Air Pollution Accountability and Compliance Tracking System

(A-PACT System)

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Abstract—**Aircraft produce emissions and pollution harmful to humans and the environment. Though aircraft are only responsible for a small percentage of transportation industry emissions, higher concentrations of air traffic at lower altitudes around major airports cause increased local pollution levels. The current monitoring systems in place at major airports are primarily designed for noise regulation purposes. There exists a need for a system to ensure compliance and accountability to pollution and emissions regulations for aircraft at major airports. The proposed Air Pollution Accountability and Compliance Tracking (A-PACT) System references existing standardized pollutant index databases using collected flight track data along with each aircraft's unique ICAO identification number to compute cumulative emission estimation called the Emissions Inventory (EI). This process is performed for each approaching and departing aircraft within designated boundaries surrounding the international airport at Dulles (IAD). The output of the A-PACT System shows the Emissions Inventory of each aircraft over each segment of the flight and is given in mass produced per unit of time. The envisioned system design can be feasibly integrated to assess air traffic at any major airport, not just at IAD. Airports and airlines can use this tool in assessments of pollution mitigation efforts such as fleet mix, level of technology and pollution attainment determination. Similarly, the system can be used as a tool to advise and guide regulatory authorities in making their decisions.** *(Abstract)*

Keywords-air pollution; aviation; data mining

I. Introduction

A. Context

CONCERN over the effects of human-created pollution on the local environment and public health has led to increased efforts to preemptively act. These pollutants are known to cause harmful health effects on humans. This concern has driven government agencies in the United States to enforce regulations posed by the National Ambient Air Quality Standard (NAAQS) [1].

High concentrations of aircraft at low altitudes around major airports cause increased local pollution. This problem had led to a need for a system to ensure compliance and accountability for emissions regulations for aircraft at major airports.

The A-PACT system stands for Air Pollution Accountability and Compliance Tracking system. The goal of the system is to act as a tool to provide individual tracking of pollution output by aircraft. A-PACT uses ICAO (International Civil Aviation Organization) data to estimate pollution of individual sources, thereby enabling accountability. The system incorporates regulation standards to track compliance.

According to a study done by the Office of Environment and Energy, the altitude of 3000 ft AGL (above ground level) distinguishes the point at which human exposure to airline emissions become negligible. Above which, pollution released does not directly affect local air quality at ground level. This is due to the fact that pollution dispersion will result in a ppm (parts per million) concentration below that which has an effect on the human population and immediate local environment. Meaning, pollution released into the atmosphere above this level has insignificant direct affect for this case study. General flight paths coincide with this level at an approximately 12 nautical miles from point of origin [2].

Current pollution monitoring systems provide a global overview of the air quality, and do not necessarily provide individual accountability for polluters. Pollution created by air traffic is currently under heavy scrutiny in foreign governmental bodies such as the European Union, and is a subject of study for the Intergovernmental Panel on Climate Change (IPCC) [3]. In such a context, any environmental management system would require a mechanism with which to gather and analyze data on the pollutants released by air traffic. Any subsequent penalty or regulation decision could feasibly be based on such detailed assessments.

The Context is assumed to be a closed system consisting of the cylindrical volume of air surrounding the airport, which is 12 nautical miles in radius, with a height of 3000 ft AGL. Other pollutants or sources are not considered in having any further effect on the system. Since this is an analysis of the effect of the airline pollution, any other sources are considered to be confounding variables.

B. Stakeholders

Any entity which can be directly impacted by the A-PACT System may be considered a stakeholder. Primary stakeholders include government pollution regulatory agencies as well as the airline industry and airport authority. The airport chosen for this study, the International Airport at Dulles (IAD) shares borders with two different Virginia counties: Loudoun & Fairfax. Therefore, regulating bodies for both counties must be considered. The A-PACT system would serve as a preliminary regulatory tool for those potentially monitoring aircraft emissions. Individual commercial airlines could use this system as a tool for self-assessment in an effort to avoid non-attainment fines. Lastly, any party involved with the environmental management aspects of aviation may be considered.

Secondary stakeholders include any residence or business local to the airport that is affected by the ambient air quality. The A-PACT system could indirectly lead to an overall increase in local air quality. Finally, airline passengers could be indirectly affected by the system. Fines imposed on airlines could potentially lead to higher airfare costs as regulation measures are enforced.

C. Scope

This case study will only encompass the area surrounding IAD (generalized to a 12 nautical mile radius). The scope encompasses pollution released by given aircraft *local* to IAD rather than over the entirety of each flight. The system will only identify the quantity of pollution released rather its dispersion thereafter. These pollutants include H/C (hydrocarbons), CO, & NO_x.

II. METHODOLOGY

A. Model Design

The system is designed to receive the majority of its inputs from databases compiled by ICAO. These databases include such information as thrust, and emission indexes for four flight conditions: takeoff, climb-out, approach, & idle. The four flight conditions relate directly to engine thrust levels (%). Types of emission include in the database are: H/C, CO, & NO_x [4][8].

The second major tool used in the system design, NIRS (Noise Integrated Routing System), has been developed by Metron Aviation and made available for use in this project. This tool is comprised of a noise monitoring system implemented at IAD, which estimates a noise footprint of incoming and outgoing aircraft. Based on theses estimations, NIRS provides aircraft routs which attempt to mitigate noise in the surrounding populated areas. In doing this estimation, NIRS first calculates thrust based on position and characteristics of the aircraft. This is given by the equation:

$$F = m * a$$

Where F is the thrust of the aircraft, m is the gross weight determined by aircraft type (as well as scheduled flight distance), and a is the acceleration of the aircraft determined by velocity and ultimately position [5]. The two pieces of information used by the A-PACT System provided by NIRS are the aircraft position tracking information as well as thrust levels for each stage of flight.

Specifically, one data output of NIRS provides position in terms of altitude and lateral distance from the origin. This origin is defined as the location of the beginning of the takeoff roll, or the end of the landing roll.

Once this information is input into the system, the total emission output of each aircraft must be calculated. This is given by the equation:

$$E.I. = \sum [ff] * [e_i] * [t] * [c_e]$$

Where *E.I.* is the total emission inventory of a particular aircraft measured in grams of pollutants; *ff* is the fuel flow of the engine; e_i is the emission index for a specific pollutant; t is the time interval for each different level of thrust; and c_e is the total number of engines. Fuel flow is a function of thrust and is given in kilograms of fuel burned per second for each engine. Emission index is a function of fuel flow and is given in grams of pollutant produced per kilogram of fuel burned. These values are summated for all thrust levels during each segment of the flight.

The output of the A-PACT System shows the total emission inventory for the three pollutant types during each flight segment as well as the total output for the entire flight path within scope.

B. Trade-Off Analysis

For this case study a trade-off analysis was performed to identify maximum utility on rate of return. For the project design six constraints, which were defined in the value hierarchy, were taken into account and used to rank and select design alternatives. Through discussion with our project sponsor and possible future stakeholder for such a system, each constraint was then weighted. The following shows each constraint and its weights:

1. Accuracy of Data Collected
2. Accessibility to User
3. Reliability
4. Usability
5. Maintainability
6. Availability

These functions were then assigned methods and mechanisms for completion that met the criteria set forth by the value hierarchy.

Constraints	1	2	3	4	5	6
Weights	0.25	0.2	0.2	0.1	0.15	0.1

C. Alternatives

Each alternative was scored for each constraint on a 1-10 scale using a house of quality model. The maximum utility based on each constraint was determined using the following function:

$$Utility_{max} = \sum_{i=1}^{6} x_i * y_{ij}$$

$$= x_1y_{1j} + x_2y_{2j} + x_3y_{3j} + x_4y_{4j} + x_5y_{5j} + x_6y_{6j}$$

Where:

x_i = the weight of the i^{th} constraint (1-6)

y_{ij} = the score for the j^{th} alternative with respect to the i^{th} constraint.

The variables i and j are represented in the utility charts for each alternative below.

1. Position & ID Retrieval

There were four different aspects of the design we analyzed. The first was the retrieval of the position and ID of the aircraft. We looked at 3 alternatives (subject to constraints 1 & 2). The first included using black-box technology called ADS-B, which is a GPS-based transponder that sends information about aircraft to a receiver. Each of the ADS-B transponders has a unique identifier tied to the tail number of the specific plane. This is still new technology which is not fully implemented. This alternative involves having the final system integrate-able for use with future FAA monitoring systems such as ADS-B [6]. The second alternative uses radar-based standard multilateration methods (ASDE-X) [7]. Based on the aircrafts position and airport schedule we can determine an aircrafts flight path and unique ID. This alternative requires more work for the design team, but yields overall greatest utility. The final alternative includes using open source public GPS based aircraft tracking methods. This alternative is much more readily accessible but is less accurate than the other alternatives.

	Constraint (*i*)	1	2	Total Utility
j	Future ADS-B	8	2	2.4
	Current Multilateration	7	6	2.95
	Public GPS Based	5	8	2.85

2. Thrust Calculations

The next phase of the design involved calculating the thrust output of each of the aircraft (subject to constraints 1, 3, 4, 5, & 6). The first alternative involved relating noise measurements of aircraft to determine thrust level. This was originally suggested due to the fact that noise monitoring systems have already been implemented at many major airports. The second alternative was thought of when introduced to the NIRS, system which was developed by our sponsor Metron Aviation. As previously stated, NIRS outputs thrust levels and tracking data for aircraft. Since thrust directly relates to fuel flow, this alternative provides the greater utility than the aforementioned.

	Constraint (*i*)	1	3	4	5	6	Tot. Utility
j	Noise Measurements	6	4	8	6	7	4.7
	NIRS Algorithms	8	5	6	6	5	5

3. Programming Language

In designing the emission estimation algorithms and program, alternative programming languages were suggested: JAVA, Php, & MATLAB (subject to constraints 1, 3, 4, 5, & 6). The system required many matrix operations as well as a moderate level of user interface. Accuracy and reliability were high priorities, as well as ease of usability.

	Constraint (*i*)	1	3	4	5	6	Total Utility
j	JAVA	7	8	6	7	5	5.5
	Php	7	9	6	6	7	5.75
	MATLAB	8	8	5	6	6	5.6

4. Data Regression

Since emission index databases only gave discrete points for thrust level, a regression was performed for each. Only four sets of data were given for each and included e_i at takeoff, climb out, approach, and idle represented by thrust level 1.00, 0.85, 0.35, and 0.07 respectively. (Regression alternatives subject to constraints 1 & 4). Some regressions resembled cubic functions, and some resembled exponential decay functions. With only four data points a cubic best fit function will always return an R^2 value of 1.0, implying perfect accuracy of fit. Due to the limited number of data points the alternative with the highest utility based on accuracy and ease of usability we decided on a third alternative: of linear by region, or "connect the dots." Alternative analysis was also based on usability, or which had highest ease of usability for mathematical programming.

	Constraint (*i*)	1	4	Total Utility
j	Cubic	8	5	2.5
	Exponential	7	6	2.35
	Linear by Region	6	9	2.4

D. Output

The Following shows an actual output example from the A-Pact System. This is a generalized flight path with fewer number of flight steps shown for convenience. An actual flight path will have many more complex flight segments.

A-PACT System Output

Aircraft Model:	B737-700	**Airport:**	KIAD
Engine Type:	CFM56-7B 2 Engine	**Runway:**	04L
Max Thrust (kN):	24000	**Type:**	Arrival

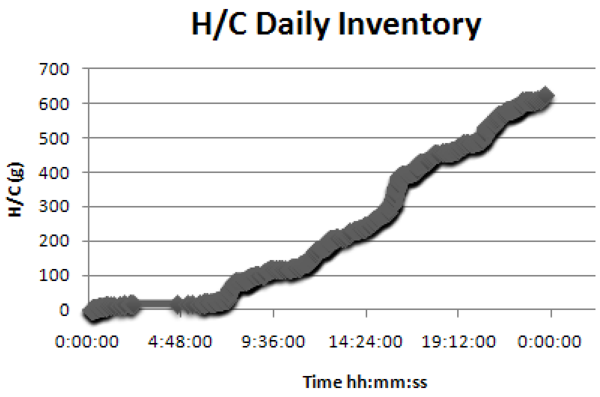
Emission Output (g)			
Flight Segments	H/C	CO	NOx
Approach	89.79	817.15	60.05
Approach	86.22	411.81	32.61
Approach	56.07	73.16	6.69
Approach	198.92	109.7	11.4
Landing	3.38	2.1	0.21
Breaking	144.54	12.25	1.49
Total Per Engine:	578.91	1426.2	21.26
Total Output:	1157.82	2852.3	42.53
Average g/s	1.81	4.46	0.35

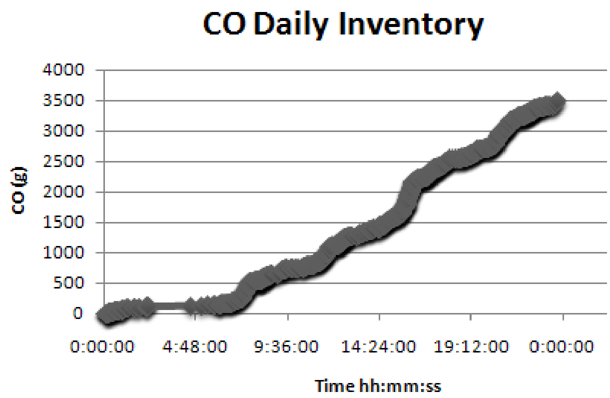
III. Preliminary Results

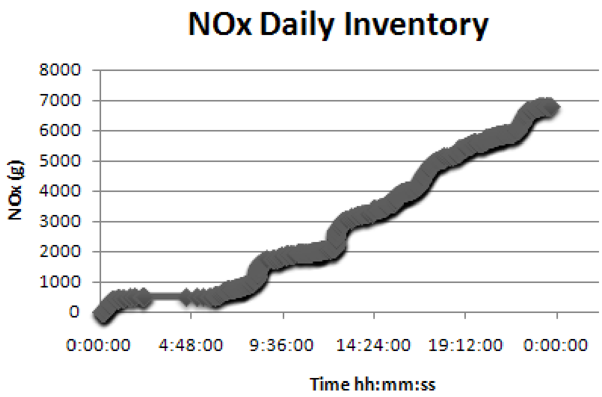
The A-PACT system computes the cumulative emissions output of each arriving and departing flight at IAD using the above methodology. It shows the aircraft type, engine type, number of engines, airport, runway, and flight type (arrival/departure). Each flight segment is shown broken down into each of its components. The emission output is summated for each segment as well as the total flight within the given radius of IAD. The output shows the total amount of emission produced in grams as well as the average given in grams/second. This process can be repeated for as many planes as required. These results can be compared to applicable regulations of the same metric.

IV. Analysis

The entire roster of flights arriving and departing from IAD was analyzed for an average given day. These data were accessed through the Metropolitan Washington Airport Authority's public databases [8]. The following graphs show a cumulative inventory for each pollutant over a 24 hour period.

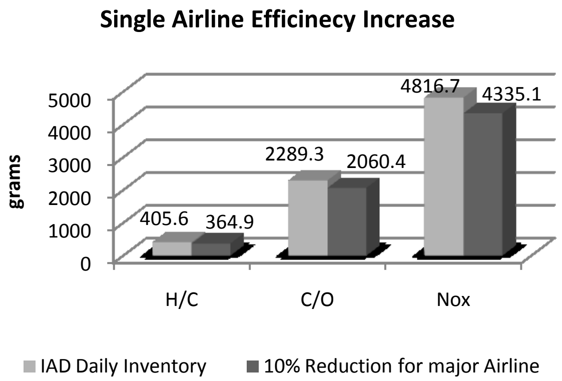






The results can be filtered in a number of different ways including airplane type, airline, runway, time of day, flight type (arrival/departure), or if it is regional, or international. This capability broadens the scope of analyses that can be performed by the systems potential stakeholders.

By allowing results to be filtered by aircraft type, the A-PACT system can enable airlines to assess the viability of different fleet mixes. An example of this analysis was performed for using data for a single major airline fleet operating at IAD. This airline accounts for a majority of the inbound and outbound flights [8]. The name of this airline is omitted for legal reasons. In this analysis the emission inventory for this airline was reduced by 10%. The graph below shows how this influences the total inventory for IAD for the day of the previous case study.



V. FUTURE WORK

The versatility of the system allows for many types of analyses. As flight frequency increases, the total emission index for the local area does as well. There is a potential link between the frequency of airport operations and overall average flight emissions. With this information airports can make routing decisions which prevent inefficiencies. By allowing regulators to perform individual analyses of airlines emission contributions, incentives and penalties can be made more appropriately. These incentives will help to motivate advancements in cleaner and more efficient technology.

VI. CONCLUSION

To meet regulation requirements, new technology will need to be implemented. Depending on an airport's attainment ranking, insertion rate of new efficiency-improving technologies will be considered and suggested. The envisioned system design can be feasibly integrated to assess air traffic pollution at any major airport, not just at IAD. Airports and airlines can use this tool in assessments of pollution mitigation efforts such as fleet mix, level of technology and pollution attainment determination. Similarly, the system can be used as a tool to advise and guide regulatory authorities in making their decisions.

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