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Environmental Impacts of Continuous-descent Operations in Paris and New York Regions

Isolation of ATM/Airspace Effects and Comparison of Models

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Abstract— **In order to better understand SESAR and NextGen metrics and models for environmental impact assessment, we analyze the differences in effects of a selected ATM improvement (CDO/CDA) on European and U.S. performance using similar regional data sets and the same analytical methods and models. We have: (1) analyzed one day of traffic for both the Paris (CDG and ORY) and New York regions (LGA, JFK, and EWR); (2) compared the relative benefit pools for reduction of environmental impacts (fuel/CO_2, noise, and NOx) in the two regions; (3) estimated the fuel, noise, and air-quality impacts in the two regions using the same modeling techniques; and (4) compared the fuel estimates obtained from 3 different models (NIRS, AEM-III, and IFSET). We find that both absolute and relative CDO/CDA benefits differ substantially for the Paris and New York regions due to significant differences in current traffic intensity, as well as the current distribution of level segments in flight trajectories. The effects estimated focus only on ATM-related trajectory changes, with fleet-composition effects removed from the analysis.**

Keywords: ***continuous-descent operations, environmental benefits pool, environmental impacts, fuel/CO_2, noise, air quality***

I. INTRODUCTION

In an earlier paper [12], we have compared prior CDO/CDA analyses in both Europe and the U.S. in terms of the major aspects of environmental impact assessment, as summarized in Appendix A. Based on this analysis, we concluded that comparison of results across different studies was complicated by substantial differences in assumptions, data, and methods being used. Consequently, we were motivated to apply very similar assumptions, data, and methods to two different regions (Paris and New York) to enable better comparison between regions. Additionally, we were motivated to include several environmental models in this analysis in order to determine the degree to which the models themselves affected the estimates of environmental impacts. This work is also related to earlier analyses of CDOs at ATM R&D Seminars [10,11] and elsewhere [8].

II. METHODS

A. *Traffic Data and Benefit-pool Analysis*

We describe below the data sources used and the processing of this data prior to analysis of CDO benefit pools and environmental impacts.

1) *Data Sources*

Paris traffic data was provided by Thales in the form of ADS-B information for several days in August and September of 2010. The day selected for analysis was 30 August 2010. This data provides time, latitude, longitude, altitude, ADS-B identifier, and aircraft call sign (in most cases). The data is formulated as ADS-B reports

New York traffic data was taken from a full days' worth of arrivals and departures at New York's three major airports: John F. Kennedy (KJFK), Newark (KEWR), and LaGuardia (KLGA). The day represented (March 10, 2010) was the same demand set used for NextGen analysis. As with the Paris data, all flights were modeled using the Boeing 757 (757PW). Trajectory information was based on PDARS data from the New York area.

2) *Data Processing*

The Paris-area ADS-B data is formulated as ADS-B reports, but individual flights and trajectories must be constructed from these reports. We constructed these linked, flight-specific trajectories and separated them into arriving and departing flights based on the resulting altitude profiles. These flight trajectories were then cast into a format that can be processed by either the NIRS or AEM environmental models.

The ADS-B data did not contain aircraft type, nor did we have access to supplementary information that would enable systematic assignment of type to each trajectory. Consequently, we assigned the same aircraft type (B757) to all trajectories. The analysis thus performed is then analyzing CDO benefits and impacts associated with solely with traffic patterns, rather than the combined effects of aircraft type and traffic patterns. This enables us to focus on ATM-related effects, rather than a combination of ATM and fleet-composition effects.

The above process resulted in 1110 arrival trajectories and 1603 departure trajectories, a few of which were later discarded due to data anomalies inconsistent with actual flights. We then utilized an in-house data-analysis tool known at ADT (Airspace Design Tool) to assign trajectories to airport-specific runways. Neither the airport nor the runway used is present in the ADS-B data, but these must be present for the environmental modeling.

The raw trajectories are processed further to develop “backbones” that represent small groups of trajectories that are spatially similar. These backbones preserve the dispersion of trajectories and the numbers of flights on each trajectory. Additionally, trajectories for which ADS-B information does not align with actual runway locations is linked to the runways during the development of the backbones. After this process, the resulting number of backbones for CDG was 334 departure backbones and 279 arrival backbones. For ORY, there were 144 departure backbones and 121 arrival backbones.

The figures below show the results of the data preparation performed within ADT.

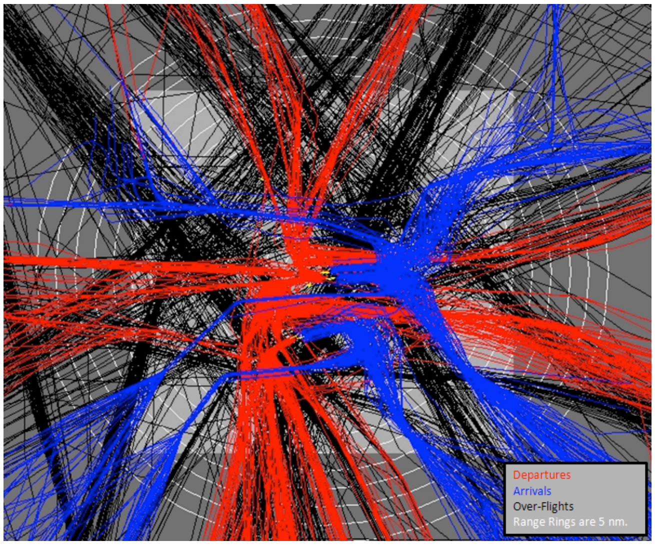

Figure 1: ADS-B Raw Data Displayed in ADT

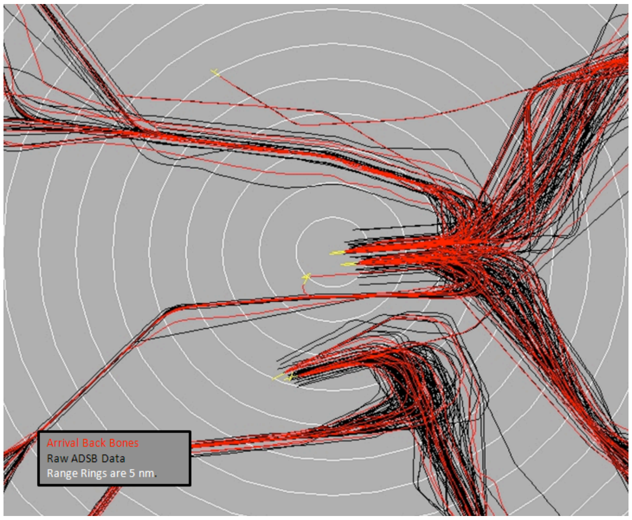

Figure 2: ADS-B Arrival Data (black) and Resulting Backbones Aligned with Runways (red)

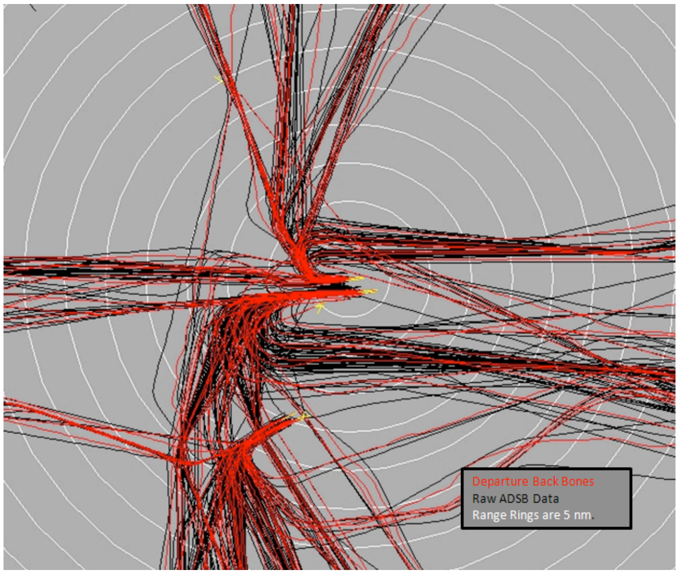

Figure 3: ADS-B Departure Data (black) and Resulting Backbones Aligned with Runways (red)

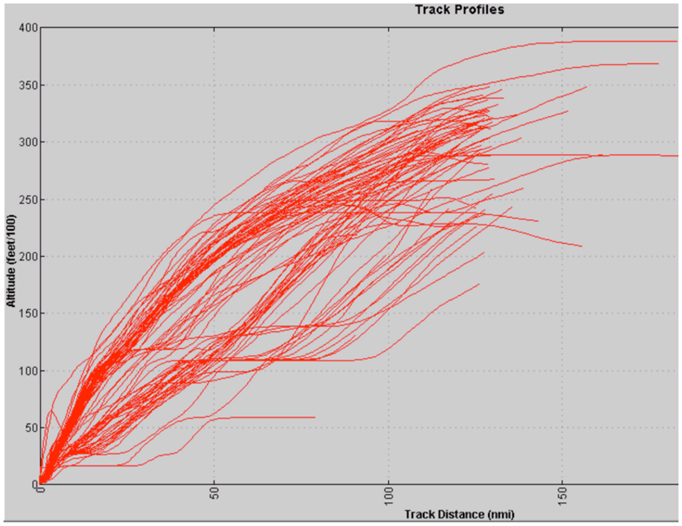

Figure 4: Profiles of Paris Backbone Trajectories After Processing in ADT

After the data-preparation step, all departing and arrival flights in the Paris data set were processed successfully by NIRS. A small number of flights in the New York demand set were not modeled due to invalid track data (Table 2).

TABLE 1: Modeled and Rejected Flights in the Traffic Demand Sets

	Departures		Non-CDA Arrivals		CDA Arrivals	
	Modeled	Rejected	Modeled	Rejected	Modeled	Rejected
New York	1736	20	1782	5	1787	0
JFK	573	0	595	0	595	0
EWR	615	17	633	0	633	0
LGA	548	3	554	5	559	0
Paris	478	0	400	0	400	0
CDG	334	0	279	0	279	0
ORY	144	0	121	0	121	0

Figures 5 through 7 below show the tracks at the three New York airports. Noise was computed against a single grid of points spaced 300 feet apart covering all the tracks (4.1 million points).

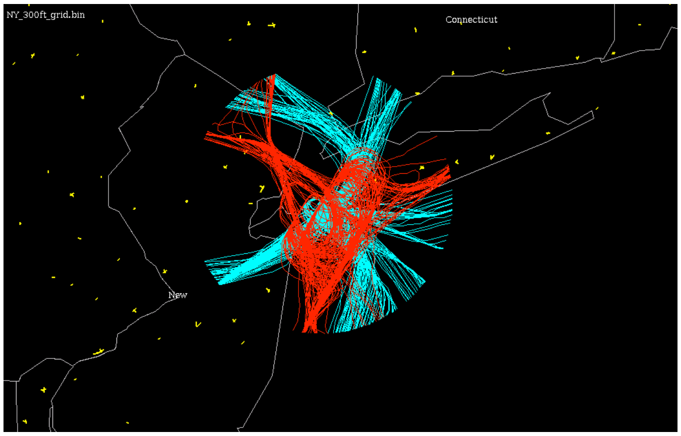

Figure 5: KJFK arrivals (red) and departures (blue)

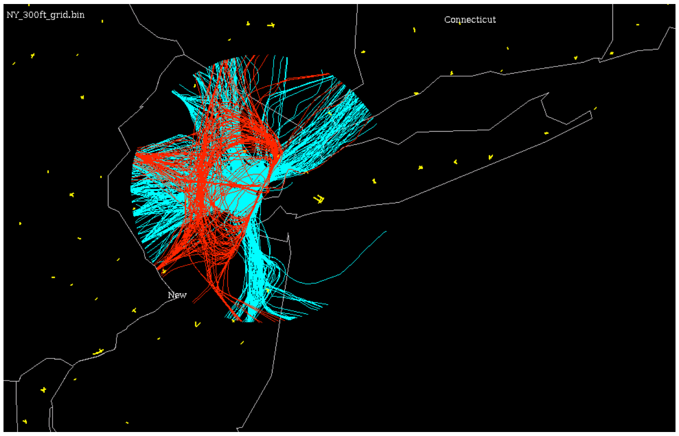

Figure 6: KEWR arrivals (red) and departures (blue)

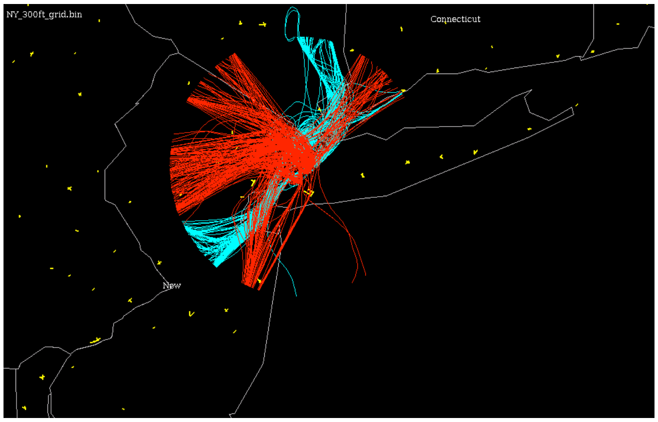

Figure 7: KLGA arrivals (red) and departures (blue)

Figure 8 shows the arrival and departure profiles for the Paris data. This data represents top of cruise to runway (about 100 nmi), thereby demonstrating the maximum theoretical benefit of a CDA.

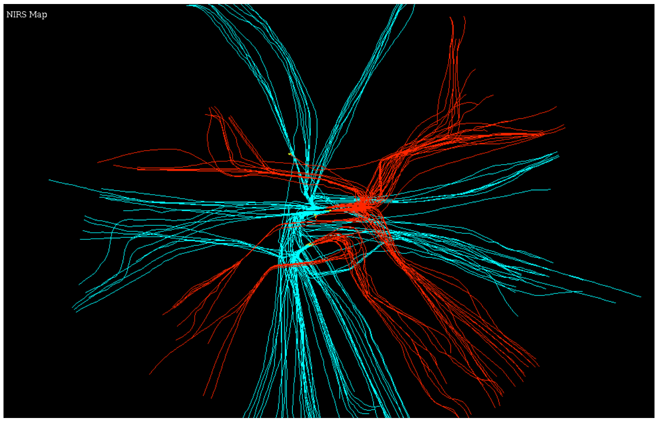

Figure 8: Arrivals (red) and Departures (blue) for LFPG (CDG) and LFPO (ORY)

3) *CDO Modeling*

The method employed here is a simplified version of the analysis conducted [12] for the NextGen program. It has been estimated that about 62% of the benefit of avoiding inefficient step-wise altitude changes occur in the TRACON-to-runway portion of the flight [13]. Multiplying this benefit by a factor of 1.3 can therefore give an estimate of the efficiency gained by eliminating vertical inefficiencies on the rest of the flight.

There are airspace limitations to executing an ideal continuous descent arrival. In a bounded CDA, a flight must descend within a limited slice of the airspace, as shown in Figure 9 [14].

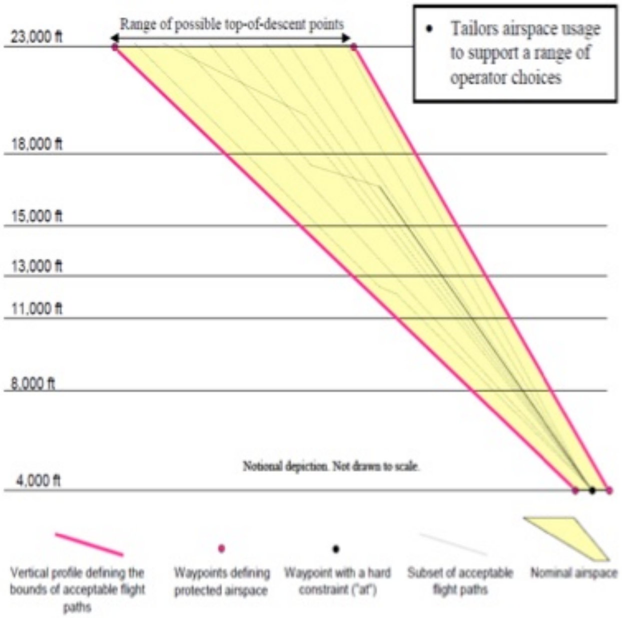

Figure 9: Bounded CDA example (source: Klein)

We estimated that a bounded CDA ought to provide about 80% of the benefit of an ideal CDA on average. So multiplying the calculated benefit by 0.8 will account for this limitation. The factors together, 1.3 * 0.8, result in a factor of 1.04. We believed this factor made a negligible difference on the benefit calculation, so decided to utilize the modeled TRACON-to-runway benefit as the optimized profile benefit for the whole flight.

For simplicity, this analysis looks at just the arrival portion of the flight. For the New York data, we modeled descent phase from TRACON to runway, about 40 nmi. The original altitude profile, which contains one or more level flight segments, is replaced with a continuous 3-degree descent. This allows the aircraft to fly at a higher altitude closer to the airport, and eliminates the need to throttle up the engines to level off from a descent. All flights were modeled successfully. Figures 10 and 11 show an example profile at JFK before and after the CDA is applied.

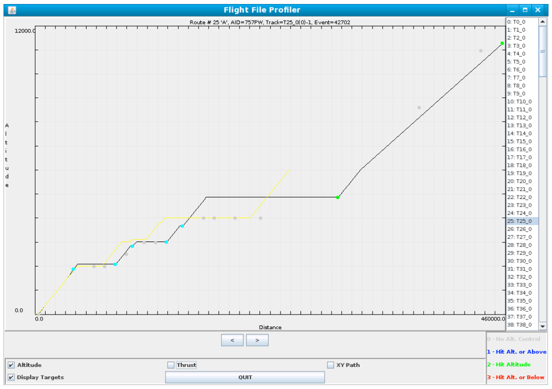

Figure 10: Example JFK arrival profile before CDA

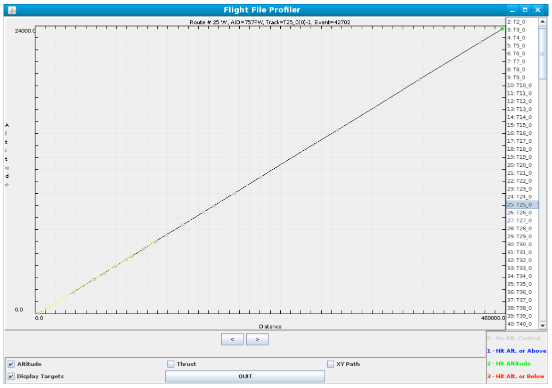

Figure 11: Example JFK arrival profile after CDA

For the Paris data, the radar-based trajectories we had available began further from the airport, up to about 100 mi. This allowed us to model the full descent from top of cruise using a continuous 3-degree descent. This allows the aircraft to stay at a higher altitude longer, maximizing the fuel benefit. These trajectories then represent the theoretical maximum benefit for a full CDA from top of cruise to the runway. Figures 12 and 13 show an example profile at CDG before and after the CDA is applied.

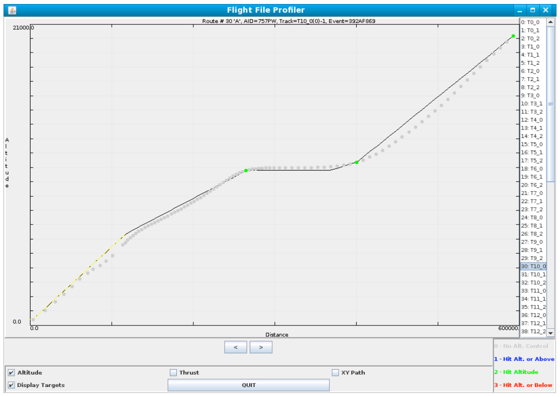

Figure 12: Example CDG profile before CDA

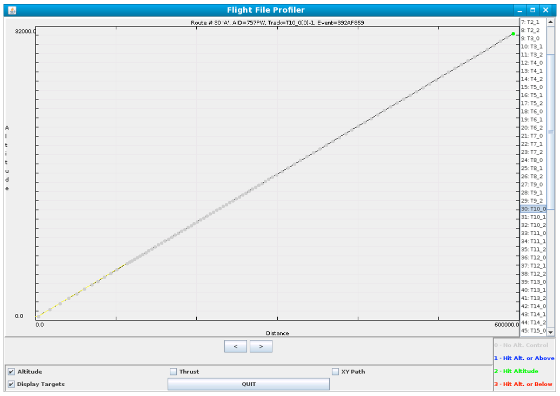

Figure 13: Example CDG profile after CDA

4) *Estimation of CDO Benefits Pool for Different Regions*

In order to understand how the magnitude of potential CDO benefits varies by region and by traffic associated with each airport, we analyzed the number and length of level segments in the trajectory data. This process consisted of the following principal steps:

a. Identify each segment having a descent angle less than a specified value (1.5 degrees) and above a specified altitude (1000 feet).

b. Calculate the length of each "level" segment and its average altitude.

c. Tabulate the total length across all flights of such "level" segments by altitude and length.

This was performed for flights at each of the Paris and New York airports, as summarized in the Table 2. From this analysis, we can conclude that:

a. In absolute terms, the benefits pool of potential fuel and noise impacts will be smaller for CDG and ORY since there are fewer flight-nm associated with level segments than at LGA, JFK, and EWR.

b. Additionally, the relative noise benefits will differ since there is a smaller percentage of level segments at low altitudes (e.g., 4000-8000 feet) for CDG and ORY, as compared with LGA, JFK, and EWR.

TABLE 2: Level-segment Total Lengths (flight-nm) and Percentage by Altitude (feet) for Paris and New York Airports

Alt (ft)	CDG and ORY		LGA		JFK		EWR	
	Flt nm	%	Flt nm	%	Flt nm	%	Flt nm	%
0-1K	0	0%	0	0%	0	0%	0	0%
1K-2K	59	1%	0	0%	80	1%	15	0%
2K-3K	399	5%	0	2%	1933	16%	437	2%
3K-4K	953	13%	2405	14%	4126	35%	3956	16%
4K-5K	26	0%	5828	34%	1856	16%	2563	11%
5K-6K	47	1%	48	0%	115	1%	5325	22%
6K-7K	148	2%	4218	25%	185	2%	11735	48%
7K-8K	0	0%	3816	22%	41	0%	178	1%
8K-9K	59	1%	356	2%	126	1%	2	0%
9K-10K	143	2%	97	1%	52	0%	18	0%
10K-11K	3121	43%	0	0%	207	2%	0	0%
11K-12K	18	0%	7	0%	11	0%	0	0%
12K-13K	123	2%	0	0%	79	1%	0	0%
>13K	2175	30%	0	0%	2938	25%	0	0%
Totals	7271	100%	16775	100%	11749	100%	24229	100%

We have learned recently of a EUROCONTROL tool that performs similar analysis of trajectory data. This tool, VPAT (previously called EFICAT), is being developed to assess flight profiles [15]. It allows statistical analysis of radar data including radar-corrected flight-plan information. One application within VPAT allows the analysis of level flight in both the descent and departure phases of flight. This has been developed specifically to assess the potential for implementing Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO) together with the potential environmental benefits. VPAT is linked to the BADA fuel and emissions database and is still under development.

B. *Environmental Impact Analysis*

We estimate the fuel, noise, and air-quality impacts associated with the change to CDO operations for the Paris and New York regions in the sections below.

1) *Fuel*

Using NIRS, CDA profiles saved 38% fuel compared to the original profiles for Paris airports (top of cruise to runway), and 51% for the New York schedule (TRACON to runway). Fuel results were computed by NIRS using BADA data for the arrival tracks and altitude profiles.

We also computed fuel for the same flights using AEM-III. The savings from CDA profiles was 35% for Paris airports, and 49% for the New York airports. For all airports studied, the percentage change in fuel consumed between CDA and non-CDA arrivals was very similar using either NIRS or AEM-III.

TABLE 3: Arrival Fuel Burn for CDA and Non-CDA Profiles

Apt	NIRS Fuel			AEM-III Fuel		
	Non-CDA Arrivals (kg)	CDA Arrivals (kg)	Change	Non-CDA Arrivals (kg)	CDA Arrivals (kg)	Change
New York	750,205	370,693	-51%	929,097	470,461	-49%
JFK	247,538	128,972	-48%	299,235	164,449	-45%
EWR	291,357	129,590	-56%	363,784	162,871	-55%
LGA	211,310	112,132	-47%	266,079	143,141	-46%
Paris	176,403	110,012	-38%	209,705	136,713	-35%
CDG	119,063	76,178	-36%	140,112	95,022	-32%
ORY	57,340	33,834	-41%	69,593	41,691	-40%

We note that total fuel computed by AEM-III was between 17% and 28% higher than that computed by NIRS. The input data for AEM was taken from the NIRS flight and traffic files, and each flight was distributed across the backbone tracks using the same weightings. A more detailed examination of the NIRS and AEM methods will be required to determine the causes of this difference. Potential causes include use of different engine types or adjustments to fuel estimates below 10Kft.

In addition, we performed similar calculations using a third model. The ICAO Fuel Estimation Tool (IFSET) was developed with the idea that it could be applied globally to determine the difference in fuel consumption before and after implementation of operational improvements at local, regional, or global levels [16]. IFSET is intended to calculate differences in fuel consumption between a baseline and an alternative scenario, but it is not meant to be used to compute absolute fuel consumption for a specific procedure. The tool is consistent with models approved by ICAO's Committee on Aviation Environmental Protection (CAEP).

Here, we used IFSET to compute differences in fuel burn from implementing CDAs. Since inputs into IFSET must be entered manually and therefore make evaluating large numbers of flights cumbersome, we only considered four individual flight operations: two at JFK (with and without CDA) and two at CDG (with and without CDA). Results from the IFSET calculations are shown in the table below, and compared to NIRS and AEM-III results for the same four flights. In all cases, the two JFK arrivals were modeled as B-757(PW) aircraft arriving from Monterrey (Mexico), while the two CDG arrivals were modeled as B-757 aircraft arriving from London Heathrow.

TABLE 4: Comparison of Four Flights in NIRS, AEM-III, and IFSET

Test Flights (2 each)	Model	Non-CDA Arrivals Fuel (kg)	CDA Arrivals Fuel (kg)	Chg
New York	NIRS	400	197	-51%
	AEM-III	506	331	-35%
	IFSET	700	300	-57%
Paris	NIRS	562	287	-49%
	AEM-III	773	419	-46%
	IFSET	800	400	-50%

We thus see that percentage changes vary more between models for this small set of four flights than they do for larger aggregates of flights, while total fuel varies quite substantially. Both of these effects merit further investigation.

On a per flight basis, the results in Tables 1 and 3 give average fuel savings per flight for the New York traffic of approximately 213 kg and 257 kg using NIRS and AEM-III, respectively. For the Paris traffic, the corresponding averages are approximately 165 kg and 182 kg for NIRS and AEM-III. From Table 4, albeit from a very small set of four flights, it would appear that IFSET calculates average savings per flight of approximately 200 kg for both New York and Paris flights.

2) Noise

We used NIRS to assess the noise impact of the CDA profiles. The CDA profiles resulted in lower noise, but the reduction was rather small. Only the regions where there was a significant difference in altitude before and after the CDA showed much difference in noise impact. These areas, farthest from the airport, already had a low level of noise in the Non-CDA profiles, typically less than 50 dB DNL. Figure 14 shows the LDN (or DNL) contours around De Gaulle and Orly airports, before applying the CDA. The contours with the CDA look nearly identical, so the minor changes that are evident in the outer edge of the contours are show in Figure 15. Nearly all of the changes larger than a few tenths of a decibel occurred in the areas between 45 and 50 dB DNL.

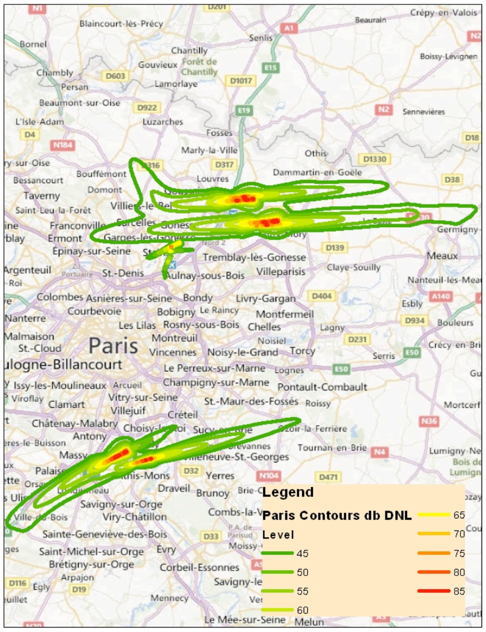

Figure 14: Paris Noise Contours (Non-CDA)

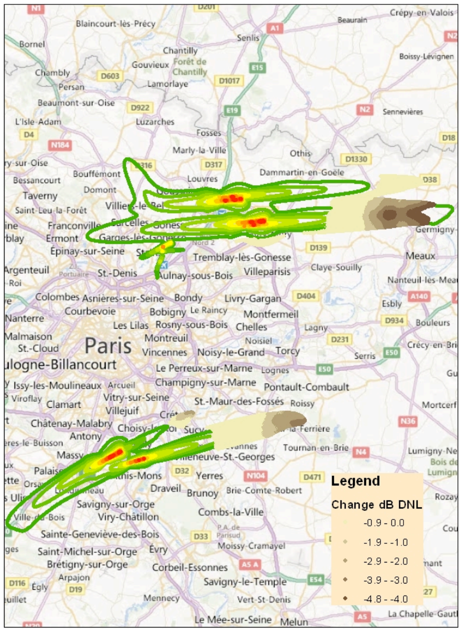

Figure 15: Paris Noise Contours With CDA Changes

For the New York airports, the noise impact followed a similar pattern. Only the areas far from the airport showed a change, and the change was small. The New York data set had more flights, so there were more points showing a change of at least 0.1 dB between the CDA and Non-CDA cases. Figure 16 shows the New York contours before the CDA, and Figure 17 shows the areas with a change in DNL.

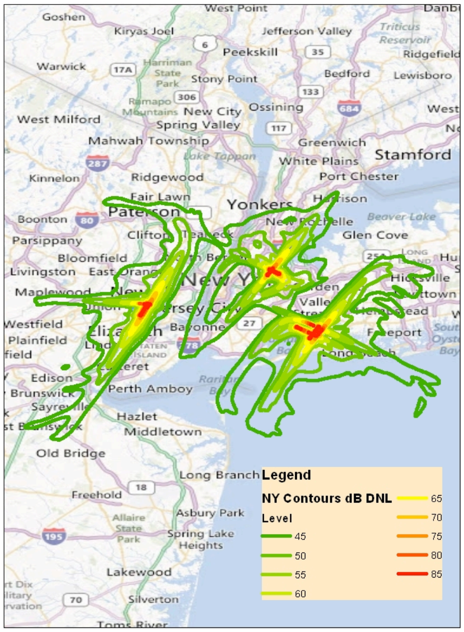

Figure 16: New York Noise Contours Before CDA

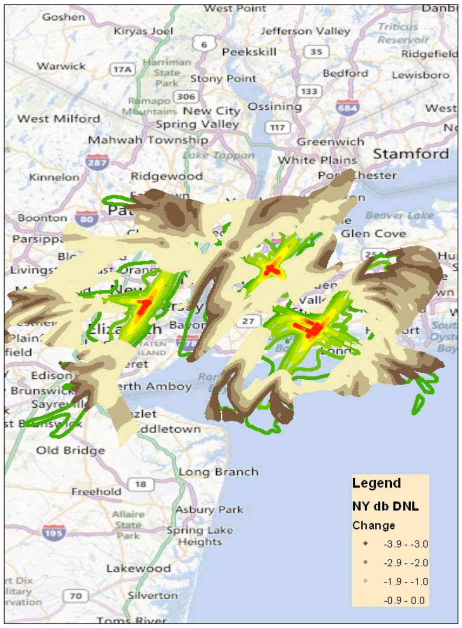

Figure 17: New York dB DNL Change with CDA

The contours described above can also be used to calculate noise impacts in terms of population totals exposed to different levels of DNL. For this study, we did not make these calculations since we do not have access to French census data at the required level of granularity.

3) Local Air Quality Emissions

The CDA profiles produced 24 percent less NOx than the original profiles for the Paris data, and 51 percent less for the

New York data, as shown in the table below. As in the fuel analysis, all flights used the B-757(PW) and only the arrival portion of the flight (from 40 nmi out to the runway). The NOx was computed using NASEIM, which uses fuel flow rates and emissions factors from the ICAO Emissions Databank and is consistent with the EDMS model. Taxi NOx was not included, but it would be the same for both the CDA and non-CDA cases since taxi fuel and emissions occur on the ground.

TABLE 5: Arrival NOx for CDA and Non-CDA Profiles

	Non-CDA Arrivals	CDA Arrivals	Change
	NOx (kg)	NOx (kg)	
New York	11,407	5,616	-51%
JFK	3,414	1,862	-45%
EWR	4,613	1,990	-57%
LGA	3,380	1,764	-48%
Paris	1,624	1,234	-24%
CDG	1,165	862	-26%
ORY	459	372	-19%

III. CONCLUSIONS

In order to better understand SESAR and NextGen metrics and models for environmental impact assessment, this paper has analyzed the differences in effects of a selected ATM improvement (CDO/CDA) on European and U.S. performance using similar regional data sets and the same analytical methods and models.

Our principal conclusion is that absolute and relative CDO/CDA benefits differ substantially for the Paris and New York regions due to significant differences in current traffic intensity, as well as the current distribution of level segments in flight trajectories. The effects estimated focus only on ATM-related trajectory changes, with fleet-composition effects removed from the analysis. This conclusion is reinforced by the use of very similar assumptions, data, and methods in the analysis.

The relative values of environmental benefits determined from detailed modeling of fuel, noise, and air-quality impacts are consistent with analysis of current traffic patterns in the Paris and New York areas with regard to the frequency and duration of level segments, as well as the altitudes at which they occur.

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AUTHOR BIOGRAPHIES

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APPENDIX A – SUMMARY COMPARISON OF STUDIES WITH REGARD TO KEY ASPECTS OF ENVIRONMENTAL IMPACT ASSESSMENT [12]

Study and Opn. Imp.	Scope	Data Sources	Metrics	Methods	Top-level Results
Alcabin, *et al*, generic CDA w/o level segments [2]	61 and 41 arrivals at two major U.S. airports; results extrapolated to 35 major U.S. airports; 3 representative aircraft used as basis	Publicly available track and fleet data; Boeing fuel model	Excess fuel per flight; excess fuel per year at top 35 U.S. airports	Boeing fuel estimators used to generate fuel/nm as function of altitude; excess fuel calculated based on altitudes in actual and CDA-like profiles	CDA impact in range of 2-3% system-wide fuel savings at top 35 U.S. airports
Robinson, *et al*, CDA (OPD) [1]	25 major U.S. airports; four month period of analysis covering 480,000 flights; single point in time (2010)	Non-public FAA radar-based data for track and fleet.	Fuel savings per flight; percent fuel savings per year at top 25 U.S. airports	BADA (adjusted for cruise, speed, and flaps) used for fuel calculations; uncongested and congested conditions emulated	CDA impact ~3% fuel savings for aggregate of 25 major U.S. airports; large uncertainty due to airport and aircraft conditions in practice
Thompson, *et al;* CDA(OPD) and RNP [3]	55 major U.S. airports; single day of traffic; two demand levels (2025 lower capacity, 2025 higher capacity)	Non-public FAA radar-based data for baseline track and fleet; non-public FAA future demand and fleet estimates; model-based OPD/RNP trajectories.	Fuel/CO$_2$ (aggregate mass), noise (population exposed to 65/55 dB LDN levels), and NOx (aggregate mass) below 3000 feet	NASEIM and NIRS tools using ICAO Emissions Databank, BADA, and standard noise-modeling techniques	Fuel savings of ~60kg per flight; for U.S. system-wide future impact, total fuel and CO$_2$ increased slightly due to increased capacity in CDA/RNP scenario; in same scenario, population exposed to 65 dB DNL increased slightly due to RNP focussing effects and increased traffic; NOx below 3000 feet unaffected
Wubben, *et al;* CDA (OPD) [6b]	One major European airport; 2 aircraft types, 10 arrivals each	Non-public carrier-provided FMS data.	Fuel (aggregate in last 45 km) and noise (65 dB contour area).	Fuel flow and trajectory data from FMS; noise NPD data source not specified.	Fuel in last 45 km decreased by ~60 kg for B737 and ~400 kg for B747; ~30-40% reduction in 65dBA contour area.

Study and Opn. Imp.	Scope	Data Sources	Metrics	Methods	Top-level Results
Graznow, *et al;* CDA (OPD) [6a]	One European airport.	Airport data.	Fuel (aggregate in arrival phase); noise levels observed as function of aircraft altitude.	Fuel method not discussed; noise monitoring.	At Cologne/Bonn, ~3000 tonnes fuel saved per year; noise levels reduced by ~2dB
SOURDINE II; CDA (OPD) [5]	2 high-traffic European airports, 1 medium- and 1 low-traffic; 4 different CDA procedures.	Model-based trajectories; 2 aircraft types for single-event analysis; 12 types for airport-level analysis	Noise (contour area and population exposed); emissions of NOx, CO, unburnt HC below 3000 feet	Airbus noise model (NLCP); INM (tailored)	~30% reduction in Lden noise-contour area; Best procedure showed 30-40% reduction in NOx below 3000 feet and neutral for CO and unburnt HC, other procedures gave mixed results.
OPTIMAL; CDA (OPD) and RNP [4]	"Nominal" and "optimized" CDA procedures at several European airports	In some cases, flight-trial for one aircraft type used to model noise reductions.	Along-track noise levels; noise contours	Airbus noise model (NLCP); INM (tailored); LEAS-IT (emissions); details not publicly-available	At Schiphol, 21% reduction in noise-contour area for Lden above 48B, 10% reduction above 58dB, and CO_2 reduction of ~12%. For the generic airport, Lden contour areas reduced by ~24-43%.
AIRE-II Trajectory-based CDAs at Schiphol [7a]	1 high-traffic European airport; 0400-0600 period; 3-day trial results annualized	FMS, simulation	Annual fuel savings; fuel savings per flight.	Time saved is estimated and weighted fuel rate is used to obtain daily fuel savings from trials. These are averaged and multiplied by 365. Fuel/flight savings treated similarly.	Schiphol annual fuel savings ~500000 kg (if every night saves time as determined in 3-day trial); fuel savings per flight ~74 kg
AIRE-II RETA-CDA2 [7b]	1 European TMA and surrounding ACCs; 5 aircraft types	FMS and FOQA	Qualitative comparison of fuel use.	Fuel usage evidently based on FMS and FOQA data.	Qualitatively, CDA flights used less fuel