EPA-AA-AC 76-04

Technical Support Report for Regulatory Action

SST Emissions Projection

June, 1976

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Abstract

This document details the derivation and estimate of the emissions from both subsonic and supersonic commercial aircraft at John F. Kennedy International Airport in 1990. The estimate includes two scenarios, one presuming there are no standards, the other presuming implementation of all existing standards and the T5 class standards recommended in "Alternative Derivations of the Standards for T5 (Supersonic Transport) Class Gas Turbine Aircraft Emissions," EPA Technology Support Report, AC-76-01. This estimate draws from several sources, principally FAA terminal passenger projections, FAA fleet type projections, and manufacturers' engine data. As the FAA information does not extend beyond 1985, this estimate has had to rely on certain extrapolations in order to reach the desired 1990 situation.

The projection shows that the emissions standards for subsonic aircraft (classes T2, T3, T4) have a significant impact on aircraft emissions at JFK in 1990. The projection further shows that if there develops a moderate sized fleet of SST aircraft (150 by 1990), then the T5 class standards recommended in EPA Technology Support Report, AC-76-01, will substantially reduce further the emissions of hydrocarbons and carbon monoxide. The T5 class standards have little effect on the emissions of oxides of nitrogen.

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Introduction and Summary

The preamble to the draft T5 class (SST) emissions regulations contains a table shown below which estimates the contributions of the subsonic fleet and the supersonic fleet to the air pollution load at John F. Kennedy Airport in New York in 1990. The table further assesses the impact of both the subsonic and the supersonic emissions regulations by presenting pollution load scenarios both with and without these regulations in effect.

This table differs somewhat from that presented in the preamble of the Notice of Proposed Rulemaking for the T5 class emissions standards (FR Vol. 39, No. 141, July 22, 1974, p. 2665-4) owing principally to new estimates of the size and distribution of both the subsonic and supersonic fleets (distribution includes both aircraft type as well as the level of compliance with the standards).

This document explains the derivation of the numbers quoted in Table I. This derivation involves far more than reference to a published estimate of the distribution of type and compliance level of aircraft at JFK in 1990 and application of that estimate to the emissions figures implicit in the respective levels of compliance. First, the distribution of type and compliance level of aircraft is not available from any published source. Rather, the work of this document has been to draw from several relevant sources of different kinds of data, make hopefully reasonable assumptions plus some arbitrary hypotheses, and arrive independently at an estimate of the size and distribution. Secondly, the typical landing-takeoff (LTO) cycle at JFK differs from the LTO cycle specified in the EPA standards. Hence the standards alone do not offer enough information to predict individual aircraft emissions by type and level of compliance. Hence, adjustments must be made to levels predicted by the standards in order to describe emissions at this particular airport. Of course, the assumption that the present LTO cycle at JFK will be similar to that experienced in 1990 is certainly arbitrary, but is as equally defensible as any other guess.

It should be recognized that often the final result is not terribly sensitive to the assumption in question. While error bands were not put into the analysis, the skeptical reader is advised to check for himself the sensitivity of the result to a reasonable departure from an assumption which is in question. The important point is that this impact analysis seeks only to (1) compare the relative importance between the subsonic (T2, T3, T4 classes) standards and the supersonic (T5 class) standards and (2) offer a rough idea of the magnitude of the aircraft pollution load. The first goal can be reasonably well met regardless of the precise accuracy of many of the assumptions. Table I, in fact, shows rather strongly that T5 standards for hydrocarbons (HC) and carbon monoxide (CO) are an important contribution to the overall aircraft picture (at an international airport such as JFK, at least) despite the relatively few SST aircraft in 1990, about 70 U.S. SSTs versus 3500 U.S. subsonic jet aircraft and a comparable ratio for foreign aircraft. The table also emphasizes the unfortunate fact that despite the large impact

TABLE I

Emissions Impact of Supersonic Transport Aircraft at

John F. Kennedy Airport in 1990

(Tons per year)

	HC	CO	NOx
Uncontrolled subsonic aircraft emissions----	3,300	7,950	3,200
Uncontrolled supersonic aircraft emissions--	2,100	7,850	1,050
Total uncontrolled aircraft emissions--	5,400	15,800	4,250
Reduction in aircraft emissions due to standards for subsonic aircraft only--------	1,900	3,700	950
Percent reduction from uncontrolled fleet----------------------------------	35	23	22
Reduction in aircraft emissions due to standards for supersonic aircraft only------	1,300	3,950	150
Percent reduction from uncontrolled fleet----------------------------------	24	25	4
Reduction in aircraft emissions due to standards for both subsonic and supersonic aircraft-------------------------------------	3,200	7,650	1,100
Percent reduction from uncontrolled fleet----------------------------------	59	48	26

Note: (1) Estimate: 150 SST aircraft in world fleet; 50 LTOs per day at JFK.

(2) JFK taxi-in and taxi-out modes are 9 minutes and 20 minutes respectively.

of SSTs in the oxides of nitrogen (NOx) picture, the SST standards do very little to improve it, largely because of the lack of effective NOx control reflected in the T5 newly manufactured engine (NME) standards.

In addition, the relatively large HC and CO output from the T5 class even with the regulations imposed on them indicates a possible need for a retrofit requirement for T5 class engines built before the compliance date for NME.

Discussion

The derivation of the emissions from aircraft at JFK in 1990 (what is presented in Table I) requires knowledge of:

I. The aircraft usage (numbers and types) at JFK in 1990.

II. The emissions from each type, including a distinction between the different levels of compliance.

The discussion below is divided according to these separate analyses:

I. Aircraft Usage at JFK in FY 1990.

The steps involved here are:

1. Estimate the passengers (PAX) departing JFK in 1990;

2. Estimate the passengers on foreign carriers (international flights only), U.S. carriers (domestic and international flights), supersonic aircraft, and subsonic aircraft (by type, e.g., short haul domestic, etc.);

3. Estimate freight;

4. Calculate the number of LTOs performed by each type in order to accomplish the necessary passengers and freight carriage.

Reference 1 indicates 16,763,000 passengers at JFK in FY 1986, the furthest projection available from the Department of Transportation. Projecting the 1985-1986 growth rate (2.04% per annum) for the next four years gives an estimated 18,173,000 passengers in FY 1990, the answer required by step 1 above.

References 2 and 3 show that U.S. carriers at JFK served 4,556,000 domestic and 2,869,000 international passengers (7,425,000 total) in CY 1973 and 4,381,000 domestic and 2,544,000 international passengers (6,925,000 total) in CY 1974. Averaging these calendar year figures gives a good approximation for FY 1974:

U.S. Carriers -	domestic	4,469,000
	international	2,706,000
	total	7,175,000

Reference 1 further cites that the total passengers for FY 1974 at JFK were 10,034,000, the difference, 2,859,000, being attributable to foreign carriers, all of which were international. For FY 1974, then,

U.S. Carriers - 7,175,000		71.5%
domestic -	4,469,000	44.5%
international -	2,706,000	27.0%
Foreign Carriers (international) - 2,859,000		28.5%
Total International		55.5%
Domestic		44.5%

For a lack of a better defined position it will be assumed that these percentages apply also to the FY 1990 data. Applying these ratios to the 18,173,000 passengers predicted at JFK for FY 1990 gives:

U.S. Carriers:		12,995,000	
international - 4,808,000			
domestic - 8,187,000			
Foreign Carriers:		5,178,000	
	Total	18,173,000	(1)
Total International		9,986,000	
Domestic		8,187,000	

This resolves step 2.

Reference 3 states that in FY 1974 450,600 tons departed JFK on all carriers, but reference 3 and 4 together show that only 392,400 tons could have been carried on U.S. freighter aircraft so the remainder was evidently carried aboard either U.S. passenger aircraft or foreign aircraft, either freighter or passenger. This implies that up to 87% of the cargo business was carried aboard U.S. freighter aircraft in 1974 and it is assumed in this report that that percentage will also apply in 1990.

Assuming, arbitrarily, a 5% growth in freight to 1985 and a 2% growth thereafter, then in 1990, 682,000 tons will depart JFK and 87% of that, or 594,000 tons, will be hauled aboard U.S. carrier freighters. The remaining 13% is carried aboard U.S. or foreign passenger craft or foreign freighters. As no data are available to predict what fraction of the 13% might be carried aboard foreign freighter aircraft (thereby adding to the number of LTO cycles at JFK), it is assumed for simplicity that all the remaining 13% is carried aboard passenger aircraft so there is no increase in the LTO cycles. This completes step 3.

In order to calculate the number of LTOs per year performed by each aircraft type, the following assumptions are made:

1. All freighters are 4 engine jumbo types.

2. All freighters operate full.

3. 4 engine jumbo types are not used domestically for passenger carriage by the U.S. fleet.

4. 4 engine narrow body types are absent from the U.S. fleet.

5. 10% of the foreign fleet are 4 engine narrow body types.

6. 2 and 3 engine narrow body types are not used internationally.

7. 2 engine jumbo types are in the foreign fleet only.

8. 3 engine super stretch types are used only by the U.S. fleet and are used domestically and internationally.

9. Load factor is 70% for passenger hauling.

10. SSTs are used on international flights only.

Examples of the aircraft types referred to above are:

2 engine narrow body - DC-9, B737
3 engine narrow body - B727
4 engine narrow body - B707, DC-8
3 engine super stretch - B7X7*, B7N7*
2 engine jumbo - A300, DC-X*
3 engine jumbo - DC-10, L1011
4 engine jumbo - B747
SST - Concorde, AST**

Freight Requirements

From reference 4 and the estimated freight to be shipped (594,000, see discussion of step 3), the number of LTO cycles per year in 1990 is:

$$\frac{594{,}000 \times 2000}{166{,}750} = 7124 \text{ LTO's/year} \qquad (2)$$

Passenger Requirements

Consider first the supersonic international flight by both U.S. and foreign carriers. It is hypothesized that there are 50 LTOs/day by SST type aircraft and further that the worldwide fleet of 150 SSTs include

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* This aircraft is not yet in production nor fully defined.

** AST = Advanced Supersonic Transport (Not yet in production nor fully defined).

110 Concorde type aircraft and 40 ASTs. Assuming that the 50 LTOs per day also reflect this distribution, then there are 37 Concorde LTOs and 13 AST LTOs per day at JFK in 1990.

Annually, this means:

Concorde type:	13,505 LTOs/year	
AST:	4,745 LTOs/year	(3)

The use of SSTs will mean, of course, fewer people to be carried on the subsonics and thus fewer subsonic LTOs per year. The passengers carried by SST aircraft are:

Concorde:	13,505 x 120 x 0.7 =	1,134,000
AST:	4,745 x 250 x 0.7 =	830,000
		1,964,000

where 0.7 is the load factor (as assumed). The full Concorde capacity of 120 is expected (reference 5), and the AST capacity is here assumed to be 250 (reference 6).

If the SST passenger (PAX) distribution follows the total international PAX distribution between U.S. and foreign carriers (see (1)) then

U.S. Carrier SST PAX =	946,000	
Foreign Carrier SST PAX =	1,018,000	(4)
	1,964,000	

This leaves for subsonic (M<1) international flight, from (1) and (3),

U.S. carrier M<1 PAX =	3,862,000	
Foreign carrier M<1 PAX =	4,160,000	(4)

The international subsonic aircraft LTOs are next calculated on the basis of the remaining passenger requirements. To this end, the subsonic LTOs for U.S. carriers and foreign carriers are considered separately.

U.S. Carriers -

It is first necessary to estimate the distribution of LTO's by different aircraft types at JFK in 1990. From reference 3, in 1974 at JFK, U.S. carriers used on <u>international flights</u>,

3 engine narrow body:	2316 LTOs/year
4 engine narrow body:	9612
3 engine jumbo:	2083
4 engine jumbo:	5995

The ratio of these types will be used for the 1990 computation with certain differences assumed. Consistent with the assumptions listed on page 5, the 3 engine narrow body will be replaced by the 3 engine super stretch for international flights. As the new aircraft has a seating capacity of 190 versus 130 for the older plane, the 2316 LTOs/year for 1974 would become effectively:

$$2316 \times \frac{130}{190} = 1585 \text{ LTO's/year}$$

if the new plane had been in use in 1974. Also consistent with the earlier assumptions is the replacement of the 4 engine narrow body types by 3 and 4 engine jumbos (190 seats vs. 380 and 400 seats, respectively). Arbitrarily assuming that the passengers of the older aircraft are divided equally among the two newer types, then the additional LTOs/year of the newer types in 1974 resulting from a replacement of the 4 engine narrow body type are:

$$\Delta \text{ 3 engine jumbo} = 9612 \times \frac{190}{380} \times \frac{1}{2} = 2403$$

and

$$\Delta \text{ 4 engine jumbo} = 9612 \times \frac{190}{400} \times \frac{1}{2} = 2283$$

Therefore, the 1974 LTO picture for U.S. carriers on international flights with a hypothetical 1990 style fleet (i.e., types in service) would be

3 engine super stretch:	1585 LTO's/year	(11.0%)
3 engine jumbo:	4486 LTO's/year	(31.3%)
4 engine jumbo:	8278 LTO's/year	(57.7%)
		(100.0%)

As stated above, these ratios of types will be used to represent the distribution of LTOs among the aircraft types for international flights by U.S. carriers. In 1990, from (4), the U.S. carriers will move 3,862,000 passengers from JFK on subsonic international flights. The total number of LTO's needed to do this (N) is:

$$N \times (.11 \times 190 \times .7 + .31 \times 380 \times .7 + .58 \times 400 \times .7) = 3{,}862{,}000$$

where 0.7 is the load factor, the ratios are as above for each type, and the capacity of each type is found in reference 4. Solving,

$$N = 14{,}883$$

So the LTO's per year by type for U.S. carrier international flights are:

3 engine super stretch:	1637 LTOs/year	
3 engine jumbo:	4613	(5)
4 engine jumbo:	8632	

Foreign Carriers -

Again some estimate of the LTO distribution of types is required for 1990. For a lack of a better resolution, it is arbitrarily taken that the foreign carrier LTOs are distributed by type according to the ratios of types found in a future U.S. fleet, appropriately adapted. This implies two pertinent thoughts: (1) the future foreign carrier fleet largely parallels the future U.S. fleet, at least for international (long range) activity; (2) for overseas travel, the flight times are comparable for all types (there being no short haul) and so it may be expected that the ratio of LTOs to number of type is the same for all the types used on international flights.

Two adaptations are made, however. First, it is arbitrarily assumed that 10% of the foreign fleet is still flying 4 engine narrow body types in 1990. This is to reflect the trend that many smaller foreign airlines have neither the need for nor the capital to purchase the large, but expensive jumbos. Second, it is postulated that the foreign fleets will not use the B7X7 for international travel, but will rely upon the 2 engine jumbo, an original European aircraft, to fill that slot. Thus, using the U.S. carrier fleet projection from reference 7 and incorporating the above adaptations, it is found that the distribution of foreign carrier LTOs at JFK in 1990 are:

4 engine jumbo -	20%
3 engine jumbo -	33%
2 engine jumbo -	37%
4 engine narrowbody-	10%
	100.0%

From this distribution and the passenger requirement (3), the total LTOs per year(N) is given by

$$N x (0.20 x 400 x .7 + 0.33 x 380 x 0.7 + 0.37 x 350 x 0.7 + 0.10 x 190 x 0.7) = 4{,}160{,}000$$

The 2 engine jumbo seating is given in reference 4, and again the load factor is 0.7. Solving for N gives

$$N = 16{,}790$$

Therefore, by types, the foreign carrier LTOs/year are:

4 engine narrow body:	1679 LTOs/year	
2 engine jumbo:	6212	
3 engine jumbo:	5541	(6)
4 engine jumbo:	3358	

Finally there are the U.S. domestic passenger who require aircraft. Reference 3 and statement (1) above give the total for JFK of

Domestic PAX ('74) = 4,469,000
Domestic PAX ('90) = 12,995,000

which is a growth factor of 2.9 times the 1974 figure over the 16 year period. It is assumed that this growth factor applies also to the individual categories of domestic travel (short, medium, and long haul) whose 1974 passenger levels are given in reference 3. While undoubtedly not true to some degree, it is the most conservative assumption to make lacking a realistic estimate of the individual growth rate of each distance category.

Then, as certain aircraft types are associated with specific categories of usage (eg, 2 engine narrow body types for short haul), the LTOs required of each aircraft type to serve the passengers of each category are readily computed as follows:

Category	Type	'74 PAX	(x2.9)	'90 PAX	Aircraft Capacity	LTOs required
short haul	2 eng narrow	497K		1445K	115	17,957
medium haul	3 eng narrow	1407K		1606K	150	15,294**
	3 eng super str	-		2486K	190	18,693**
long haul	4 eng narrow	1168K		-	-	-
	3 eng jumbo	783K		7459K	380	28,041***
	4 eng jumbo	614K		-	-	-

* at 70% load factor

** Ratio of LTOs based upon project fleet ratio of these types at the time in question. Fleet projection is discussed on pp. 16.

***This scenario is consistent with the assumptions listed on p. 5.

This concludes step 4.

Part I may then be summarized:

Table II

Total JFK LTO cycle frequency (per year) in 1990

Type	U.S. PAX Domestic	U.S. PAX International	Foreign PAX	U.S. Freight	Total
2 engine narrow	17,957				17,957
3 engine narrow	15,294				15,294
4 engine narrow					1,697
3 engine super str.	18,693	1,637			20,330
2 engine jumbo			6,212		6,212
3 engine jumbo	28,041	4,613	5,541		38,195
4 engine jumbo		8,632	3,358	7,124	19,114
Concorde		6,505	7,000		13,505
AST		2,285	2,460		4,745
					137,031

II. <u>Aircraft Emissions in FY 1990.</u>

This part consists of two phases, the first being the specification of the LTO emissions by aircraft type and standard involved and the second being the prediction of the fleet distribution by type and standard met.

<u>Specification of the LTO Emissions</u>

In order to compare the effect of the standards on the aircraft emissions in general it is necessary to assume on one hand that in 1990 the standards do not exist (save for the present JT8D in-use smoke standard which is already in force), and on the other, that the present standards are being enforced in 1990. Therefore, it is necessary for each type to specify emissions performance for no standards, newly manufactured engine standards, newly certified engine standards, and the special JT3D in-use smoke standard.

The EPA standards are predicated upon an LTO cycle which has 26 minutes of taxi/idle time total for inbound to and outbound from the terminal. If the emissions performance of an engine is known in terms of the EPA regulatory parameter (EPAP) or if it is presumed (ie, to meet a particular standard), then the pounds of pollutant over that cycle can be found by

Pounds of pollutant = EPAP x (Impulse/1000)

where the impulse is that over the entire cycle in pounds-thrust x hours.

However, at JFK the typical LTO cycle (at least in 1976) has a 29 minute taxi/idle duration (reference 8). This has a significant effect on the hydrocarbon (HC) and carbon monoxide output as both are produced nearly exclusively in that mode, but a much more diluted effect (5-15%) on the oxides of nitrogen (NOx) output as that produced largely in the high power modes. For those engines for which the EPA has modal data (ie, pounds of pollutant per hour per mode), the extra three minutes of idle in the JFK LTO cycle can be handled directly, but for those engines for which only EPAP data are available, the effect of the extra idle must be estimated by reliance upon the modal patterns of similar engines.

Table III below shows all the relevant engines, and their JFK LTO cycle emissions (ie, 29 minutes of taxi/idle) in their present production form (ie., with no standards imposed except for the JT8D in-use smoke standard). The emissions per LTO cycle at JFK for nonregulated engines can now be tabulated (Table IV).

It is next necessary to consider the emissions performance of engines that comply with the standards for newly manufactured engines (NME). Actual emissions performances cannot be predicted so it is necessary to assume only that each engine will just meet the standards with no margin. This is conservative as the standards require all engines of a kind to comply which implies with the statistical variation involved in the testing procedure that the average emissions of a type of engine must surpass the standards by a healthy margin.

For all engines except the JT3D and the Olympus 593, the emissions levels are estimated as follows:

lbs of HC or CO (JFK LTO) =

$$EPAP_{HC,CO\ Std} \times (Impulse/1000) \times (29/26)$$

lbs of NOx (JFK LTO) = (7)

$$EPAP_{NOx\ Std} \times (Impulse/1000) \times [0.15x(29/26) + 0.85]$$

and the relevant standards are:

	EPAP Std
HC	0.8
CO	4.3
NOx	3.0

Table III

No Standards Emissions

Pollutant (lbs/LTO cycle - JFK)

Engine	HC	CO	NOx	Reference
CF6-50C	18.4	46.4	29.8	9
CFM56	1.5	19.0	6.8	10
CF6-6D	11.3	33.3	21.9	11
JT10D		assumed same as CFM56		
JT9D-70	9.6	39.6	28.8	12
JT9D-7	27.0	71.8	22.6	12, 13
JT8D-17*	7.2	26.1	12.2	13, 14
JT8D-15*+	5.9	24.1	10.5	11, 15, 16
JT3D-7*	33.5	47.4	9.6	11, 15
JT3D-7	60.0	72.0	6.4	11, 15
RB211-22B++	57.5	82.4	27.6	17
RB211-524++	41.1	57.7	39.8	17
Olympus 593	53.0	199.7	26.7	18
AST engine	68.8	259.4	34.7	**

* Smokeless type combustor (already in use on the JT8D, but not on the JT3D).

\+ Distribution of pollutants in each mode assumed to be the same as for the JT8D-17 from reference 16.

++ For the -22B, the following corrections to the EPAP value were used based upon the known modal distribution of the CF6-6D: For HC, CO:

$$\text{lbs of pollutant} = (\text{lbs of pollutant})_{\text{EPAP LTO}} \times \{0.9 \times (29/26) + 0.1\}$$

For NOx:

$$\text{lbs of NOx} = (\text{lbs of NOx})_{\text{EPAP LTO}} \times \{0.1 \times (29/26) + 0.9\}$$

For the -524, the corrections were based upon the known modal distribution of the CF6-50C:

$$\text{lbs of HC} = (\text{lbs of HC})_{\text{EPAP LTO}} \times (29/26)$$

$$\text{lbs of CO} = (\text{lbs of CO})_{\text{EPAP LTO}} \times \{0.95 \times (29/26) + 0.05\}$$

$$\text{lbs of NOx} = (\text{lbs of NOx})_{\text{EPAP LTO}} \times \{0.05 \times (29/26) + 0.95\}$$

** Engine not in existence. Estimated by assuming a 50K lb thrust engine and ratioing the Olympus 593 values by the the AST engine/ Olympus 593 thrust ratio (50K lbs /38.5K lb)

Table IV

Non-regulated Emissions
lbs/LTO/engine

Aircraft Type	Characteristic Engine	HC	CO	NOx
2 engine narrow	JT8D-15	5.9	24.1	10.5
3 engine narrow	JT8D-15	5.9	24.1	10.5
4 engine narrow	JT3D-7 (smokey)	60.0	72.0	6.4
3 engine super str.	CFM56, JT10D	1.5	19.0	6.8
2 engine jumbo	CF6-50C	18.4	46.4	29.8
3 engine jumbo	***	29.1	54.0	26.4
4 engine jumbo	JT9D-7	27.0	71.8	22.6
Concorde	Olympus 593	53.0	199.7	26.7
AST	AST engine	68.8	259.4	34.7

*** assumes an equal mix of DC-10-10s (CF6-6), DC-10-30s (CF6-50), and L1011s (RB211-22B)

The first equation presumes that all the HC and CO comes from the idle mode, which is essentially true for the low emissions combustors that would be used to comply with the standards. The second equation is based upon an estimate that 15% of the LTO NOx comes from the idle mode. On the average, this appears to be true for the low emissions combustors explored so far (a high of 25% at idle for JT8D-17 and a low of 10% for the CF6-6D, for instance).

The JT3D will not meet the NME standards but will be forced to comply with an in-use engine smoke standard. The data are supplied in Table II.

The Olympus 593 performance is based on reference 18. The AST, if it is to meet any standard, will meet the NCE standards and so is not included in Table V below. For aircraft having engines which comply with the newly manufactured engine standards, the emissions performance over the JFK LTO cycle is shown in Table VI.

Finally, the emissions levels of engines complying with the newly certified engine (NCE) standards must be addressed. As with the NME standards emissions discussed above, it can only be assumed that each engine will just barely comply with the requisite levels; it cannot be assumed that any one will exceed the standards. Furthermore, in this case, only new types of engines are to be considered. Hence, no existing engine types are referenced. For each category of aircraft an appropriate sized engine is selected and LTO (EPA) impulse computed assuming a 5% idle. The emissions are then computed using equation (7) with the EPAP standard values for newly certified engines (NCE) of,

Table V

Newly Manufactured Engine Standards Emissions Pollutant
(lbs/LTO cycle-JFK)

Engine	Impulse*	HC	CO	NOx
JT3D-7**	1584	.5	47.4	9.6
JT8D-17	1456	1.3	7.0	4.4
JT9D-7	4546	4.1	21.8	13.9
JT9D-70	4666	4.2	22.4	14.2
JT10D		(assumed same as CFM56)		
CF6-6D	3007	2.7	14.4	9.2
RB211-22B	3731	3.3	17.9	11.4
RB211-524	4442	4.0	21.3	13.6
Olympus 593	3002	12.6	96.0	26.7

* Pounds-thrust x hours over the EPA LTO cycle (26 minutes taxi/idle). EPA LTO cycle available from reference 19, rated thrust information available from reference 4, and engine idle point definitions available in references 9-18.

** Complies with in-use smoke standard, not NME standards.

Table VI

Newly Manufactured Engine Standards Emissions
lbs/LTO/engine

Type	Engine	HC	CO	NOx
2 engine narrow	JT8D-17	1.3	7.0	4.4
3 engine narrow	JT8D-17	1.3	7.0	4.4
4 engine narrow*	JT3D-7	33.5	47.4	9.6
3 engine super str.	CFM56 (JT10D)	1.6	8.5	5.4
2 engine jumbo	CF6-50C	3.5	18.6	11.8
3 engine jumbo	**	3.4	18.1	11.5
4 engine jumbo	JT9D-70	4.2	22.4	14.2
Concorde	Olympus 593	12.6	96.0	26.7

* Complies only with in-use smoke standard, not NME standards

** Equal mix of DC-10-10 (CF6-6D), DC-10-30 (CF6-50C), and L1011 (RB211-524).

	EPAP Std
HC	0.4
CO	3.0
NOx	3.0

The engines are:

A. Jumbo aircraft: 50,000 pound-thrust engine, idle = 5%, impulse (EPA T2 LTO cycle) = 4225 pound-thrust x hours.

B. 3 engine super stretch and 2 - 3 engine narrow body: 22,000 pound-thrust engine, idle = 5%, impulse = 1859 pound-thrust x hours.

C. AST: 50,000 pound-thrust engine, idle = 5%, impulse (EPA T5 LTO cycle) = 3899 pound-thrust x hours.

Thus, the engine emissions over the JFK LTO cycle are:

lbs/LTO cycle (JFK)

Engine	Impulse	HC	CO	NOx
A	4225	1.9	14.1	12.8
B	1859	0.8	6.2	5.6
C*	3899	4.1	32.8	17.8

* Modal contribution is determined by Tables X and XII of reference 20, scaled to 50K lb thrust, not by equation (7).

The emissions per LTO cycle at JFK for NCE regulated engines are then:

Table VII

Newly Certified Engine Standards Emissions
lbs/LTO/engine

Type	Engine	HC	CO	NOx
2 engine narrow	B	0.8	6.2	5.6
3 engine narrow	B	0.8	6.2	5.6
3 engine super str.	B	0.8	6.2	5.6
2 engine jumbo	A	1.9	14.1	12.8
3 engine jumbo	A	1.9	14.1	12.8
4 engine jumbo	A	1.9	14.1	12.8
AST	C	4.1	32.8	17.8

There are no 4 engine narrow body aircraft which would comply with the NCE standards.

The second step of this part is the projection of the fleet distribution of the level of compliance with the emissions standards. This is necessary in order to ratio the LTOs of each type according to the level of emissions compliance (ie, no standards, NME or NCE standards compliance). The basic data come from reference 7 which offers a U.S. fleet projection through 1985. It is then necessary to extrapolate this projection to 1990 and to assume that a comparable distribution holds for the aircraft types in the foreign fleet using JFK.

Reference 7 postulates that there is no SST in the U.S. fleet and is therefore distorted for this purpose. The existence of an SST in the U.S. fleet would impact the numbers of 3 engine and 4 engine jumbo aircraft, specifically through a lower production rate in the 1980's.

From (4), U.S. carriers haul 48% of the SST PAX and it is thus assumed that the U.S. will possess 48% of the global SST fleet of 110 Concordes and 40 ASTs. Therefore, the U.S. SST fleet carries

Concorde: 120 x .7 x 53 x 2 = 8904 PAX
AST: 250 x .7 x 19 x 2 = 6650 PAX

per day, assuming two departing flights per day.

Subsonic competitor aircraft (3 and 4 engine jumbo) individually carry per day,

3 engine jumbo: 380 x .7 x 1 = 266 PAX
4 engine jumbo: 400 x .7 x 1 = 280

assuming one departing flight per day. Also assuming, for convenience, about equal numbers of PAX on the two subsonic types, then

$$N = \frac{8904 + 6650}{.5 \times (266 + 280)} = 28.5$$

or about 29 three engine jumbos and 28 four engine jumbos are equivalent to the U.S. SST fleet of 53 Concordes and 19 ASTs (out of a global SST fleet of 150). Furthermore, as the Concorde is basically an aircraft whose engine will be held to the NME standards as far as the U.S. airline purchases are concerned, it is logical to assume that its subsonic equivalent fleet would also be subject to the NME standards. Thus, U.S. Concordes serve

120 x .7 x 53 x 2 = 8,900 PAX/day

(all airports) and the equivalent subsonic fleet would be

$$N = \frac{8,900}{.5x(266 + 280)} = 32 \text{ NME aircraft}$$

of which, as postulated above, half are 3 engine jumbo and half are 4 engine jumbo. Treating the AST in the same fashion, it is found that 25 subsonic jumbos are necessary to replace the AST (and vice versa), again equally split between 3 and 4 engine aircraft. Thus in summary, the U.S. SST fleet of 53 Concordes (NME) and 19 ASTs (NCE) is equivalent to

Standard	3 engine jumbo	4 engine jumbo
NME	16	16
NCE	13	12
	29	28

Reference 7 records only the net aircraft of each type (2 engine narrow, etc.) in the fleet each year up to 1985. Three additional pieces of information must be added by hypothesis or assumption:

1. Attrition - With or without continued production, older planes (those complying with no standards) are removed from service. Attrition is estimated here by postulating a 20 year life (initial production dates given in reference 5), and guessing at the initial production rate on the basis of the fleet size after five or more years (as given by reference 7). The attrition rate after the first twenty years of service is then roughly equal to that initial production rate.

2. Extrapolation - As reference 7 goes only up until 1985, the projection is extrapolated to 1990 by continuing the net growth rate of the 1983-1985 period through 1990. The production rate is thus determined by the net growth and the attrition. While there is no sound reason for this simple extrapolation, any other projection is equally arbitrary within the available knowledge and also suffers from a lack of a historical basis.

3. Production of NCE aircraft - The T2 class NCE standards go into effect in 1981, but it cannot be expected that after that date all newly produced aircraft will be powered by engines subject to those standards (Recall that the NCE standards apply only to engines that are newly certified; continued production of existing engine types must comply only with the NME standards). It is assumed here that the first NCE type engines will be produced during 1984 and will constitute 20% of the production. Each succeeding year will add another 20% until 1989, during which and thereafter, all engines built will meet the NCE standards.

Tables VIII through XII summarize the information of reference 7 as extended and amended according to the above mentioned criteria.

As no projections are available for the foreign fleet using JFK, it is necessary to assume, as discussed above, that each type in that fleet will have a distribution of levels of emissions compliance the same as the U.S. fleet. The presence of the 2 engine jumbo in the foreign fleet

Table VIII

Type: 2 engine narrow body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	0	0	0	0	0	0	0	0	0	0	0	
(NME)	37	32	19	14	5	11	10	6	15	0	0	
(NCE)	0	0	0	0	0	3	6	10	61	76	76	
Attrition												
(No std)	0	4	5	4	7	20+	20	20	80++	80	80	
Net in* Fleet												
(No std)	684	684	680	675	671	664	644	624	604	524	444	364
(NME)	0	37	90	88	102	107	118	128	134	149	149	149
(NCE)	0	0	0	0	0	0	3	9	19	80	156	236

* As of January 1

\+ standard body aircraft began production in 1964; estimated initial production rate ≈20/year

++ stretched body aircraft began production in 1967; estimated initial production rate ≈60/year

Net growth rate (1983 - 1985) = 0.5%

Table IX

Type: 3 engine narrow body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)												
(NME)	0	0	0	0	0	0	0	0	0	0	0	
(NCE)												
Attrition												
(No std)	5	22+	63	48	23	20	32	32	32	92++	92	
Net in* Fleet												
(No std)	840	835	813	750	702	679	659	627	595	563	471	379
(NME)	0	0	0	0	0	0	0	0	0	0	0	0
(NCE)	0	0	0	0	0	0	0	0	0	0	0	0

* As of January 1

\+ standard body aircraft began production in 1961; average estimated production rate ≈32/year (these attrition figures to 1985 based on reference 7 directly).

++ stretched body aircraft began production in 1968; estimated initial production rate ≈60/year.

Table X

Type: 3 engine super stretched body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	0	.	.	.	0	0	0	0	0	0	0	
(NME)	51	.	.	.	78	54	33	36	20	0	0	
(NCE)	0	.	.	.	0	14	22	53	82	118	136	
Attrition												
(No std)	0	0	0	0	0	0	0	0	0	0	0	0
Net in* Fleet												
(No std)	77+	77	.	.	.	77	77	77	77	77	77	77
(NME)	0	51	.	.	.	379	433	466	502	522	522	522
(NCE)	0	0	.	.	.	0	14	36	89	171	289	425

* As of January 1

\+ Production starts 1978

Net growth rate (1983 - 1985) = +15.3%

Table XI

Type: 3 engine jumbo body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	0	.	.	.	0	0	0	0	0	0	0	
(NME)	22	.	.	.	40	34	28	20	11	0	0	
(NCE)	0	.	.	.	0	8	19	31	45	61	97	
Attrition												
(No std)	0	0	0	0	0	0	0	0	0	0	30+	
Net in* Fleet												
(No std)	305	305	.	.	.	305	305	305	305	305	305	275++ (275)
(NME)	0	22	.	.	.	157	191	219	239	250	250	250 (234)
(NCE)	0	0	.	.	.	0	8	27	58	103	164	261 (248)

* As of January 1

\+ Production started in 1969; estimated initial production rate ≈30/year

Net growth rate (1983 - 1985) = +9.3%

++ SST adjustment in parentheses. NME and NCE production has been reduced by 1990 by 16 and 13 aircraft respectively to account for the SST aircraft in the U.S. fleet.

Table XII

Type: 4 engine jumbo body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	0	.	.	.	0	0	0	0	0	0	0	
(NME)	17	.	.	.	29	26	22	16	9	0	0	
(NCE)	0	.	.	.	0	6	14	24	36	70	76	
Attrition												
(No std)	0	0	0	0	0	0	0	0	0	20+	20	
Net in* Fleet												
(No std)	164	164	.	.	.	164	164	164	164	164	144	124 (124)++
(NME)	0	17	.	.	.	107	133	155	171	180	180	180 (166)
(NCE)	0	0	.	.	.	0	6	20	44	80	150	226 (214)

* As of January 1

\+ Production began in 1968; estimated initial production rate ≈20/year

Net growth rate (1983 - 1985) = 11.9%

++ SST adjustment in parentheses. NME and NCE production has been reduced by 1990 by 16 and 12 aircraft respectively to account for the SST aircraft in the U.S. fleet.

requires the additional assumption that its distribution of levels of compliance is the same as that of the 3 engine jumbo in the U.S. fleet, an aircraft of similar age and generally similar use.

If the LTO cycle frequency at JFK of the different aircraft types reflects the distribution of levels of emissions compliance as presented in Tables VIII through XII then, the LTO cycle frequency for 1990 at JFK (Table II) can be broken down as follows:

Table XIII

LTO cycles per year (JFK)

Type	No Standards	NME Standards	NCE Standards
2 engine narrow	8,727	3,572	5,658
3 engine narrow	15,294		
4 engine narrow+	1,679		
3 engine superstr.++	1,528	10,364	8,438
2 engine jumbo*	2,173	1,976	2,063
3 engine jumbo	13,363	12,149	12,683
4 engine jumbo	4,472	6,492	8,150
SST**	4,867	8,517	4,866

\+ Foreign carriers only. Production assumed ceased prior to 1979.

* Foreign carriers only. See comment in text regarding assumed distribution.

++ U.S. carriers only.

** Global distribution postulated based on anticipated production rates and possible entry date of an AST.

III. Impact Calculation

The annual pollution contribution of each type of aircraft is calculated according to the formula:

$$\text{Pollutant/year/type} = \sum_{i=1}^{3} \text{(Number of LTOs/type/year)} \times$$

(Number of engines per aircraft for given type) x
(pollutant/engine over JFK LTO cycle for given type);

for each of the three pollutants, HC, CO, and NOx. The summation over i (1, 2, 3) is for the independent consideration of each of the three levels of compliance, No Standards, NME Standards, and NCE Standards. The distinction of the level of compliance affects two terms, (1) the number of LTO cycles per year per type (Table XIII), and (2) the pollution level per engine over the cycle (Tables IV, VI, and VII).

Two Opposite Cases are Treated:

(1) No Standards. This estimates the aircraft pollution load in 1990 if all standards not presently enforced (e.g., the JT8D smoke standard is presently enforced) are revoked. This then forms a baseline against which to compare the utility of the standards if enforced as presently promulgated (or about to be, in the case of the T5 class).

(2) Standards implemented as presently promulgated, including the draft T5 class standards. This represents the optimum situation (maximum control). Further improvements in the emissions by aircraft at JFK in 1990 must come from one or more of four possible choices: (a) promulgation of standards for in-use engines for either or both of the T2 and T5 classes (retrofit), (b) improvements in the time in the taxi/idle mode at JFK in the future, (c) more rapid replacement of old aircraft with new, principally those meeting the NCE standards, and (d) a different distribution of aircraft types. The EPA has control over (a), the FAA might be able to achieve improvements through (b) and (c), the latter indirectly through noise control regulations, while improvements through method (d) would arise largely through market forces.

Consider first the case of no standards at all (except for the T4 class or JT8D in-use engine smoke standard now in force, which achieves large reductions in HC and CO). The results are presented in Table XIV.

Table XIV

JFK 1990 Emissions with No Emissions Standards in Effect

Type	LTOs/ year		No. of engines	Pollutants/LTO/engine HC	CO	NOx	Tons of pollutant/year HC	CO	NOx
2 eng nr	17,957	x	2	x (5.9,	24.1,	10.5)	106	433	189
3 eng nr	15,294	x	3	x (5.9,	24.1,	10.5)	135	553	241
4 eng nr	1,679	x	4	x (60.0,	72.0,	6.4)	201	242	21
3 eng nr superstr	20,330	x	3	x (1.5,	19.0,	6.8)	46	579	207
2 eng J	6,212	x	2	x (18.4,	46.4,	29.8)	114	288	185
3 eng J	38,195	x	3	x (29.1,	54.0,	26.4)	1,667	3,094	1,513
4 eng J	19,114	x	4	x (27.0,	71.8,	22.6)	1,032	2,745	864
				subsonic subtotal			3,301	7,934	3,220
Concorde	13,505	x	4	x (53.0,	199.7,	26.7)	1,432	5,394	721
AST	4,745	x	4	x (68.8,	259.4,	34.7)	653	2,462	329
				supersonic subtotal			2,085	7,856	1,050
				grand total			5,386	15,790	4,270

Consider next the case in which all the presently promulgated standards and the about to be promulgated T5 class standards are implemented. The results are presented in Table XV. The figures of Tables XIV and XV or manipulations of these numbers appear in Table I of the preamble to the draft T5 class (SST) emissions regulations, appropriately rounded off.

Table XV

JFK 1990 Emissions with Standards
in Effect

Type	Level of Compliance*	LTOs/ Year		No. of Engines		Pollutants/LTO/cycle HC	CO	NOx	Tons of Pollutant/year HC	CO	NOx
2 eng narrow	NS	8,727	x	2	x	(5.9,	24.1,	10.5)	51.5	21.03	91.6
	NME	3,572	x	2	x	(1.3,	7.0,	4.4)	4.6	25.0	15.7
	NCE	5,658	x	2	x	(0.8,	6.2,	5.6)	4.5	35.1	31.7
3 eng narrow	NS	15,294	x	3	x	(5.9,	24.1,	10.5)	135.4	552.9	240.9
4 eng narrow	**	1,679	x	4	x	(33.5,	47.4,	9.6)	112.5	159.2	32.2
2 eng Jumbo	NS	2,173	x	2	x	(18.4,	46.4,	29.8)	40.0	100.8	64.8
	NME	1,976	x	2	x	(3.5,	18.6,	11.8)	6.9	36.8	23.3
	NCE	2,063	x	2	x	(1.9,	14.1,	12.8)	3.9	29.1	26.4
3 eng Jumbo	NS	13,363	x	3	x	(29.1,	54.0,	26.4)	583.3	1,082.4	529.2
	NME	12,149	x	4	x	(3.2,	17.0,	10.8)	58.3	309.8	196.8
	NCE	12,683	x	3	x	(1.9,	14.1,	12.8)	36.2	268.5	243.5
4 eng Jumbo	NS	4,472	x	4	x	(27.0,	71.8,	22.6)	241.5	642.2	202.1
	NME	6,492	x	4	x	(4.1,	22.0,	14.0)	53.2	285.7	181.8
	NCE	8,150	x	4	x	(1.9,	14.1,	12.8)	31.0	229.8	208.6
3 eng	NS	1,528	x	3	x	(1.5,	19.0,	6.8)	3.4	43.6	15.6
superstr	NME	10,364	x	3	x	(1.6,	8.5,	5.4)	24.9	132.1	84.0
	NCE	8,438	x	3	x	(0.8,	6.2,	5.6)	10.1	78.5	70.9
					subsonic subtotal				1,401.2	4,221.8	2,259.1
Concorde	NS	4,867	x	4	x	(53.0,	199.7,	26.7)	515.9	1,943.9	259.9
	NME	8,517	x	4	x	(12.6,	96.0,	26.7)	214.5	1,635.3	454.8
AST	NCE	4,866	x	4	x	(4.1,	32.8,	17.8)	39.9	319.2	173.2
					supersonic subtotal				770.4	3,898.4	887.9
					grand total				2,171.6	8,120.2	3,147.0

* NS = No Standards
NME = Newly Manufactured Engine standards
NCE = Newly Certified Engine standards

** Complies only with the T3 class (JT3D) in-use engine smoke standard which produces substantial gains in HC and CO control.

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