Constraints in aviation infrastructure and surface aircraft emissions

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1) Abstract

Air transportation growth and capacity constraints in the United States national airspace system (NAS) have resulted in increasing congestion in airways and terminal areas. This study discusses the growth in aviation emissions from ground operations in the United States from 1995 to 2000 and investigates the potential for emissions reductions by comparing actual emissions to those under several scenarios: improved operations, single-engine taxiing and towing aircraft between gate and runway. Unlike previous efforts, emissions estimates are not based on fleet averages and schedules but are based on actual mission times and aircraft types from the *Airline Service Quality Performance* (ASQP) data, that is compiled by the US Department of Transportation (DOT) using information provided by the ten largest US carriers. Results indicate that surface emissions have been growing faster than airborne operations or total mission time in domestic US aviation and may therefore become a constraint to airport expansion. The potential for emissions reductions through improved ground operational performance and single-engine taxiing is significant. The net environmental benefits from using tow trucks are not clear and should be investigated further.

2) Local and global impact of aircraft emissions

Air transportation is a significant source of pollution that impacts both local air quality and the global climate. Aircraft emissions include carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), sulfur oxides (SO_x), and particulates. Local air quality is affected, for example, by CO and NOx which are precursors of tropospheric ozone, a toxic compound. Furthermore, NOx's are a key ingredient of smog and of acid rain, which aggravates asthma and affects forests and wildlife, respectively. On the other hand, tropospheric ozone as well as CO_2 are greenhouse gases which contribute to global climate change. According to a 1999 report by the Intergovernmental Panel on Climate Change (IPCC) [IPCC], air transportation accounted for 3.5% of the total accumulated anthropogenic radiative forcing of the atmosphere in 1992. This is estimated to increase to as much as 12.2%, by 2050.

Air transportation has experienced substantial growth over the past 2 decades and this trend is expected to continue in years to come. Passenger traffic on scheduled airlines has increased by 60% in the past 10 years and forecasts indicate a 5% per year growth rate for the next 10 to 15 years [IPCC]. The aviation sector consumes approximately 13% of the total fossil fuel used in transportation, which corresponds to roughly 2-3% of the total fossil fuels used worldwide [IPCC]. Given the strong growth trends in air transportation, the aviation sector will increasingly become an important source of GHGs and its impact on local air quality and global climate change is expected to increase in the future.

Air transportation growth and capacity constraints in the United States national airspace system (NAS) have resulted in increasing congestion in US airways and terminal areas. The system has been experiencing mounting delays and increased taxi times with an associated growth in local air quality impact from aircraft surface emissions [EPA, 1999]. Concerns over local air quality can become a pressing constraint on airport operations. For example, Boston's Logan airport has recently fallen under heavy criticism for being one of Massachusetts largest smog producers and airport authorities are being requested to find solutions to this problem [Boston Globe].

This study discusses the increase in aviation emissions from ground operations in the United States from 1995 to 2000 and investigates the potential for emissions reductions from operational measures.

3) New methodology to support aircraft surface emissions reduction policy

Two fundamental alternatives to reduce aviation emissions are to increase stringency on the allowed emissions levels or to improve the operational performance of the air transportation system. The former addresses primarily the technological aspect of aviation, namely engine and aircraft design. Stricter emissions standards would force equipment manufacturers to improve the design of both powerplants and airframes. The latter addresses how this technology could be used more efficiently. For example, current research at the Massachusetts Institute of Technology (MIT) on the Departure Planner (DP) concept supports the development of decision-aiding systems to assist air traffic controllers in improving the performance of departure operations at major congested airports [Anagnostakis]. The design of such systems is expected to increase the overall efficiency of terminal area operations, maximize system throughput, minimize taxi time and yield benefits for all stakeholders involved in Air Traffic Management (ATM) operations, users as well as service providers.

Policy-making requires understanding of how and where emissions are being generated and how these are expected to change in the future. Current models make use of many assumptions that increase the uncertainties in their forecasts. For instance, aircraft trajectories are usually modeled as ideal great circle routes, traffic is inferred from scheduled information provided in sources such as the Official Airline Guide (OAG) instead of using actual mission times and fleet averages are used to determine aircraft performance [Baughcum; FAA-SETA]. Constraints due to weather or traffic delays, for example, are only accounted for in general terms. While these models have been valuable for understanding the magnitude and extent of aircraft emissions and to infer possible future scenarios, in order to plan and implement effective policies, more detail is necessary to pinpoint inefficiencies in the system and identify options with the greatest potential for emissions reductions.

In this paper, a new methodology is used to evaluate the potential for ground emissions reductions through operational measures. This methodology is based on the *Airline Service Quality Performance* (ASQP) data, which contains reported airline information to the US Department of Transportation (DOT) from the ten largest US carriers. This database provides several pieces of information for every flight in the domestic US market, including actual mission time and aircraft tail number. Thus, it provides a basis to calculate emissions without the need to approximate schedules or fleet averages.

This study has two primary goals. First, to identify the distribution and growth rate of ground and airborne emissions of CO, NOx and CO_2. The purpose is to assess the historical trends of pollution from ground operations that have a direct impact on local air quality. Emissions during take-off and portions of climb, descent and approach also impact local air quality. However, these are not taken into account here given difficulties to accurately model these flight stages. The second goal is to illustrate the potential for ground emissions reductions by comparing actual emissions to those under several scenarios: improved operations (e.g. Departure Planner), single-engine taxiing and towing aircraft to and from the runway. The paper focuses on all domestic flights of the top 10 US carriers for the month of July of every year between 1995 to 2000. This month was chosen because it has traditionally been among the busiest months of the year in terms of air traffic.

4) Calculation of airborne and surface emissions

4.1) ASQP-based methodology to calculate aircraft emissions

The ASQP data provides the number of operations at each airport and for each flight, it includes taxi time, airborne time and aircraft tailnumber. Emissions of a given pollutant per mode (i.e. taxi-out, take-off, climb, cruise, descent, approach and taxi-in) are calculated by multiplying time-in-mode (TIM) by the mode-specific fuel flow coefficient and the mode-specific emission index (EI) of the aircraft/engine combination flying that mission (see Eq. 1). Total emissions for a given pollutant is the sum of all modes over all flights (see Eq. 2). Tail number information from the ASQP database is matched with specific aircraft types with the *JP Airline Fleet International Directory* [Bucher]. This register contains a listing of aircraft of most airlines in the world linking tail numbers to airframe models and number and type of engines. Mode-specific fuel burn coefficients and emission indices for each engine type are obtained from the *ICAO Engine Performance Database* [ICAO] and other sources [Baughcum; Lee; Olivier]. Note that EI for CO2 (EI_{CO2}= 3155 g/kg_{fuel}) is mode independent and only a function of fuel burnt [Baughcum].

$$E_{ijk} = TIM_j \cdot FF_{coefficient} \cdot EI_k \qquad \text{(Eq. 1)}$$

where,

E_{ijk}: emissions of pollutant k in mode j for flight i, [g]

TIM_j: time-in-mode j, [s]
$FF_{coefficient}$: mode-specific fuel burn coefficient, [kg/s]
E_k: emissions index for pollutant k, [g/kg$_{\mathrm{fuel}}$]

$$E_{total\_k} = \sum_{allflights} \sum_{all\,modes} E_{ij} \qquad \text{(Eq. 2)}$$

where,

E_{total_k}: total emissions of pollutant k, [g]

The time data in the ASQP database is divided into two large blocks: ground (taxi-out and taxi-in) and airborne time. Consequently, emissions for the ground segments can be calculated directly, whereas emissions for the airborne segments can not be determined unless some approximations are made. Therefore, aircraft ground and airborne emissions will be treated separately.

4.1.1) Actual aircraft ground emissions

The ASQP data provides actual taxi times and tailnumber information for all flights considered. Therefore, actual ground pollution is calculated with Equations 1 and 2, as explained above.

4.1.2) Actual airborne emissions

Actual airborne emissions can not be calculated directly from the ASQP data because time information is not divided into the different airborne mission segments (take-off, climb-out, cruise, descent and approach). By using aircraft performance data and a series of approximations for take-off and cruise time, however, it is possible to divide total mission time in three parts: take-off, cruise, and a portion called *terminal area operations (TAO)*, which contains climb-out and descent and approach plus any inefficiencies in terms of time not covered in take-off or cruise (Equation 3).

$$T_{air(actual)} = T_{take-off(actual)} + T_{cruise(actual)} + T_{TAO} \qquad \text{(Eq. 3)}$$

where,

$T_{air(actual)}$: actual airborne time, [s]
$T_{take\text{-}off(actual)}$: actual take-off time, [s]
$T_{cruise(actual)}$: actual cruise time, [s]
T_{TAO}: actual terminal area operations time, [s]

Once this time distribution is determined, airborne emissions are determined with Equations 1 and 2. For terminal area operations, two cases are considered. In the first, fuel flow coefficients and emissions indices for climb-out are used. This constitutes an upper bound on fuel consumption, CO_2 and NOx, since fuel burn coefficients and NOx EIs during climb-out are larger than during cruise, descent or approach (see Table 1). In the second case, cruise fuel flow coefficients and emission indices are considered. This represents a lower bound on fuel consumption, CO_2 and NOx, since cruise fuel flows and

NOx EIs are smaller than during climb-out and slightly smaller than during descent and approach. For CO, the opposite is true: climb EIs are smaller than cruise EIs.

Table 1. Effect of different assumptions for fuel flow coefficients and EIs on TAO calculations.

	Calculations using climb fuel coeff. and EIs	**Calculations using cruise fuel coeff. and EIs**
TAO Fuel burn	Upper bound	Lower bound
TAO CO_2	Upper bound	Lower bound
TAO NOx	Upper bound	Lower bound
TAO CO	Lower bound	Upper bound

4.1.2.1) TIMs for actual airborne fuel consumption calculation

Terminal area operations time can be determined by subtracting actual take-off time and actual cruise time from actual flight time (Equation 4):

$$T_{TAO} = T_{air(actual)} - T_{take-off(actual)} - T_{cruise(actual)} \qquad \textit{(Eq. 4)}$$

In order to determine actual take-off and actual cruise time, a series of approximations must be made. First, baseline take-off, climb, cruise, descent and approach times are found. Then, actual take-off and actual cruise times are determined based on the baseline times.

Airborne baseline times

In order to determine airborne baseline times, the following mission profile was used (see Figure 1). It assumes great circle trajectory, direct climb to cruise altitude and unrestricted descent and approach following the aircraft's nominal operating parameters. It is not affected by congestion around terminal areas or by delays of any type. It approximates what an aircraft might do given the ability to fly directly between origin and destination and perfect scheduling at airports and terminal areas to avoid congestion.

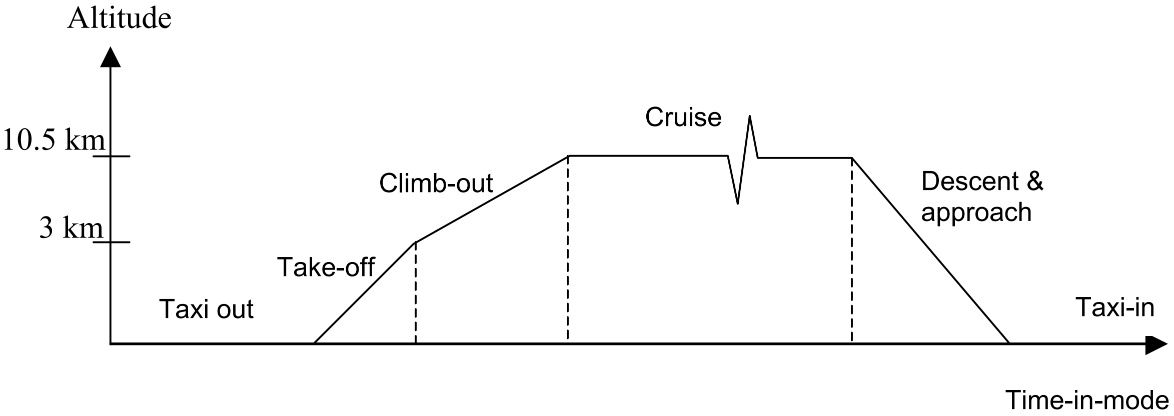

Figure 1. Assumed mission profile (not to scale).

Take-off is assumed to cover 0-3 km, climb-out between 3-10.5 km, cruise altitude is 10.5 km and descent and approach is from 10.5 – 0 km. Time-in-mode (TIM) for take-off, climb and descent for every mission can be calculated from take-off rate, rate of climb (ROC) and rate of descent (ROD) data for every aircraft provided in the *BADA Aircraft Performance Database* [Eurocontrol]. Baseline cruise time for every route was determined by taking the 15th percentile of the distribution of airborne times for each route and subtracting the corresponding baseline take-off, climb-out and descent times (see Equation 5):

$$T_{cruise(baseline)} = 15^{th} T_{airborne(actual)} - T_{take-off(baseline)} - T_{c\lim b(baseline)} - T_{descent(baseline)} \qquad \textit{(Eq. 5)}$$

where,

$T_{cruise(baseline)}$: baseline cruise time, [s]
$15^{th} T_{airborne(actual)}$: 15th percentile of distribution of actual airborne time for every route, [s]
$T_{take-off(baseline)}$: baseline take-off time, [s]
$T_{climb(baseline)}$: baseline climb time, [s]
$T_{descent(baseline)}$: baseline descent time, [s]

Actual airborne times

Take-off is usually a small portion of the flight mission and it can be assumed that for the first few minutes of flight, the ascent is governed by aircraft performance and is influenced little by conditions at the originating airport. Therefore, knowledge on aircraft performance allows the calculation of take-off time for every mission independent of where it started from. This assumes further that take-off time is not likely to be affected by delays or other inefficiencies in the system. Thus, actual take-off time can be assumed to be equal to take-off time under the baseline scenario.

Similarly, actual cruise time was taken to be equal to baseline cruise time. Literature shows that savings during cruise from flying great circle routes is on the order of 6% [IPCC; FAA-SETA]. Therefore, since fuel burn is proportional to cruise time, this means that actual cruise time is approximately 6% longer than baseline cruise time. By assuming actual cruise time equal to baseline cruise time all the cruise inefficiencies in terms of time are being captured by TAO time. Depending on the choice of mode-specific fuel flow coefficients and EIs, this assumption leads to lower or upper bounds in fuel burn and emissions, according to Table 1.

Consequently, TAO time is calculated as follows:

$$T_{TAO} \approx T_{air(actual)} - T_{take-off(baseline)} - T_{cruise(baseline)} \qquad \textit{(Eq. 6)}$$

Once take-off, cruise and TAO time are known, airborne emissions are calculated with equations 1 and 2.

4.1.3) Sources of Uncertainty:
There are some records on the ASQP database for which no time information is known. These include approximately 1.5% of the total number of records for every July. In addition, 2.8% of tailnumbers could not be matched. In those cases, an average of the known aircraft types for the given route was assumed. For a small number of engine models (approximately 4%), performance characteristics were not known and had to be inferred from similar powerplants. Likewise, information for certain aircraft types was not present in BADA and had to be inferred from similar types.

5) Results of airborne and surface emissions analysis

Total number of operations and total mission time in domestic US aviation have grown considerably during the last 6 years, as evidenced in the percentage growth from July of 1995 to July of 2000 (see Figure 2). Notice that the increase in taxi-out and taxi-in times has been larger than airborne time, total mission time and total number of operations.

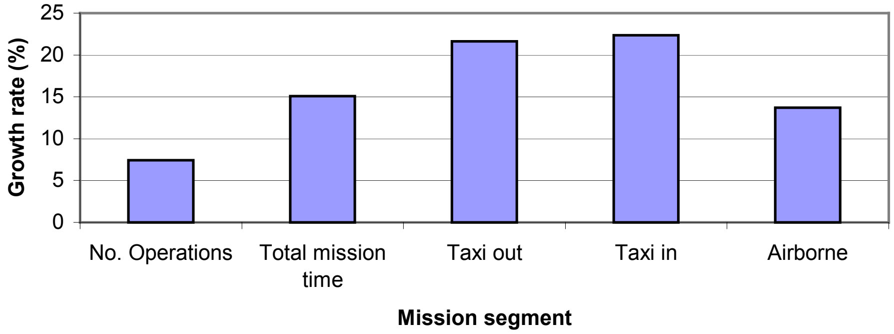

Figure 2. Growth rates in US domestic aviation comparing data for July of 1995 with data for July of 2000.

The large increase in taxi time is also reflected in a larger growth rate of surface fuel burn and surface CO_2 and NOx emissions compared to the growth rate in airborne fuel burn and CO_2 and NOx emissions (see Figure 3). Only the increase of CO emissions has been smaller on the ground than in the air. Notice that these observations are valid for both cases assumed to calculate airborne emissions (i.e. using climb-out fuel flow coefficients and emission indices and cruise fuel flow coefficients and emission indices).

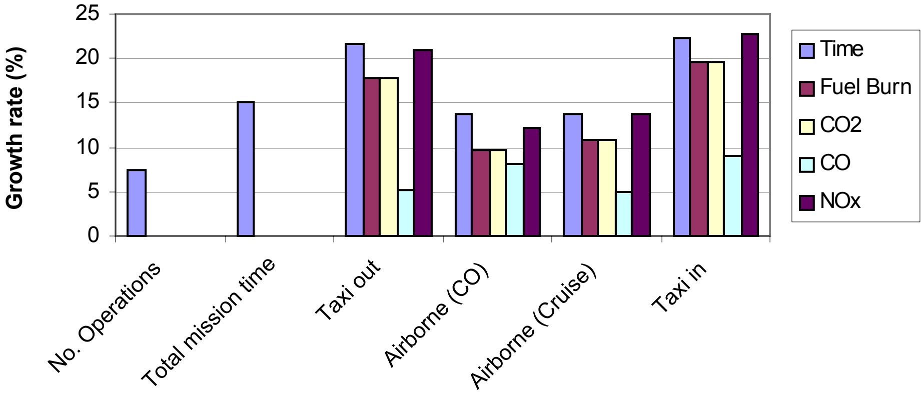

Figure 3. Fuel burn and emissions growth rates in US domestic aviation comparing data for July of 1995 with data for July of 2000. The figures for Airborne (CO) and Airborne (Cruise) refer to the scenarios in which climb-out fuel flow coefficients and emission indices and cruise fuel flow coefficients and emission indices were used, respectively.

Figure 4 shows the percentage distribution of mission time in taxi-out, airborne and taxi-in time. Ground operations are still a small portion of the total flight mission. Consequently, surface emissions constitute a small fraction of total aircraft emissions, but their relative growth has been greater.

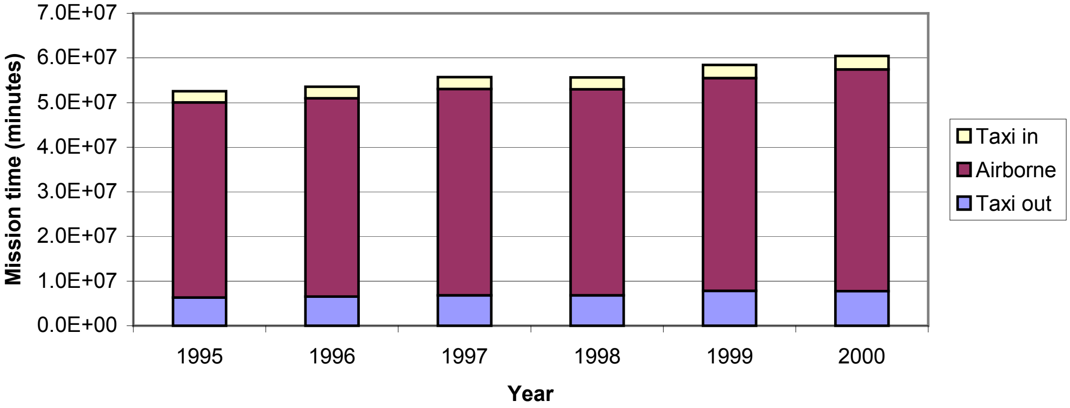

Figure 4. Distribution of total mission time between ground and airborne segments for US domestic aviation in July of the indicated year (1995-2000).

6) Surface emissions reduction strategies

The purpose of this study is to investigate the *potential for emissions reductions* through a series of different strategies and to identify those with the greatest potential benefits. Implementation considerations, such as cost, maintenance and re-fueling logistics, are not considered at this point.

6.1) Improved operations

This scenario represents the potential benefits from organizing aircraft surface movements so that there are minimal delays in travel from the gate to the runway and vice-versa. This approximates what a tool like the Departure Planner may be able to achieve. First, the distribution of taxi out and taxi in times between 11pm and 5am at every airport is determined. Then, the 15th percentile of each distribution is taken. It is assumed that ground congestion is minimal at those times of the night and therefore the taxi times represent the uninterrupted travel time between runway and gates. Gate and runway configuration/usage vary throughout the day and therefore this base case does not necessarily give an unbiased representation of minimum taxi out and taxi in times at each airport. However, it does illustrate a possible improved operational scenario from many that can be chosen. Once the baseline taxi times are determined, emissions are calculated with Equations 1 and 2.

6.2) Single-engine taxiing

Thrust requirements during taxiing maneuvers are low and therefore aircraft do not need to have all engines running while on the ground. The assumptions of this strategy are as follows [CARB]:

a) Number of engines shut-down during taxiing:

Table 2. Number of engines shut-down during single-engine taxiing according to the number of engines per aircraft.

Number of engines per aircraft	**Number of engines shut down**
2	1
3	1
4	1

b) All engines work for at least five minutes during taxi-out for warm-up and for at least five minutes during taxi-in for cool-down.

To calculate emissions, actual taxi times from the ASQP database are used. According to the assumptions above, for each mission, all engines operate for five minutes during taxi-out and taxi-in. The remaining time, the aircraft operates with the reduced number of engines according to Table 2. Equations 1 and 2 are used to determine the emissions.

6.3) Towing aircraft from/to the runway

Tow trucks are currently used for push-back and for moving aircraft around terminal areas, but they are seldom utilized to bring aircraft to/from the runway. Since aircraft engines are optimized for cruise altitudes, there may be environmental benefits from using tugs for surface operations. The purpose of this study is to evaluate the emissions reductions potential from utilizing tugs. Therefore, calculations are focused on determining the amount of pollution generated by tow trucks *without further logistic considerations such as increased traffic congestion on the tarmac due to the presence of* *additional tugs*. Four types of tow trucks are being considered in this study based on their operating fuel: gasoline, diesel, existing compressed natural gas (CNG) and original engine manufactured (OEM) optimized CNG.

Emissions from tow trucks depend on operating time, engine horsepower and fuel-specific factor index (see Eq. 7):

$$E_{ij} = Time \cdot BHP \cdot EF_j \qquad \textit{(Eq. 7)}$$

where,

E_{ij}: emissions of pollutant j for mission i, [g]
Time: tow time, [hr]
BHP: engine horsepower, [bhp]
EF_j: fuel-specific emission factor for pollutant j, [g/bhp hr]

The following assumptions were made to determine use time, engine horsepower and emissions factors:

1) Tow time

Tow truck specifications were obtained from Douglas Equipment Limited (DEL) to benchmark the performance of these vehicles [Douglas]. Their trucks, also known as "super tugs", operate on diesel and are in use in many US airports. Since manufacturer information for other types of tugs (i.e. gasoline, CNG and OEM optimized CNG) was unavailable, the top speed for the super tugs was also assumed for these. The following table shows relevant information about the DEL tow trucks:

Table 3. Specifications for two tow trucks manufactured by Douglas Equipment Ltd.

Tug model	Aircraft that can be handled	Fuel	Top speed (towing)	Engine horsepower
			kph	bhp
TBL-200 Tugmaster	DC9, MD80, B737, B727, A300, B767	diesel	21	125
TBL-400 Tugmaster	A310, A330, L1011, DC10, B777, B747	diesel	16	400

Several studies identify average aircraft taxi times to be within 16 and 20 knots (30 and 37 kph, respectively) [BAAPS; Lasswell]. Compared to the TBL-200, aircraft taxi with their own power approximately 40-75% faster, and compared to the TBL-400, the difference increases to 85% to 130%. Therefore, in order to account for the slow speeds of the tugs, the emissions calculations multiply taxi times by a factor of 2.5. This is a conservative estimate to account for differences in the performance of other types of tugs and to cover other time inefficiencies, such as time spent docking and undocking aircrafts to the tugs.

2) Engine horsepower

Engine horsepower for different generic types of tugs are given in Table 4 [CARB; EPA, 1995]:

Table 4. Engine horsepower for different generic types of tugs.

Equipment type	Engine type	Engine horsepower
		bhp
Aircraft tug (narrow body aircraft)	Diesel	175
	Gasoline	130
	CNG and OEM CNG	130
Aircraft tug (wide body aircraft)	Diesel	500
	Gasoline	500
	CNG and OEM CNG	500

In general, engine horsepower for both the narrow body aircraft and wide body aircraft tugs given in Table 4 are larger than the manufacturer information given in Table 3. Therefore, engine horsepower values from Table 4 were used to determine emissions from tow trucks.

3) Tow trucks emissions factors

The following fuel specific emissions factors were assumed (no data was available for CO_2) [CARB; EPA, 1995]:

Table 5. Fuel-specific emissions factor used in this study.

Engine type	Emission factor (g/ bhp hr)	
	NOx	CO
Diesel	11.0	4.0
Gasoline	4.0	240.0
Existing CNG	6.0	120.0
OEM optimized CNG	3.5	2.1

7) Results of aircraft surface emissions reductions analysis

The potential for surface emissions reductions from the different strategies considered is illustrated below. Figure 5 shows the potential NOx reductions during taxi-out. All of the options, except for the diesel tugs, result in less emissions compared to the aircraft engines operating at current conditions.

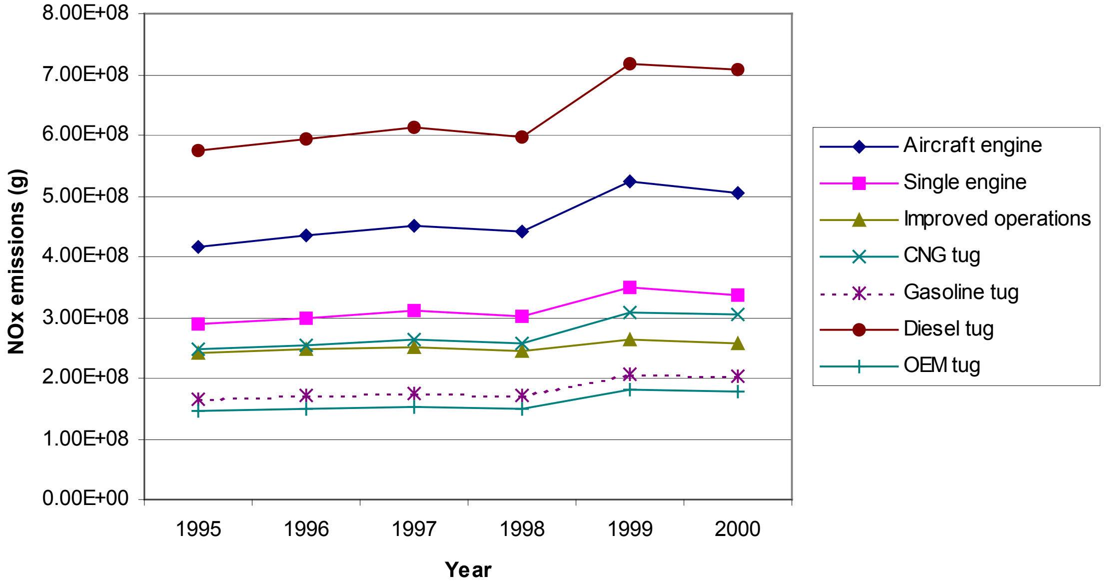

Figure 5. Potential for taxi-out NOx emissions reductions of different strategies compared to normal aircraft engine operations. The data shown corresponds to July of the indicated year.

The potential for CO emissions reductions during taxi-out is shown in Figure 6. Here, the gasoline and CNG tugs generate more CO than aircraft during normal operations.

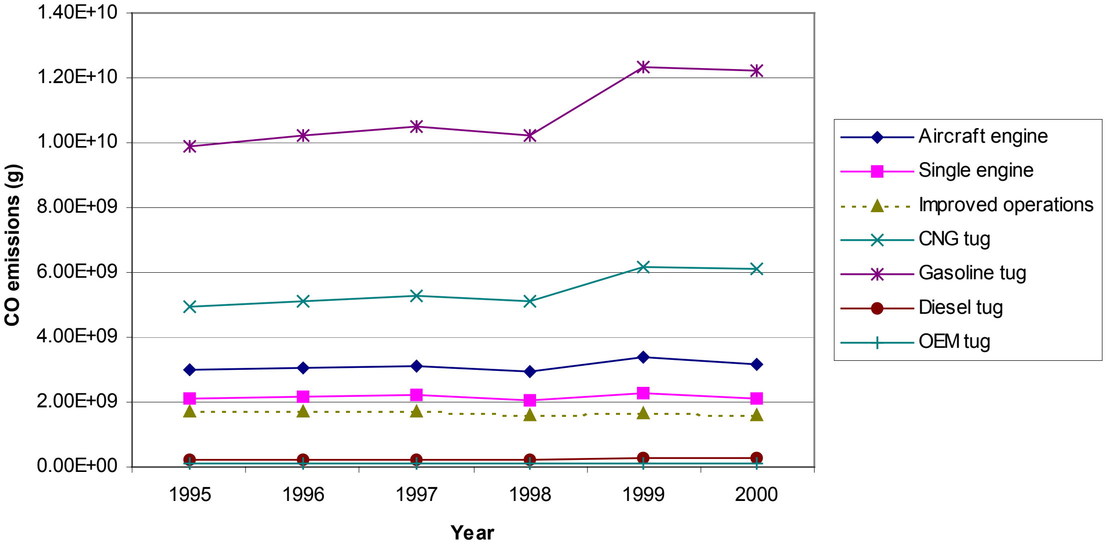

Figure 6. Potential for taxi out CO emissions reductions of different strategies compared to normal aircraft engine operations. The data shown corresponds to July of the indicated year.

Table 6 summarizes the potential emissions reductions during taxi-out and taxi-in for all cases analyzed.

Table 6. Comparison of average percentage difference in emissions for the different strategies. The data shown compares values for July of 2000 with figures for July of 1995.

Average percentage change in emissions as compared to the baseline						
Strategy	**NOx**		**CO**		**CO2**	
	Taxi out %	**Taxi in %**	**Taxi out %**	**Taxi in %**	**Taxi out %**	**Taxi in %**
Improved Operations	-45.36	-45.31	-46.29	-45.61	-45.27	-45.12
Single engine	-31.82	-7.97	-30.38	-7.96	-31.39	-7.76
CNG tugs	-40.92	-41.04	75.35	77.14	N/A	N/A
Gasoline Tugs	-60.92	-60.70	250.71	254.28	N/A	N/A
Diesel tugs	37.50	37.47	-92.58	-92.49	N/A	N/A
OEM optimized CNG tugs	-65.54	-65.61	-96.93	-96.90	N/A	N/A

The data in Table 6 evidences an ample margin for emissions reductions through improved operations, which highlights the importance of developing tools like the Departure Planner. Single engine-taxiing offers significant environmental benefits, especially during the taxi-out phase. Given the constraint of running all engines for at least five minutes during taxi-out and taxi-in, and due to the fact that taxi-in times are shorter than taxi-out times, emission reductions from single-engine taxiing during taxi-in are not as large. With respect to the tow trucks, apart from the OEM optimized CNG tugs, it is not clear if there are environmental benefits from using them. CNG and gasoline tow trucks reduce NOx, but generate excess CO. The opposite is true for the diesel tugs. OEM optimized CNG show the greatest advantage of all towing strategies considered. Further work should investigate the feasibility of implementing this option.

8) Conclusions

8.1) Large increase of ground emissions at terminal areas

Compared to overall growth in aviation activity, this study has identified an abnormally higher increase in taxi times, which translates into increased fuel consumption and ground emissions. This is significant because ground emissions are more likely to affect local air quality, as opposed to airborne emissions, which are more associated with global climate change. People are more sensitive to local air pollution than to global climate change, therefore this increase in ground emissions may be taken more seriously by governments and communities neighboring terminal areas. Thus, increased ground emissions may become a limiting factor for the expansion of capacity and operations at airports. Note that these results are at an aggregate level and the specific reductions at any individual airport may vary depending on local conditions.

8.2) Emissions reductions potential through improved operations is large

In general terms, current surface operations are very inefficient as reflected in the significant potential for emissions reductions through improved operations on the ground. Implementation of a perfect system that would achieve this performance is probably very difficult, however the potential environmental gains justify resources spent in tools such as the Departure Planner.

8.3) Potential for emissions reductions through single-engine taxiing is significant

Single-engine taxiing stands out as a promising alternative to reduce emissions, especially during taxi-out. Further work should consider the widespread implementation of this strategy. In particular, attention should be paid to the potentially higher maintenance costs due to running one engine cold during take-off.

8.4) Unclear environmental advantage of diesel, gasoline and CNG tugs

It is not clear whether towing aircraft to/from the runway with either one of these tow truck types will lead to net environmental benefits. Gasoline and CNG tugs help reduce NOx emissions, but increase CO pollution. The opposite is true for diesel tugs. More research should be done to better characterize the performance (engine horsepower, tow speed, emissions factors) of these tractors.

8.5) OEM optimized CNG tugs may be promising

OEM optimized CNG tugs yield the largest emissions reductions from all options considered according to the assumptions made in this study. Further research should investigate the validity of those assumptions and determine the feasibility of implementing this strategy.

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