity or expected timeframe for completion:
The research was completed.

Order of magnitude of expected benefits:

- Noise: Difference of 2-9dB was calculated between NADP-1,-2 and steepest climb at 6km from brake release point depending on aircraft type.
- Emissions: Difference of 90-630kg (CO_2) per take off was calculated between NADP-1,-2 and steepest climb depending on aircraft type.
- Fuel burn: Difference of 60-440lbs per take off was calculated between NADP-1,-2 and steepest climb depending on aircraft type.

Disbenefits or other considerations:
{capacity, etc.}
>In case of introducing NADP-2, noise affected area to have been taken noise counter measures possibly spread out.
>In case of introducing NADP-2, many types of aircraft exceed the speed restriction of 200kts in the airspace below 3,000ft in the control zone as regulated in civil aeronautical law in Japan.

Prerequisites:

- **Technical equipment{aircraft and airport}:**
  Performance and noise data of A320-200 calculated by ANA using Airbus tool, and data of B737-700,B747-400,B767-300,B777-200 and B777-300ER calculated by Boeing.

- **Method of introduction in existing fleet:**
  N/A

- **Cost:**
  N/A

- **Acceptance {controllers, pilots}:**
  N/A

- **Safety/Risk assessment:**
  N/A

Example of implementation:
N/A

Formal references:
AIP/JAPAN, as for steepest climb procedure

— END —