Technical Support Report for Regulatory Action

Cost-Effectiveness Analysis of the Proposed Revisions in the Exhaust Emission Standards for New and In-Use Gas Turbine Aircraft Engines Based on Industry Submittals

by

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NOTICE

Technical support reports for regulatory action do not necessarily represent the final EPA decision on regulatory issues. They are intended to present a technical analysis of an issue and recommendations resulting from the assumptions and constraints of that analysis. Agency policy considerations or data received subsequent to the date of release of this report may alter the recommendations reached. Readers are cautioned to seek the latest analysis from EPA before using the information contained herein.

Standards Development and Support Branch
Emission Control Technology Division
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Office of Air and Waste Management
U.S. Environmental Protection Agency

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INTRODUCTION

This report contains a cost-effectiveness analysis of the proposed revisions in exhaust emission standards for new and in-use aircraft gas turbine engines using information supplied by engine manufacturers. The resulting cost-benefit ratios may be compared with those of other aircraft and non-aircraft pollution abatement control strategies in order to determine the most cost effective means of achieving the National Ambient Air Quality Standards (42 CFR §420).

The control strategies analyzed are:

1. Control of newly manufactured gas turbine engines in 1981 for HC and CO only;

2. Retrofit of in-use gas turbine engines in 1985 for HC and CO only (to the same levels as in #1); and

3. Control of newly manufactured gas turbine engines in 1984 for HC, CO, and NOx.

The lack of detailed data available for study has made a rigorous analysis impossible. The cost information received thus far is incomplete and poorly documented; therefore, it is impossible to determine the validity of the data submitted (Appendix A).

Furthermore, the very nature of the study necessitates using assumptions and projections in an attempt to ascertain future facts. No matter how carefully considered, these forecasts will be subject to error and interpretation.

Within the constraints described above, the cost-effectiveness figures generated by this analysis represent EPA's best estimate of the costs imposed by the control strategies under consideration based on industry submittals.

In this analysis, the JT8D is assumed to be out of production by 1984. However, shortly after finalization of the report, the EPA learned that production of this engine would continue and, in fact, a growth version of the engine was planned. This new information along with EPA's independent cost estimate of the proposed standards will be addressed in a subsequent report.

METHODOLOGY

The procedure used in this analysis consisted of determining the cost increment and the total reduction in fleet exhaust emissions for each control strategy. A portion of the total cost was then applied to each individual pollutant. The resulting HC, CO, and NOx cost-effectiveness factors are defined in terms of dollars spent per ton of pollutant saved ($/Ton). A discussion of each part of the methodology is presented in the following sections. The undiscounted lifetime costs (zero discount rate), expressed in 1976 dollars, are used throughout this analysis.

Emissions Reduction

The pollution abatement brought about by the use of a low-emission version of an engine is computed by finding the net reduction per landing-takeoff (LTO) cycle and multiplying that figure by an estimate of the total LTO cycles that engine will experience during its useful life (References 1 and 2).

A complete discussion and table of the emission performances for the engines affected by the proposed regulations are presented in Appendix B.

Cost

The incremental cost of each control strategy is conveniently separated into four major components: non-recurring, manufacturing, operating, and maintenance. In most instances, the amounts of each cost

component were supplied by gas turbine engine manufacturers (References 3, 4, and 5). When the costs associated with a specific engine were not identified, estimates based on other engines produced by the same manufacturer or a similar model from a different manufacturer were used.

Non-recurring. This cost component is composed of several elements: design, development, certification, and initial production. These funds represent the corporate investment associated with the application of demonstrated technology to specific engine families and must be recovered in the engine selling price. Not included are the research and development (R&D) costs of initial design and engine demonstration which were funded through U.S. Government contract and Independent Research and Development (IR & D) money.

Manufacturing. The cost of manufacturing refers only to the increment in engine selling price as a consequence of the increased complexity or more expensive materials found in a low-emission engine. This burden is generally attributed to the combustor and fuel supply system, but may include increased costs to manufacture the pressure casing and equipment bay.

Appendix C contains a discussion and table of the non-recurring costs and unit costs, which reflect the manufacturing expenses, associated with the various control strategies.

Operating. In this analysis, the operating cost is defined as the increment in fuel consumption between regulated and non-regulated

engines. No performance penalties (such as a loss of thrust) are expected from the use of low-emission technology.

The incremental fuel use is discussed and calculated in Appendix D.

Maintenance. Although generally considered an operating expense, maintenance cost is segregated in this study because it includes subject areas for which no estimates are available, or elements which are too abstract to define with any certainty. These expenses, typically incurred by the air carriers, are excluded from this analysis.

Fleet Projection

Having obtained the emissions reduction and cost of control for each engine model, it is necessary to average them over the fleet in order to obtain overall figures. Three fleets are of interest: (1) the fleet of pre-1981 aircraft which is subject to the 1985 Retrofit Standard, (2) the 1981 to 1984 aircraft fleet which is subject to the 1981 NME Standard; and (3) the 1984 and beyond fleet of new aircraft which is subject to the 1984 NME Standard.

The projection used to obtain each fleet mix is based on EPA TSR AC76-03, (Reference 6). In addition to this, certain further assumptions had to be made, e.g., that the 3 engine wide body fleet (given in the projection) consists of equal numbers of each candidate aircraft. These

assumptions along with a summary of the fleet projection from TSR AC76-03 that is relevant to this analysis are given in Appendix E.

Cost Apportionment

The costing methodology employed in this analysis is consistent with that used for automobile emission control strategies (Reference 7). For the 1981 NME and 1985 Retrofit Standards which control only HC and CO, no quantitative approach to cost application exists since the same technology controls both species. For this reason, the cost of control is divided equally between the two pollutants.

The 1984 NME Standard regulates NOx in addition to HC and CO. Since the allowable levels for HC and CO are the same as 1981 NME, the same cost of control is assigned to these two pollutants for 1984 NME and any additional burden is attributed to NOx control.

Cost-Effectiveness

The cost effectiveness for each of the proposed standards is calculated by first finding the total cost as follows:

Total Cost =

$$\text{Total non-recurring costs} + \text{Total selling price increment} + \text{Total fuel consumption increment} \quad (1)$$

For the 1981 NME and 1985 Retrofit Standards, 50 percent of the total cost is applied to the total reduction in each pollutant which yields the final cost-effectiveness ratio.

$$\text{Cost effectiveness for pollutant A} = \frac{\text{50\% of equation 1}}{\text{Total reduction in pollutant A}} \qquad (2)$$

For the 1984 NME Standard, the cost-effectiveness ratio for HC and CO is the same as that found in Equation 2 for the 1981 NME Standard. These ratios are then used to determine the NOx cost-effectiveness ratio in the following manner:

$$\text{HC allocation} = (\text{Total reduction in HC})\ (\text{Eq. 2 for HC}) \qquad (3)$$

$$\text{CO allocation} = (\text{Total reduction in CO})\ (\text{Eq. 2 for CO}) \qquad (4)$$

$$\text{NOx allocation} = \text{Eq. 1 for 1984 NME} - (\text{Eq. 3} + \text{Eq. 4}) \qquad (5)$$

$$\text{Cost effectiveness for NOx} = \frac{\text{Eq. 5}}{\text{Total reduction in NOx}} \qquad (6)$$

DISCUSSION

EMISSION REDUCTIONS

The exhaust emission reductions are calculated over a 15 year period to approximate the corporate accounting lifetime. This interval is somewhat arbitrary because the rigorous maintenance schedule of an aircraft turbine engine essentially precludes its ever being discarded. Since the engine's service life is practically limitless, the exhaust reductions are also. In this respect aircraft engines differ from other mobile sources, such as automobile engines, which have rather definite useful lives.

It should be noted that because of limitations in the 1984 NME fleet forecast, only a 10 year production period is accounted for. Since the production runs of engines in compliance with this standard are expected to be greater than 10 years, this limitation causes the total emission reductions to be under estimated.

Tables 1, 2, and 3 summarize the lifetime reductions in gaseous exhaust emissions for each engine as well as the total reduction for each fleet affected by the 1981 NME, 1985 Retrofit, and 1984 NME Standards, respectively.

By comparing the total lifetime reductions in each of the tables, the significance of the pollution abatement brought about by the 1985

Table 1

Reductions in Gaseous Emissions
Resulting from the 1981 NME Standards

Model	Tons/Engine/Lifetime[a] HC	CO	In-Service[b] Engines	Total Tons/Lifetime (000) HC	CO
JT8D-17	70	204	76	5.3	15.5
JT9D-7	146	264	140	20.4	37.0
JT9D-70	72	242	140	10.1	33.9
CF6-6	87	174	100	8.7	17.4
CF6-50	125	207	100	12.5	20.7
CFM56	42	205	732	30.7	150.1
RB211-22	386	447	52	20.1	23.2
RB211-524	351	472	52	18.3	24.5
TOTAL			1388	126.1	322.3

[a] See Appendix B.

[b] See Appendix E.

Table 2

Reductions in Gaseous Emissions
Resulting from the 1985 Retrofit Standard

Model	Tons/Engine/Lifetime[a] HC	CO	In-Service[b] Engines	Total Tons/Lifetime (000) HC	CO
JT8D-17	47	136	3399	159.8	462.3
JT9D-7	97	176	804	78.0	141.5
CF6-6	58	116	358	20.8	41.5
CF6-50	83	138	358	29.7	49.4
CFM56	42[c]	205[c]	78	3.3	16.0
RB211-22	257	298	358	92.0	106.7
TOTAL			5355	383.6	817.4

[a]Retrofitted engine lifetime is 10 years since most engines have already expended some of their useful life. See Appendix B.

[b]See Appendix E.

[c]Most of these engines will be new, therefore, the full 15 year lifetime value is used.

Table 3

Reductions in Gaseous Emissions
Resulting from the 1984 NME Standards

Model	Tons/Engine/Lifetime[a] HC	CO	NOx	In-Service[b] Engines	Total Tons/Lifetime (000) HC	CO	NOx
JT9D-7	140	220	121	892	124.9	196.2	107.9
JT9D-70	53	195	63	892	47.3	173.9	56.2
CF6-6	87	195	87	554	48.2	108.0	48.2
CF6-50	122	225	97.5	554	67.6	124.7	54.0
CFM56[c]	42	205	26	3030	127.3	621.2	78.8
RB211-22B	386	447	55	277	106.9	123.8	15.2
RB211-524	338	446	95	277	93.6	123.5	26.3
TOTAL				6476	615.8	1471.3	386.6

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[a] See Appendix B.

[b] Normalized to 10 years production (2 x 5 years production). See Appendix E.

[c] JT10D's burden included.

retrofit is apparent. Furthermore, the number of JT8D engines is so large that its contribution to the total lifetime reduction of the retrofitted fleet is approximately 40 percent for HC and 60 percent for CO (Table 2).

The JT10D was omitted in the 1981 NME and 1985 retrofit fleets (Tables 1 and 2). The engine's production design has not been finalized and no companion airframe exists at this time. For these reasons, it is unlikely that JT10D engines will be produced under the above standards.

The JT10D is expected to hold a significant share of the market in compliance with the 1984 NME Standard. However, the EPAP values and rated thrust of the engine are unknown; therefore, these values were arbitrarily considered to be equivalent to those for the CFM56, an engine of similar size. For this reason, the JT10D is included in the CFM56 values used in Table 3.

The retrofit projection (Table 2) omits the JT9D-70 since very few of these will be in the fleet. The impact of its exclusion is negligible.

COST

Within this section, engine costs and operating costs are discussed. Engine costs are separated into non-recurring and recurring categories. Recurring costs are represented by (1) the selling price increment engine which reflects increments in the manufacturing complexity and

hardware costs. Neither the selling price increment nor the retrofit unit cost include pro-rated non-recurring expenses.

Engine Costs

The quantification of future costs is difficult, and when combined with the incomplete and undocumented cost estimates submitted by the engine manufacturers, conclusions must be accepted with caution. Furthermore, the results of this section should be regarded only as accounting for a significant share of the impact brought about by the proposed standards.

Some important cost elements are excluded in this analysis. NOx control schemes (category 3) may initially degrade the durability of the combustor and various high pressure turbine parts below contemporary levels, causing higher operating costs from increases in parts and service, and increased engine removal rates. Although the technology has been defined, its application to specific engine families remains. Until more hardware is finalized, the quantification of any maintenance increment imposed on the airline industry is tenuous at best; therefore, this type of expense is not considered in the cost-effectiveness calculations.

Other expenses to the airlines and airframe manufacturers such as the development and installation costs to incorporate low-emission engines into existing airframe designs are also unaccounted for since the magnitude of this change is unknown. It should be noted, however, that the implementation date of the 1985 retrofit was chosen to minimize installation costs by

allowing sufficient lead time for incorporating low-emission engine parts into existing maintenance schedules.

Similarily, elements which may offset some of the costs associated with the proposed standards are excluded from consideration.

1. The aromatic content of jet fuel has been escalating in recent years and the use of high-aromatic shale and coal derived fuels in the future is almost certain. Conventional technology combustors cannot cope with these fuels: combustion becomes smokey and increases in flame luminosity cause combustor cooling problems. Category 3 technology combustors avoid these problems since they are lean burning and, therefore, operate at cooler temperatures. Moreover, higher aromatic fuels are expected to be lower in price.

2. The application of non-recurring expenses in this analysis artifically inflates the final cost-effectiveness figures. In reality this money will be amortized over a greater number of engines since (1) engines used by airlines not operating within the U.S. are not included and (2) the 1984 NME section considers only the engines produced in the first 10 years.

3. The effects of the learning curve reduce production costs as experience accumulates.

4. As technology progresses, maintenance problems will be solved by re-establishing or improving component durability levels.

5. The economic value of the physical, biological, and medical consequences of lower pollutant concentrations are not estimated.

To derive a more accurate estimate of the total selling price increment, a 20 percent increase in the in-service fleet numbers (Appendix E) is used to develop cost information. These extra units reflect the spare parts inventory of the airlines.

The costs associated with the 1981 NME, 1985 Retrofit, and 1984 NME Standards are summarized in Tables 4, 5, and 6, respectively. The differences between engine families are attributed to engine size and combustor complexity. No additonal R & D is required for the 1985 retrofit because the same hardware is used to meet the 1981 NME Standard.

Operating Costs

The only operating expense identified as a consequence of the control schemes is the increment in fuel consumption between regulated and non-regulated engines. To meet the proposed standards, one of the design points will be an improvement in the combustion efficiency at idle from approximately 95 percent to essentially 100 percent, resulting in a 5 percent decrease in the idle specific fuel consumption (SFC) for most engines (Reference 8). The JT8D is an exception; its smokeless combustor is already better than average. Therefore, a 1 percent improvement is allowed for this engine.

Table 4

The Costs Associated with the 1981
NME Standard (Category 1 and 2 Technology)

(In thousands of dollars)

Model	Non-Recurring[a] Costs	Selling Price[a] Increment/Engine	Total Engines	Selling Price Increment/Family
JT8D	15,000	13	91	1,183
JT9D-7	16,000	50	168	8,400
JT9D-70	24,000	70	168	11,760
CF6-6	8,000	10	125	1,250
CF6-50	8,000	10	125	1,250
CFM56	8,000	10	878	8,780
RB211-22B	10,000	3	62	186
RB211-524	10,000	3	62	186
TOTAL	99,000			32,995

[a] See Appendix C.

Table 5

The Costs Associated with the 1985 Retrofit Standard
(Category 1 and 2 Technology)

(In thousands of dollars)

Model	Retrofit[a] Unit Cost	Total Engines	Retrofit Cost/Family
JT8D	25	4079	101,975
JT9D-7	90	965	86,850
CF6-6	90	430	38,700
CF6-50	90	430	38,700
CFM56	60	94	5,640
RB211-22B	31	430	13,330
TOTAL			285,195

[a] See Appendix C.

Table 6

The Costs Associated with the 1984 NME Standard
(Category 3 Technology)

(In thousands of dollars)

Model[a]	Non-Recurring[b] Costs	Selling Price[b] Increment/Engine	Total Engines	Selling Price Increment/Family
JT9D-7	70,000	190	1070	203,300
JT9D-70	100,000	190	1070	203,300
CF6-6	30,000	70	665	46,550
CF6-50	40,000	70	665	46,550
CFM56	40,000	50	1818	90,900
RB211-22	55,000	130	332	43,150
RB211-524	55,000	130	332	43,150
JT10D	50,000	120	1818	218,200
TOTAL	440,000			895,100

[a] JT8D is assumed to be out of production and replaced by CFM56.

[b] See Appendix C.

The General Electric engines produced in compliance with the proposed 1981 NME and 1985 Retrofit Standards will experience a net increase in idle SFC. The use of sector burning (category 1) by these engines causes a 10 percent decrease in component efficiency, which coupled with the 5 percent benefit in combustion efficiency, yields a 5 percent overall penalty in idle SFC.

The fuel consumption increments associated with the 1981 NME, 1985 Retrofit, and 1984 NME Standards are summarized in Tables 7, 8, and 9, respectively, in 1976 dollars.

The penalty associated with the GE engines is significant for the 1981 NME and 1985 retrofit fleets (Table 7 and 8). However, as shown in Table 8, the large reduction in fuel consumption for the JT8D engine family offsets the GE penalty and provides an overall fuel savings for the 1985 retrofit fleet. The fuel savings are more pronounced for the 1984 NME fleet. The use of category 3 technology provides a 5% reduction in idle SFC for all engine families.

Cost Effectiveness

The overall cost effectiveness for each of the standards under consideration is presented in Table 10. Cost-effectiveness figures are not presented for specific engine families because the data lacked sufficient detail to produce meaningful results.

As shown in Table 10, requiring the 1985 retrofit in conjunction

Table 7

The Fuel Consumption Increment Associated with the 1981 NME Fleet

Model	In-Service[a] Engines	$ Saved/Engine[b] ($\times 10^{-3}$)	$ Saved/Family ($\times 10^{-6}$)
JT8D	76	9	0.7
JT9D-7	140	27	3.8
JT9D-70	140	26	3.6
CF6-6	104	-20	-2.1
CF6-50	104	-20	-2.1
CFM-56	732	-23	-16.8
RB211-22	52	31	1.6
RB211-524	52	31	1.6
TOTAL			-9.7

[a] See Appendix E.

[b] See Appendix D.

Table 8

The Fuel Consumption Increment Associated with the 1985 Retrofit Fleet

Model	In-Service[a] Engines	$ Saved/Engine[b] ($\times 10^{-3}$)	$ Saved/Family ($\times 10^{-6}$)
JT8D	3399	6	20.4
JT9D-7	804	18	14.5
CF6-6	358	-20	- 4.7
CF6-50	358	-20	- 4.7
CFM-56	78	-23	- 1.8
RB2211-22	358	21	7.5
TOTAL			31.2

[a] See Appendix E.

[b] See Appendix D.

Table 9

The Fuel Consumption Increment Associated with the 1984 NME Fleet

Model	In-Service[a] Engines	$ Saved/Engine[b] ($\times 10^{-3}$)	$ Saved/Family ($\times 10^{-6}$)
JT9D-7	892	27	24.1
JT9D-70	892	26	23.2
CF6-6	554	20	11.1
CF6-50	554	20	11.1
CFM-56[c]	3030	23	69.7
RB211-22	277	31	8.6
RB211-524	277	31	8.6
TOTAL			156.4

[a] See Appendix E.

[b] See Appendix D.

[c] Includes JT10D burden.

with the 1981 NME Standard is more cost effective than the 1981 NME Standard alone.

The cost effectiveness of controlling aircraft turbine engines for HC in 1981 and 1985, and NOx in 1984 is considered to be comparable with that of other sources under consideration (Table 11).

Table 10

The Overall Cost-Effectiveness of the Standards Under Consideration ($/Ton)

Pollutant	1981 NME	1985 Retrofit in addition to 1981 NME	1984 NME
HC	560	390	560[a]
CO	220	170	220[a]
NOx	-	-	1316

[a] The HC and CO values are the same as for 1981 NME.

Table 11

The Overall Cost-Effectiveness of Other Control Strategies Under Consideration ($/Ton)

Strategy	HC	NOx[a]
Stationary Engines (75% control)		340
LDV (1.0 g/mile)		450
Utility Boilers (90% control)		1200
LDV (0.4 g/mile)		2300
Gasoline Handling, Stage 1	100[a]	
Gasoline Handling, Stage 2	700[a]	
LDV (0.41 g.mile)	470[a]	
LDV (IM)	420[b]	
Neighborhood Dry Cleaners	770[b]	

[a] Reference 7.

[b] Reference 9.

CONCLUSIONS

The cost-effectiveness information generated in this report is based on a limited amount of data and lacked sufficient detail to allow a rigorous analysis. Within this constraint, the cost-effectiveness figures are considered to be a reasonable approximation of the control costs as a consequence of the standards under consideration based on industry submittals.

The costs of controlling HC and CO to the levels prescribed by the 1981 NME Standard are similar to other control strategies and in combination with the 1985 Retrofit Standard, they are more cost-effective. The price of NOx control under the 1984 NME Standard is considered to be comparable to other proposed control strategies for mobile and stationary sources.

A fuel consumption penalty is associated with the 1981 standard, although when combined with the 1985 retrofit an overall reduction in fuel usage is expected. A very substantial fuel savings is expected from engines in compliance with the 1984 standard.

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APPENDIX A

Aircraft Turbine Engine Manufacturer's Cost Submittals

The pertinent portions of the manufacturer's submittals are presented as follows:

Manufacturer	Page
Pratt and Whitney Aircraft Division of United Technologies	A-2 and A-3
General Electric Aircraft Engine Group	A-4 and A-5
Rolls-Royce (1971) Limited	A-6 and A-7

ATTACHMENT A

5 YEAR LOW EMISSIONS EFFORT SUMMARY

Tabulated below are the expenditures in thousands of dollars for both visible and invisible exhaust emissions reduction efforts for the period 1971 through 1975 by category in then year dollars.

	1971	1972	1973	1974	1975	Total
JT3D/TF33	289.7	131.9	772.4	673.6	313.4	2,181.0
JT3/J57, JT4/J75	204.9	257.2	302.5	786.1	24.8	1,575.5
JT8D	148.6	70.2	90.2	38.3	740.7	1,088.0
JT9D	30.4	172.9	49.9	202.0	2,537.0	2,992.2
FT9	--	--	--	--	46.9	46.9
JT10D	--	--	148.4	103.8	331.2	583.4
JT12/J60	11.0	3.4	0.5	--	--	14.9
TF30	89.2	136.0	16.8	3.0	--	245.0
J52	299.5	150.9	80.6	--	--	531.0
Technology Contracts	208.1	225.0	896.2	783.3	1,677.7	3,790.3
Proposals	61.9	117.4	107.4	223.3	261.6	771.6
Emissions R&D	290.3	790.6	1,066.2	2,504.9	2,798.6	7,450.6
Work for Other Div.	--	181.5	155.0	21.8	--	358.3
Industrial Power	538.0	2,423.6	2,143.1	1,203.4	2,579.5	8,887.6
Total	2,171.6	4,660.6	5,829.2	6,543.5	11,311.4	30,516.3

The source of the funding is as follows:

Government contracts	$ 5,794,100
Independent Research and Development	24,722,200
Total	$30,516,300

ATTACHMENT B

LOW EMISSION BURNER PRICING INFORMATION

MODIFIED CURRENT BURNER

The pricing information given below must be considered as "rough order of magnitude" estimates only, and is in no way to be construed as forming any commitment on the part of Pratt & Whitney Aircraft for use as a basis for the establishment or negotiation of actual prices. The cost of development must be recovered over the number of engines in which the hardware is installed. In the case of the JT8D where no retrofit is planned, and the JT9D-70 where there are relatively few engines in the field the development cost increment will be significant.

	1976 Dollars		
	JT8D	JT9D-7	JT9D-70
Production price increment for modified low emission burners w/o specific development	$13,000	$50,000	$70,000
JT9D retrofit kit price w/o specific development	--	$90,000	$115,000
Development cost	$15,000,000	$16,000,000	$24,000,000

ADVANCED STAGED BURNER

Estimates of the development cost and a price for the JT9D advanced staged burner for the JT9D are an order of magnitude cruder than the above estimates for modified current burners.

The development of this burner for incorporation in production engines in the 1984 time period is estimated to cost up to 100 million (1976) dollars. This assumes this concept can be developed to meet all the operational and reliability criteria of a commercial engine burner, which is still a question at this time. The production engine price increment for this burner is estimated to be 190,000 (1976) dollars exclusive of the development cost increment.

Estimated Costs Of Incorporating Gaseous Pollutant Emissions Control Features Into Operational Engines

Detailed and precise estimates of the costs associated with incorporating gaseous pollutant emissions control capabilities into our CF6 or CFM56 engines are not presently available. Such detailed estimates cannot be made at this time, because the full extent of the changes needed in these engines to meet the applicable standards are not fully known as yet.

In the statement we presented at the public hearings, we recommended that the gaseous pollutant emissions standards applicable to engines already in production or in development be modified to permit the use of current technology combustors. As is discussed in our statement, we believe current technology combustors can be developed and modified to meet or approach the presently defined standards for carbon monoxide and unburned hydrocarbons emissions, but cannot be made to meet the presently defined standards for oxides of nitrogen emissions.

Based on the assumed use of modified versions of current technology combustors, the following are preliminary estimates of the costs involved in the case of our two CF6 engine families:

	Approximate Costs For Each CF6 Engine Family (In 1976 Dollars)
Design, Development, Qualification And Initial Production Costs	$8,000,000
Added Price Per Production Engine - For Newly Manufactured Engines (Excluding Pro-rated Design, Development, Qualification And Initial Production Costs)	$ 10,000
Unit Engine Price To Retrofit (During Overhaul) Existing Engines (Excluding Pro-rated Design, Development, Qualification And Initial Production Costs)	$ 90,000

Continued on Page 6

These estimated costs and prices are based on the assumed use of both sector burning at idle and combustor dome design modifications to attain reduced carbon monoxide and unburned hydrocarbons emissions levels.

As is discussed in the statement we presented at the hearings and in our accompanying report submittal, we believe that consideration of the use of an advanced technology combustor design concept, such as the Double Annular Dome combustor design concept we are currently developing in the NASA Experimental Clean Combustor Program, in existing production or development engines is not appropriate at this time. However, for comparative purposes only, the following are some very preliminary estimates of the costs of incorporating such an advanced technology combustor design concept into our CF6 engines:

	Approximate Costs For Each CF6 Engine Family (In 1976 Dollars)
Design, Development, Qualification And Initial Production Costs (Excluding NASA Experimental Clean Combustor Program Funding)	$32,000,000 to $40,000,000
Added Price Per Production Engine - For Newly Manufactured Engines (Excluding Pro-rated Design, Development, Qualification And Initial Production Costs)	$ 70,000 to 100,000

These latter estimates are based on the use of the Double Annular Dome Combustor design concept in its present form and, of course, are based on the assumption that this advanced combustor design approach is found to be generally satisfactory in the forthcoming demonstrator engine tests.

We trust this information will be useful in your assessments of the presently defined and proposed gaseous pollutant emissions standards. If you have any questions or comments on any of this information, or any contained in our previously submitted statement and report, please do not hesitate to contact me.

Very truly yours,

D. W. Bahr

D. W. Bahr, Manager
Advanced Combustion &
Emissions Control Technology

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Attachments

4. Cost of Incorporating New Combustors - Large Engines

4.1 Introduction

The prices quoted in the main Rolls-Royce response to the EPA Public Hearings of 27/28 January 1976 (DP 279) were derived assuming a worldwide application. This is considered realistic as far as newly manufactured large engines are concerned since Rolls-Royce would want to maintain only one production standard. This would not apply, however, to new hardware required for retrospective fitment to in-service engines - since only US operators would be required to purchase the new reduced pollution combustors and water injection kits.

The prices are derived from the estimated manufacturing unit cost plus the recovery of the associated non-recurring costs.

4.2 Newly Manufactured Engines

It is assumed that the new combustor will be a modified version of the existing design. Therefore its unit manufacturing cost will be only slightly greater than the existing version. The majority of the additional costs, however, are non-recurring and are largely associated with recovering the engineering programme expenditure. Thus the increase in price for each engine incorporating the improved combustor is mainly dictated by the projected sales for these engines. On the other hand if water injection is required, this represents a major addition to the engine equipment and thus also to the unit price. Again the price per engine will vary depending on the projected sales.

The extra price per engine assuming fitment to the engines of US operators only, is shown for comparison with those based on world wide application in the table below at 1976 rates:

RB211 Engines	New Combustor Alone	New Combustor plus Water Injection Equipment
Worldwide Market (quoted in DP 279)	$10,000	$54,000
US Only	$22,000	$72,000

4.3 Retrospective Application

4.3.1 Replacement within a 4 Year Period

Rolls-Royce confirms that it could produce new combustors and water injection equipment at a rate which should enable the operators of its engines in the USA to replace existing RB211 liners by the reduced pollution combustor within the four year period to 1985. The investigations which have been carried out have shown, however, that it will not be possible to rework the existing liners to the configuration of the new combustor. Hence costs have been calculated on the basis that new combustors will be purchased. Note also that no allowance has been made in the prices quoted for stripping and rebuilding the engine specially to fit the new combustor or for loss of revenue to the operator caused by the unscheduled removal of the engine should this be required to meet the retrofit programme schedule.

The predicted price per engine for the retrofit parts, calculated on the above assumptions, is shown in the table below:

RB211 Engines	New Combustor Alone	New Combustor plus Water Injection Equipment
US Market only	$47,000	$98,000
Worldwide (quoted in DP 279)	$37,000	$82,000

It should be noted that the true cost of retrofit action to the airline operators would in effect be greater than the values specified. No attempt has been made to assess the write off value of the existing combustor hardware which should be included in any estimate of the real cost of a four year replacement programme.

Cont'd...

APPENDIX B

Derivation of Emissions Reduction over an Engine's Lifetime

The regulated EPAP values used to derive the exhaust emission reductions per engine reflect the actual levels achievable based on current test results. By using these values instead of the more conservative approach of limiting the EPAPs to the maximum allowable levels permitted by the regulation, a more realistic simulation of the actual decrease in air pollutants at major air carrier terminals is accomplished.

In a few instances where the demonstrated EPAPs were above the maximum permissable levels, they were adjusted to meet the standard. This is consistent with the fact that all engines must comply with the regulation or they will not be certified. Where no data were available and no reasonable basis for estimating the engine's emissions existed, EPAP values which conformed to the standard were assigned.

The useful life of a new engine is considered to be 15 years. A retrofitted engine has already been in service, therefore, it is assumed to have 10 years of the normal 15 year lifetime remaining. The retrofitted CFM56 is an exception; it is a new engine without an existing application. This means the CFM56 engines in commercial service before 1981 will be practically brand new, hence, the full 15 year lifetime is used.

The retrofitted RB211 engines are likely to be almost entirely of the dash 22 variety. The dash 524 makes up a relatively small share of the total population at this time and is expected to remain a minor element of the RB211 fleet produced prior to 1981 (the engines subject to the retrofit rule). For simplicity, it is assumed that the RB211 retrofit fleet is exclusively composed of the dash 22.

The pounds of pollutant reduced per engine during each LTO cycle is computed by using the following equation:

$$\text{Net Reduction of Pollutant A} = [\text{EPAP(A)}_{\text{unregulated}} - \text{EPAP(A)}_{\text{regulated}}]\ (\text{Impulse}/1000) \qquad (1)$$

Where impulse power is defined as:

$$(\text{Pounds of Rated Thrust})\ \Sigma_{\text{cycle}}\ [(\%\ \text{Power}_{\text{mode}})(\text{Hours}_{\text{mode}})] \qquad (2)$$

The tons of pollutant saved over the lifetime of an engine is determined in the subsequent equation:

$$\text{Lifetime net reduction of Pollutant A} = (\text{Equation 1})(\#\text{LTOs/year})(\text{useful life})/2000\ \text{lbs/T} \qquad (3)$$

where the useful life is the total number of years in service.

The exhaust emission reductions for each engine affected by the standards under consideration are summarized in Tables B-1, B-2 and B-3.

Table B-1

Exhaust Emissions Reduction per Engine Resulting from the 1981 NME Standard (Category 1 and 2)

Engine Model	Pounds Thrust (000)	Impulse	LTOs/yr	EPAP (Unregulated) HC	EPAP (Unregulated) CO	EPAP (Regulated) HC	EPAP (Regulated) CO	Pounds Net Reduction/LTO HC	Pounds Net Reduction/LTO CO	Tons Lifetime[a] Net Reduction/Unit HC	Tons Lifetime[a] Net Reduction/Unit CO
JT8D-17	16	1456	2455	3.1	12.8	0.5	5.2[b]	3.8	12.4	69.7	203.8
JT9D-7	46.2	4598	900	10.4	10.4	0.1	1.9	21.6	39.1	145.9	263.9
JT9D-70	51.2	4655	900	2.4	9.7	0.1	2.0	10.7	35.8	72.3	241.9
CF6-6	38.9	3016	1200	3.4	10.0	0.2	3.6	9.7	19.3	86.9	173.7
CF6-50	49.9	3867	1050	4.3	10.8	0.2	4.0	15.9	26.3	124.9	207.1
CFM56	22.2	1764	2455	1.4	10.6	0.1	4.3[b]	2.3	11.1	42.2	204.6
RB211-22	42	3502	1300	12.0	17.4	0.7	4.3[b]	39.6	45.9	385.8	447.3
RB211-524	50	4442	1300	8.6[c]	14.6[c]	0.5	3.7	36.0	48.4	350.8	471.9

[a] Useful life for new engines is 15 years.

[b] Adjusted to meet standard.

[c] No data; baseline emissions were estimated on the basis of the RB211-22B.

Table B-2

Exhaust Emissions Reduction per Engine Resulting from the 1984 NME Standard (Category 3 Technology)

Engine[a] Model	Pounds Thrust (000)	Impulse	LTOs/yr	EPAP (Unregulated) HC	EPAP (Unregulated) CO	EPAP (Unregulated) NOx	EPAP (Regulated) HC	EPAP (Regulated) CO	EPAP (Regulated) NOx	Pounds Net Reduction/LTO HC	Pounds Net Reduction/LTO CO	Pounds Net Reduction/LTO NOx	Tons Lifetime[b] Net Reduction/Unit HC	Tons Lifetime[b] Net Reduction/Unit CO	Tons Lifetime[b] Net Reduction/Unit NOx
JT9D-7	46.2	4598	900	4.8	10.4	6.5	0.3	3.3	2.6	20.7	32.6	17.9	139.7	220.4	121.0
JT9D-70	51.2	4655	900	2.4	9.7	5.8	0.7	3.5	3.8	7.9	28.9	9.3	53.4	194.8	62.8
CF6-6	38.9	3016	1200	3.4	10.0	7.2	0.2	2.8	4.0	9.7	21.7	9.7	86.9	195.4	86.9
CF6-50	49.9	3867	1050	4.3	10.8	7.7	0.3	3.4	4.5[c]	15.5	28.6	12.4	122.1	225.3	97.5
CFM56	22.2	1764	2455	1.4	10.6	4.8	0.1	4.3[c]	4.0	2.3	11.1	1.4	42.2	204.6	26.0
RB211-22	42	3502	1300	12.0	17.4	5.6	0.7[d]	4.3[d]	4.0[d]	39.6	45.9	5.6	385.8	447.3	54.6
RB211-524	50	4442	1300	8.6[e]	14.6[e]	6.2[e]	0.8[f]	4.3[f]	4.0[f]	34.6	45.8	9.8	337.8	446.1	95.3

[a] JT8D is assumed to be out of production and replaced by the CFM56.

[b] Useful life for new engines is 15 years.

[c] Adjusted to meet standard.

[d] No data; HC and CO levels are the same as 1981 NME (Category 1 and 2) and the NOx level is equal to the standard.

[e] No data; baseline emissions were estimated on the basis of the RB211-22B.

[f] No data; HC, CO, and NOx levels are equal to the standard.

Table B-3

Exhaust Emissions Reduction per Engine Resulting from the 1985 Retrofit Standard (Category 1 and 2 Technology)

Engine Model	Pounds Thrust (000)	Impulse	LTOs/yr	EPAP (Unregulated) HC	EPAP (Unregulated) CO	EPAP (Regulated) HC	EPAP (Regulated) CO	Pounds Net Reduction/LTO HC	Pounds Net Reduction/LTO CO	Tons Lifetime[a] Net Reduction/Unit HC	Tons Lifetime[a] Net Reduction/Unit CO
JT8D-17	16	1456	2455	3.1	12.8	0.5	5.2[b]	3.8	12.4	46.5	135.8
JT9D-7	46.2	4598	900	4.8	10.4	0.1	1.9	21.6	39.1	97.3	175.9
CF6-6	38.9	3016	1200	3.4	10.0	0.2	3.6	9.7	19.3	57.9	115.8
CF6-50	49.9	3867	1050	4.3	10.8	0.2	4.0	15.9	26.3	83.3	138.1
CFM56	22.2	1764	2455	1.4	10.6	0.1	4.3[b]	2.3	11.1	42.2[c]	204.6[c]
RB211-22	42	3502	1300	12.0	17.4	0.7	4.3[b]	39.6	45.9	257.2	298.2

[a] Retrofitted engine lifetime is 10 years since most engines have already expended some of their useful life.

[b] Adjusted to meet standard.

[c] Most of the engines will be new, therefore, the full 15 year lifetime value is used.

APPENDIX C

Derivation of the Incremental Engine Costs Associated with the Proposed Standards

The cost increments considered in this section are the main determinants of selling price: non-recurring costs, the increment in new engine selling price because of increased complexity or more expensive materials, and the parts cost of a retrofit kit. These costs represent the expenses and corporate profits which must be recovered by the engine manufacturers.

The incomplete cost estimates submitted by the manufacturers make the use of several assumptions necessary. The assumptions used to complete the 1981 NME and 1985 retrofit estimates are:

1. The JT8D retrofit unit cost was estimated based on experience with the smoke retrofit and assuming the only necessary change would be new fuel nozzles and minor modifications to the combustor liner; and

2. The CFM56 selling price increment and retrofit unit cost, as well as the R&D cost for the two RB211 dash numbers were estimated by comparing the engine similarities and degree of complexity with the CF6 engine families.

3. The manufacturer's submittal regarding the selling price increment and retrofit unit cost for the two RB211 engines included pro-rated non-recurring costs, therefore, these costs were re-evaluated to exclude this burden.

The 1984 NME estimates were completed using the following assumptions:

1. The R&D for the JT9D-7 was reduced from the manufacturers estimate of $100 million to $70 million because of a mutual benefit between similar engine families (as with the CF6 families);

2. The CF6-6 value for R&D represents the lower end of GE's estimate and the CF6-50 R&D represents the high end;

3. The R&D cost for the CFM56 is considered to be the same as the CF6-50; the incremental selling price is less since the engine is smaller;

4. The values for the two RB211 dash numbers were arbitrarily computed by averaging the JT9D-7 and CF6-50 expenses; and

5. The JT10D values were estimated by comparing the similarities and degree of complexity with the JT9D-7 and CFM56.

Tables C-1 and C-2 summarize the cost information used in this study.

Table C-1

Cost Increment Associated with 1981 NME and
1985 Retrofit Standards (Category 1 and 2 Technology)

(In thousands of dollars)

Model	Non-Recurring Costs	Selling Price Increment/Unit	Retrofit Unit Cost
JT8D	15,000	13	25[a]
JT9D-7	16,000	50	90
JT9D-70	24,000	70	115
CF6-6	8,000	10	90
CF6-50	8,000	10	90
CFM56	8,000	10[a]	60[a]
RB211-22B	10,000[a]	3[a]	31[a]
RB211-524	10,000[a]	3[a]	31[a]
TOTAL	99,000		

[a] Estimated.

Table C-2

Cost Increment Associated with 1984 NME Standards
(Category 3 Technology)

(In thousands of dollars)

Model	Non-Recurring Costs	Selling Price Increment/Unit
JT9D-7	70,000[a]	190
JT9D-70	100,000	190
CF6-6	30,000[a]	70
CF6-50	40,000[a]	70
CFM56	40,000[a]	50[a]
RB211-22	55,000[a]	130[a]
RB211-524	55,000[a]	130[a]
JT10D	50,000[a]	120[a]
TOTAL	440×10^6	

[a] Estimated.

APPENDIX D

Derivation of Fuel Savings Associated with the Proposed Standards

In order to meet the standards under consideration, most manufacturers will improve the combustion efficiency of their engines at idle power from approximately 95 percent to essentially 100 percent. This results in a 5 percent improvement in idle fuel consumption for most engines.

The General Electric engines complying with the 1981 NME and 1985 Retrofit Standards will experience a net increase in idle specific fuel consumption (SFC). The use of sector burning (category 1) by these engines causes a 10 percent decrease in component efficiency, which coupled with the 5 percent benefit in combustion efficiency as described above, yields a 5 percent overall penalty in idle SFC. The 1984 newly manufactured GE engines will use category 3 technology; accordingly, they will be subject only to the 5 percent benefit in combustion efficiency.

The useful life of new engines is 15 years. Retrofitted engines have a 10 year useful life with the exception of the CFM56, a new engine, which has a useful life of 15 years.

The gallons of fuel saved over an engine's useful life are calculated using the following equation:

$$(\#\text{LTOs/yr})(\text{useful life})(\dot{M}_f \text{ Idle})(26/60)(\pm 0.05) \;/\; (6.7) \qquad (1)$$

where:

1. useful life is the number of years the engine will be in service;
2. $\dot{M}_f$ Idle is the fuel flow in pounds per hour;
3. 26/60 is the time in idle mode defined by EPA;
4. $\pm$ 0.05 is the percent fuel benefit or penalty; and
5. 6.7 is the weight of jet fuel in pounds per gallon.

The dollar value of the fuel saved is found by:

$$(\text{Equation 1})(\$0.33) \qquad (2)$$

where \$0.33, including tax, represents a nominal value for jet fuel in 1976.

The lifetime savings for each engine affected by the proposed standards are given in Tables D-1 and D-2.

Table D-1

Lifetime[a] Idle Fuel Savings per Engine
(1981 NME and 1984 NME Standard)

Engine	$\dot{M}_f$ Idle (lbs/hr)	LTOs/yr	Gallons Saved (000)	Dollars[e] Saved (000)
JT8D-17[b]	1150	2455	27	9
JT9D-7	1850	900	81	27
JT9D-70	1800	900	79	26
CF6-6	1060	1200	± 62[d]	± 20
CF6-50	1210	1050	± 62[d]	± 20
CFM56	600[c]	2455	± 71[d]	± 23
RB211-22B	1475	1300	93	31
RB211-524	1500[c]	1300	95	31

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[a]15 year useful life.

[b]1 percent improvement only (smokeless combustor already better than average).

[c]Estimated by authors.

[d]GE engines experience a 5 percent increase in idle SFC under the 1981 NME Standard and a 5 percent improvement under the 1984 NME Standard.

[e]At $0.33 per gallon.

Table D-2

Lifetime[a] Idle Fuel Savings per Engine
(1985 Retrofit Standard)

Engine	$\dot{M}_f$ Idle (lbs/yr)	LTOs/yr	Gallons Saved (000)	Dollars Saved (000)
JT8D[b]	1150	2455	18	6
JT9D-7	1850	900	54	18
JT9D-70	1800	900	53	17
CF6-6	1060	1200	-42[d]	-13
CF6-50	1210	1050	-42[d]	-13
CFM56	600[c]	2455	-71[d]	-23
RB211-22B	1475	1300	62	21
RB211-524	1500[c]	1300	64	21

---

[a]10 year useful life for all retrofitted engines except the CFM56 which has a useful life of 15 years.

[b]1 percent improvement only (smokeless combustor already better than average).

[c]Estimated by authors.

[d]GE engines experience a 5 percent increase in fuel consumption when using stage combustion at idle.

[e]At $0.33 per gallon.

APPENDIX E

Fleet Projection and Engine Inventory

There are three aircraft fleets of interest, each associated with one of the three dates of the standards: 1981 (NME, HC, CO), 1984 (NME, NOx), and 1985 (Retrofit of pre-1981 engines to 1981 levels). These fleets are obtained from an aircraft projection (Reference 1) which is described in terms of airframe classification (e.g., 3 engine wide body) and production rate. With certain simplifying assumptions, the numbers of each kind of engine affected by the standards are found from the fleet information.

Table E-1 through E-5 are amended versions of the original projection. The significant alterations are:

1. Elimination of an early introduction date for engines complying with the NCE (newly certified engine) standards. The progress of the NASA Quiet Clean Experimental Combustor Program and others suggest that there will be no newly certified engines prior to 1990;

2. Delay in production of the new three engine super stretched body aircraft (i.e., B7N7, B7X7) until 1981; and

3. Change of the dates which divide the fleet into the smaller segments subject to the different standards to reflect the newly proposed standards.

Utilization of these tables is achieved by examining the "Net in Fleet" row at the appropriate date. In particular:

Rule	Date and Standard
1985 Retrofit	1985, (No Std)
1981 NME	1984, (NME-1981)
1984 NME	1989, (NME-1984)

The 1985 Retrofit is self explanatory, but the others may not be. The 1981 NME Standard is in effect for only three years, until January 1, 1984, at which time it is replaced. Thus, to enumerate that fleet, the 1984 date is chosen, when all affected engines are built. The 1984 NME Standard is indefinite in duration so for the purposes of calculation, it is postulated that the non-recurring costs will be written off in 10 years of production. However, inasmuch as the projection does not go to 1994, only 5 years are taken (1989) and that number doubled.

Certain simplifying assumptions are also required. The first has already been mentioned: a 10 year projection to 1994 is found by

doubling the 5 year projection to 1989. The second is that each airframe classification is associated with a specific engine or engines representative of that class. While certainly artificial, it is impossible to predict with any certainty the number of alternate engines which may be used in any airframe class. The error is to a degree self compensating since each time a given engine is replaced by an alternate in some application, it may become an alternate for another engine in another application. The engine designations for the airframe classes are:

1. 2 engine narrow body: JT8D through 1983, CFM56 thereafter;

2. 3 engine narrow body: JT8D;

3. 3 engine super stretched: CFM56;

4. 3 engine wide body: CF6, RB211; and

5. 4 engine wide body: JT9D.

For the 3 engine wide body classification, there are basically three aircraft: the DC-10-10, DC-10-30, and L1011. These aircraft use the CF6-6, CF6-50, and RB211, respectively. It is assumed, arbitrarily, that the fleet of this type is divided equally among those airframes and, therefore, also among those engines. As necessary, the RB211 and JT9D families are assumed to be represented equally by their various models.

In summary, the engine inventories are given in Table E-6.

Table E-1

Type: 2 engine narrow body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	37	32	0	0	0	0	0	0	0	0	0	
(NME)	0	0	19	14	5	14	16	16	76	76	76	
Attrition												
(No std)	0	4	5	4	7	20	20	20	80	80	80	
Net in Fleet*												
(No std)	684	721	749	744	740	733	713	693	673	593	513	433
(NME-1981)	0	0	0	19	33	38	38	38	38	38	38	38
(NME-1984)	0	0	0	0	0	0	14	30	46	122	198	274

* As of January 1

JT8D through 1983
CFM56 thereafter

Table E-2

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	
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

* As of January 1

JT8D

Table E-3

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	0	0	0	
(NME)	0	0	77	83	84	83	78	68	55	89	102	
Attrition												
(No std)			0	0	0	0	0	0	0	0	0	
Net in Fleet*												
(No std)	0	0	0	0	0	0	0	0	0	0	0	0
(NME-1981)	0	0	0	77	160	244	244	244	244	244	244	244
(NME-1984)	0	0	0	0	0	0	83	161	229	284	373	475

* As of January 1

Production starts 1980

CFM56 or JT10D

Table E-4

Type: 3 engine wide body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	22	31	0	0	0	0	0	0	0	0	0	
(NME)	0	0	31	33	40	42	47	51	56	61	97	
Attrition												
(No std)	0	0	0	0	0	0	0	0	0	0	30	
Net in Fleet*												
(No std)	305	327	358	358	358	358	358	358	358	358	358	328
(NME-1981)	0	0	0	31	64	104	104	104	104	104	104	104
(NME-1984)	0	0	0	0	0	0	42	89	140	196	277	374

* As of January 1

CF6 or RB211

Table E-5

Type: 4 engine wide body

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production												
(No std)	17	20	0	0	0	0	0	0	0	0	0	
(NME)	0	0	20	21	29	32	36	40	45	70	76	
Attrition												
(No std)	0	0	0	0	0	0	0	0	0	20	20	
Net in Fleet*												
(No std)	164	181	201	201	201	201	201	201	201	201	181	161
(NME-1981)	0	0	0	20	41	70	70	70	70	70	70	70
(NME-1984)	0	0	0	0	0	0	32	68	108	153	223	299

* As of January 1

JT9D

Table E-6

Engine	STANDARD 1985 Retrofit	1981 NME	1984 NME
JT8D-17	3399	76	0
JT9D-7	804	140	892
JT9D-70	0	0	892
JT10D	0	0	1515
CF6-6	358	104	554
CF6-50	358	104	554
CFM56	78	732	1515
RB211-22B	358	52	277
RB211-524	0	52	277

REFERENCES

(APPENDIX E)

1. Munt, R. 1976. SST emissions projection. Environmental Protection Agency, AC 76-03.