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Johnston, Harold S.

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Harold S. Johnston

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GROUND-LEVEL EFFECTS OF SUPERSONIC TRANSPORTS
IN THE STRATOSPHERE

by

Harold S. Johnston
Department of Chemistry
and
Inorganic Materials Research Division
Lawrence Berkeley Laboratory
Berkeley, California

In 1971 it was stated that the oxides of nitrogen (NO_x) from 500 Boeing supersonic transports (SST) would be expected to reduce stratospheric ozone by about 23 percent as a worldwide average and up to a factor of two in the vicinity of the most highly traveled corridor¹. This prediction was confirmed by a simultaneous study that indicated about a 10 percent reduction of global ozone, but more or less than this figure depending on the (then unknown) background concentration of NO_x in the natural stratosphere². These calculations were followed by a statement that the reduction of ozone would be less than 0.1 percent³. For an NO_x concentration three times greater than that predicted to reduce ozone by a factor of two,¹ an earlier study had concluded that nitrogen oxides in the stratosphere "may be neglected"⁴. Thus it can be seen that in 1971 and early 1972 the potential of nitrogen oxides to reduce stratospheric ozone was "controversial". These four estimates are entered in Table 1.

There are several components to the problem of ozone reduction by nitrogen oxide catalysts: the mass of NO_x in the SST exhaust per unit mass of fuel, the amount and distribution of nitrogen oxides in the natural stratosphere, and mean residence time of exhaust gases in the stratosphere, which determines the world-wide increase of stratospheric NO_x . Widely divergent values of each of these values were stated in 1971-72. In 1970 Crutzen⁵ proposed that the oxides of nitrogen were important in the natural ozone balance, and he estimated the natural background to be 12 parts per billion (ppb, 10^{-9} mole fraction). For this quantity Johnston¹ estimated 6.6 ppb and Goldberg³ stated 100 ppb. In 1970 the Study of Critical Environmental Problems (SCEP)⁴ had estimated

NO_x exhaust emissions to be 65 grams (as NO_2) per kilogram of fuel; Johnston¹ used a figure of 23; and Goldberg³ asserted that the value was 4.5. These widely divergent estimates are listed in Table 1.

In 1971 J. E. McDonald⁷ noted how ozone varies with latitude, and he pointed out the very strong variation of skin cancer incidence with latitude among uniform populations. McDonald estimated 8000 additional skin cancer cases per year in the United States for each one percent reduction in the average ozone. He thought, like most other atmospheric scientists at the time, that additional water from the SST would reduce ozone; but his contribution concerned the biological effect of reduced ozone, not its photochemical mechanism. Goldberg³ reviewed McDonald's work, criticized his photochemical mechanism, and concluded that "the calculable impacts are moving toward neutral". An ad hoc panel of the National Academy of Sciences - National Research Council considered the biological implications⁸ of SSTs in the Fall of 1971 and their report was published in 1973; they estimated that at least 8000 additional skin cancer cases per year (US) would follow a 5 percent ozone reduction. These statements are also entered in Table 1.

From Table 1, it can be seen that in 1971-72, strongly different statements could be made about the essential components of the problem. The Department of Transportation (DOT) set up a large, interdisciplinary, research program (Climatic Impact Assessment Program, CIAP) in the Fall of 1971 to establish the facts and to resolve this controversy. There have been more than fifty projects supported by CIAP; other U.S. agencies and foreign groups have cooperated in this effort. CIAP has encouraged

open publication in the scientific literature of findings by their contractors. There have been three CIAP conferences: (1), February 15-16, 1972, (2), November 14-17, 1972; and (3), February 26 - March 1, 1974. An especially useful article⁹ is that by Grobecker, the director of CIAP. This review is largely organized on the basis of Table 1. The current (1974) status of each entry I through V in Table 1 is the substance of this review. The final section, VI, concerns the DOT projections for the period 1990-2025.

I. Emission Index of NO_x in SST Exhaust

At the second CIAP conference, Williams¹⁰ reported measurements of pollutants from the Concorde engine (Olympus MK 602) under simulated supersonic cruise conditions. The measured emission of NO_x, calculated as NO₂, varied between 17.8 and 19.3 grams per kilogram of fuel. This number is intermediate between the high and low values in Table 1. For model calculations of the effect of SST's in the stratosphere, the number 18 g NO₂ per kg fuel has been taken as standard in a number of cases. Although no engine was ever completed of the type that was to have been used in the Boeing SST, a somewhat similar engine was tested under simulated stratospheric conditions (Neely and Davidson¹¹). They used two different methods of measuring NO in the exhaust and for unexplained reasons these methods differed by a factor of two. Depending on which of these analytical results one accepts, one finds that the Boeing SST would have produced NO_x at a rate either equal to or one half that of the Concorde. Until this question is resolved, modellers have usually assumed

TABLE 1

CONTROVERSY CONCERNING THE IMPACT OF 500 BOEING SST
ON STRATOSPHERIC OZONE (1971-72)

	Examples of values stated	ref.
I. NO_x (as NO_2) in SST exhaust g/kg fuel	65	4
	23	1
	4.5	3
II. Ambient stratospheric NO_x (ppb)	100	3
	12	5
	~ 10	2
	6.6	1
III. World-wide increase of stratospheric NO_x (ppb)	6.8	4
	2.4	1
	1.2	6
	1	3
IV. World-wide decrease of stratospheric ozone (%)	23	1
	~ 10	2
	< 0.1	3
	"may be neglected"	4
V. Biological effects	+8000 skin cancer cases (US) for 1% ozone decrease	7
	+8000 skin cancer cases (US) for 5% ozone decrease	8
	"neutral" environmental impact	3

large advanced SSTs and the Concorde SST to have about the same emission index, namely, 18 g NO_2 per kg fuel.

II. Ambient Stratospheric NO_x

Hard (1974) issued a summary of recent measurements of trace species in the stratosphere¹². His data for nitrogen dioxide (NO_2) and nitric oxide (NO) are given as Figure 1, references 13-23. These substances show substantial variation from time to time and from place to place. Nitric acid vapor has been extensively measured in the stratosphere²⁴⁻²⁶. Over a period of two years Lazrus and Gandrud²⁵ measured nitric acid profiles from northern Alaska to southern South America. With some extrapolation, their data indicate a global average mixing ratio by volume (mole fraction) of 1.7 ppb HNO_3 . Of the total oxides of nitrogen (NO , NO_2 , N_2O_5 , and HNO_3), nitric acid averages about one-half. Thus, the global inventory of nitrogen oxides, including nitric acid is about 3.4 ppb in the stratosphere. Generally speaking, the greater the ambient NO_x , the less is the expected reduction of ozone by added NO_x^2 . The NO_x ($\text{NO} + \text{NO}_2$) profiles predicted by reference 1 and by reference 3 in 1971-72 (Table 1) are included in Figure 1. There remains an absence of observations above 35 km for NO and above 28 km for NO_2 . In the range of observations, 15 to 30 km, the observed NO_x is close to that predicted in reference 1 and far less than that stated in reference 3. This scarcely came as a surprise; because with the amount of NO_x asserted by Goldburg³ the moon would always appear red from stratospheric NO_2 .

The natural source of NO_x in the stratosphere was discovered in

1971 by Crutzen³⁰, and the magnitude of this source has been calculated by Crutzen³⁰, McElroy and McConnell³¹, Nicolet and Vergison³², Isaksen³³, McElroy et al³⁴, and others. There is good agreement between these investigators, and a value of about $3/4 \pm 1/4$ MT NO₂ per year is indicated (megaton, MT, 10¹² g). This is in the middle of the range of values calculated by Crutzen (1971).

The primary natural process for NO_x removal from the stratosphere is reversible conversion to nitric acid, transport of nitric acid into the troposphere, and rainout in the troposphere. From the observed gradient of nitric acid vapor and from a model of air motions calibrated against the removal of radioactive debris from the stratosphere, Lazrus and Gandrud²⁵ calculated the removal rate of NO_x from the stratosphere to be between 0.5 and 1.5 MT NO₂ per year, in satisfactory agreement with the independently calculated source from N₂O ($3/4 \pm 1/4$ MT yr⁻¹).

In the natural stratosphere, ozone is formed from the photolysis of oxygen

The global rate of formation of ozone is readily calculated (Johnston and Whitten³⁵). In the natural stratosphere, ozone is destroyed by several mechanisms. The most important mechanism and the approximate contribution of each is as follows:

A. NO_x catalytic cycle (about 70 percent) B. O_x reactions (about 20 percent) C. HO_x catalytic cycles (about 10 percent) D. Transport to troposphere and destruction on the surface of the earth (less than 1 percent)^{36,35}.

The rate of formation of ozone and destruction by various mechanisms is given (according to McElroy³⁴) by Figure 2. The full

chemical mechanism used in these studies involves 50 to 100 chemical reactions of measured rate constants (Garvin and Hampson³⁷). The full details of the chemistry are not described here although they are considered by the modellers of stratospheric photochemistry.

III. Increase in Stratospheric NO_x from SST Operations

Grobecker⁹ gives the number of SSTs projected by various studies out to the year 2025. These projections include subsonic fleets as well as supersonic fleets. These numbers of aircraft were translated into mass of fuel expected to be burned each year at various altitude bands⁹. Supersonic transports that cruise near 17 km (Concorde-like) were projected to increase slowly from 1990 to 2025. Advanced supersonic transports that cruise near 20 km were projected to increase very rapidly from 1990 to 2025. On the further assumption that the emission index for NO_x of future SST remains the same as for current Concorde (an assumption that Grobecker emphasizes need not be so), the rate of NO_x pollution in various altitude bands is given by Figure 3. The estimated natural flux (3/4 MT yr⁻¹) is given as a dashed line. The projected artificial NO_x input from SSTs between 15 and 21 km is 0.70 MT in 1990 and 30 MT yr⁻¹ in 2025. These artificial injections into the stratosphere are approximately equal to the natural source of NO_x in 1990 and about 40 times greater than the natural source in 2025.

Before 1990, the projected SSTs are Concorde and Tupolevs, with properties given in Table 2. The emissions from 375 Concorde-like SSTs are about 0.35 MT (as NO₂) per year (375 Concorde is the number

TABLE 2

PROPERTIES OF 375 CONCORDE-TYPE SST

(on basis of 1974 emission index
for nitric oxide in engine exhausts¹⁰).

Cruise height at 17 km	
Fuel per hr (cruise mode)	20,000 kg
hr service per day	7
days service per year	365
g NO ₂ /kg fuel	18
no. of Concorde	375
MT NO ₂ /yr	0.35

projected to 1990 by the Environmental Protection Agency³⁸. These emissions are about one-half the natural rate of formation of NO_x in the stratosphere.

IV. Reduction of Ozone by NO_x from SST Exhausts

Including the first report of reduction of stratospheric ozone by nitrogen oxide catalysts from supersonic aircraft exhausts, there have been at least 12 different studies of this problem. These are listed in Table 3 with a reference code^{1,39-49} to subsequent figures. These 12 studies encompass a wide range of sophistication so far as atmospheric motions are concerned, simple box model, seven different models of vertical eddy transport, three models with vertical and north-south transport, and one model involving three-dimensional atmospheric motions. Elaborate calculations have been made involving only one-dimensional motion, for example, Chang⁴¹ studied the effect of seasonal variations and of diurnal variations on the role of SSTs in reducing ozone, including a full set of chemical reactions. The most extensive calculations have been made by Chang⁴¹ and Hunten⁴⁹. Figures 4 and 5 give the recent results from eight of the modellers, with the results by Chang and by Hunten indicated by lines. The reduction of global ozone is plotted against the global rate of insertion of NO_2 at 20 km in Figure 4 and at 17 km in Figure 5. For reasons given below, points 7 may be dropped from these figures. The spread between the low estimate by Chang and the high estimate by Hunten is about a factor of 2.5 at 20 km and about a factor 3.5 at 17 km.

TABLE 3

MODELLERS WHO HAVE CALCULATED THE REDUCTION OF STRATOSPHERIC OZONE AS A
RESULT OF NO_x FROM SST EXHAUST, A REFERENCE CODE FOR FIGURES
4 AND 5 AND CALCULATED OZONE REDUCTION BY 1.8 MT NO_x (AS
NO₂) PER YEAR INSERTED AT 20 KM (GLOBAL AVERAGE)

No.	Author (year	Dimension of atmospheric motion		Ozone reduction %
			Ref.	
1.	Johnston (1971)	Box	1	23
2.	Crutzen (1974)	1	39	9
3.	Hesstvedt (1972, 1973, 1974)	2	40	12
4.	Chang (1974)	1	41	8
5.	Stewart (1973)	1	42	12*
6.	McElroy <u>et al</u> (1974)	1	43	11
7.	Whitten and Turco (1974)	1	44	-
8.	Shimazaki and Ogawa (1974)	1	45	22
9.	Vupputuri (1974)	2	46	9
10.	Widhopf (1974)	2	47	16
11.	Cunnold <u>et al</u> (1974)	3	48	12
12.	Hunten (1974)	1	49	19

* as recalculated by Chang

The global average reduction of ozone for insertion of 1.8 MT $\text{NO}_2 \text{ yr}^{-1}$ at 20 km for various models is included in Table 3. With one exception, the other models fall between the limits set by Hunten and by Chang, including the models with two and three dimensional motion.

The one-dimensional models can be put to a sharp test⁵⁰ by seeing how well they predict the dissipation of carbon-14 produced by the nuclear bomb tests of 1961-62^{51,52}. Only those models that had a major barrier to transport in the lower stratosphere and that had increasing vertical transport with an increase in height in the middle and upper stratosphere gave a qualitatively correct prediction (McElroy, Hunten, Stewart); and of these, Hunten's model gave the best quantitative prediction of the distribution of the carbon-14 clouds. As recalculated by Chang⁴¹, these three models give very nearly the same predicted reduction of ozone by supersonic transports. Also, the two-dimensional model of Widhopf⁴⁷ gives about the same prediction as these three models. Model 7 sweeps carbon-14 from the stratosphere so much faster than observations that it may be omitted from further consideration.

The ozone reductions predicted by Widhopf or by Hunten, McElroy, or Stewart (as recalculated by Chang) are very nearly the same as the large reductions predicted in 1971, Table 1.^{1,2} In sections V and VI, McElroy's model is used for the quantitative prediction of ozone reduction by artificial nitrogen oxides.

V. Biological Effects

The principal biological effect of supersonic transports derives

from the increase in band b ultraviolet radiation (UV-b, 280-320 nm) that reaches the surface of the earth after nitrogen oxides from the SSTs reduce stratospheric ozone. Susceptible biological systems^{7,8,53-63} include human skin, human and animal eyes, insects, plants, and plankton. Solar radiation is absorbed by ozone in the stratosphere, scattered by air molecules in the troposphere, and strongly scattered by particles and by clouds in the troposphere. For a given distribution of ozone and particles, the transmission and scattering of solar radiation is a strong function of solar angle. Realistic calculations of the transmission of solar radiation have been made by Green and Mo^{62a}, Mo and Green^{62b} and Venkateswaran⁶³.

The absorption spectrum of ozone (Ackerman⁶⁴) is given on a logarithmic scale in Figure 6. The peak absorption occurs at 255 nm. At standard temperature and pressure, a sample of pure ozone gas 0.37 cm thick transmits the fraction 5×10^{-49} of the incident radiation at 255 nm, the fraction 0.12 at 305 nm, and the fraction 0.99 at 345 nm. The quantity of sunlight transmitted by 0.23 cm (STP) of ozone as a function of wavelength is given in Figure 6. The sharp cut-off of sunlight near 300 nm is apparent.

The relative absorption spectrum of DNA and the action spectrum for erythema (Setlow⁶¹) are also given by Figure 6. The shape of the DNA absorption curve and the shape of the ozone absorption curve are similar. Ozone in the stratosphere cuts out most solar radiation that would be absorbed by DNA. When DNA absorbs UV-b, the molecule is damaged, but the DNA chain is usually not broken (Smith⁶⁵). Higher plants and animals

have several processes that repair the DNA damage: one repair process is brought about by deep violet visible light, one process involves cutting out the damaged portion of the DNA and replacing with a fresh section, and one process involves bypassing the damaged strand upon replication. Cells are quickly killed by UV-b radiation if they lack repair mechanisms (Smith⁶⁵).

The action spectrum for DNA damage is the product of transmitted sunlight (which decreases with decreasing wavelength) with the DNA absorption curve (which decreases with increasing wavelength). This action spectrum is sharply peaked and the peak depends on the vertical column of ozone. Three such curves for different columns of ozone (0.37, twice 0.37, and one-half 0.37 cm STP) are given by Figure 7. The DNA damage is proportional to the area under the curve. The erythema dose is the area under similar curves where the erythema sensitivity is used instead of the DNA absorption spectrum. For small decreases of ozone, DNA damage increases 2.3 times faster than the decrease of ozone⁶¹; for large decreases of ozone, the relative increase in DNA damage approaches the 2.5 power of the relative decrease of ozone.

Ozone is subject to natural variations in both time and place⁶⁶. In temperate and polar regions, the overhead ozone column is a maximum in February or March and a minimum in September or October, and there is a large difference (approaching 50 percent) between the maximum and minimum. In tropical regions the amount of ozone is very nearly the same throughout the year. The difference between polar maximum and tropical minimum is about a factor of two. In the late summer and early fall, the

difference between polar, temperate, and tropical zones are small. A moderate reduction in ozone in temperate zones in the summer or fall could bring the tropical distribution of radiation to the temperate zone. A large reduction of ozone in the tropics would set up a radiation distribution unlike any now on earth.

The difference in erythemal dose, averaged over hours of the day and seasons of the year, for various latitudes were calculated by Mo and Green⁶². There is about a factor of four differences in erythemal dose between 50°N and the equator. Green and Mo⁶² constructed an "epidemiological index" which includes the factors of latitude, cloudiness, and ground reflection on erythemal dose. Urbach⁶⁰ gave the expected increase (per 10⁵ population) in skin cancer in USA as a function of percentage ozone reduction, according to Green's erythema function. For a susceptible population of 200 million, this increase in skin cancer cases as a function of small ozone depletions is given in Figure 8. The DNA spectrum is at somewhat shorter wavelengths than the erythema curve. The upper line in Figure 8 corresponds to the DNA absorption as the cause of skin cancer. The solid line is the average of the other two. It is interesting to compare these 1974 results with McDonald's 1971 statement⁷, Table 1. McDonald said that a systematic one percent ozone reduction would increase the number of skin cancer cases in US by 8000 per year. Figure 8 gives 8000 per year for a one percent ozone reduction for the erythema action spectrum, and over 11,000 per year for the DNA action spectrum. McDonald's value agrees with current knowledge; the estimate of the National Academy of Sciences was unduly conservative, Table 1.

The amount per year of emitted NO_x (as NO₂) for

one Concorde or for any number of Concordes is obtainable from Table 3. The reduction of ozone as a function of NO_x injection at 17 km is given by Figure 5 for various modellers. The reduction of ozone as a function of the number of Concordes is given by Figure 9. The lower curve in Figure 9 is the reduction of ozone if the NO_x is introduced uniformly worldwide. If virtually all the traffic is in the northern hemisphere, ozone reduction near the zone of maximum traffic will be about double the worldwide average (Cunnold *et al.*,⁴⁸). The upper line corresponds to this pattern of high traffic density in the northern hemisphere. The solid line is an average of the other two and a reasonable model of what to expect.

The increase in skin cancer cases in USA as a function of percentage ozone depletion is given in Figure 8. The decrease of ozone as a function of number of Concorde SST is given in Figure 9. The combination of these two figures gives the relation of interest. The increase of skin cancer cases in USA as a function of number of Concorde SST is given by Figure 10. The center line is based on the center lines of Figures 8 and 9, and the spread arises from the sources of spread given on those two figures.

In round numbers, one sees that there would be an increase of 10,000 skin cancer cases per year in USA for each 100 Concordes. For 375 Concordes, the central estimate of increase of US skin cancer cases is about 37,000 per year.

VI. Beyond 1990

As can be seen from Figure 3, large increases in SSTs are expected after 1990 (reference 9). If there is no reduction in NO_x emission

index, the projected fleets of SSTs lead to very great reductions of ozone. These ozone reductions were derived from McElroy's model. The percentage reduction of ozone and the percentage increase in biologically damaging ultraviolet radiation are given in Figure 11 for the years 1990, 2000, 2010, and 2020. The worldwide ozone is reduced by a factor of two in the year 2011, and it is reduced a factor of three by the year 2021. Biologically damaging radiation is doubled by the year 2001, increased more than five-fold by the year 2011, and it is off-scale of anyone's model by the year 2020. The indicated increase in USA skin cancer cases is about a half million per year with the radiation distribution of the year 2001, and over 2 million per year for year 2011. The effects on plants and plankton may be much worse. Even if the emission index for NO_x is reduced by a factor of 100, the SST fleets of 2025 would increase U.S. skin cancer cases by 35,000 per year.

Most of the references in this report are for the year 1974. There has been a flood of new evidence during 1974. The major uncertainties of 1971-72 have been resolved. The new evidence supports the thesis that NO_x in the stratosphere reduces ozone and that the amount of NO_x contributed by a few hundred SST would be a serious matter.

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TITLES TO FIGURES

Figure 1 - Observed (1973-74) and estimated (1971-72) vertical profiles of NO and NO₂. The estimated profiles are those of references 1 and 3. The observations were made by reference 13-23, identified by the letter codes: AM, Ackerman and Muller (1972, 1973); FT, Farmer et al (1974); M. Murcray et al (1974); A, Ackerman et al (1973); FG, Fontenella et al (1974); L. Lowenstein et al, (1974); P, Patel (1974); R, Ridley et al (1974); T, Toth et al (1974).

Figure 2 - Relative photochemical rates in the natural stratosphere:

A. Photochemical formation of ozone:

B. The NO₂ catalytic cycle

C. The elementary reaction $\text{O} + \text{O}_3 \rightarrow \text{O}_2 + \text{O}_2$.

D. $\text{HO} + \text{O} \rightarrow \text{H} + \text{O}_2$.

E. $\text{HOO} + \text{O} \rightarrow \text{HO} + \text{O}_2$.

F. $\text{HO} + \text{O}_3 \rightarrow \text{HOO} + \text{O}_2$.

G. $\text{H} + \text{O}_3 \rightarrow \text{HO} + \text{O}_2$

H. $\text{HO}_2 + \text{O}_3 \rightarrow \text{HO} + 2 \text{ O}_2$

Figure 3 - Upper bound NO_x emissions from the fleets of SST projected by Grobecker⁹ of the U.S. Department of Transportation.

The NO_x is expressed as if NO_2 , the units are MT per year.

The projected artificial input is given by the lines. The estimated natural input of NO_x into the stratosphere is indicated by a dashed line; the indicated value for this quantity in 1974 is about 3/4 MT per year, world-wide.

Figure 4 - Calculated reduction of vertical ozone column in terms of annual global rate of NO_x (as NO_2) addition at 20 km. The year to be attained refers to the projections of future SST fleets (reference 9, Figure 3). The lines by Hunten and by Chang, the points numbered 2, 6, 7, and 8 represent models with one-dimensional motion; points 3 and 10 represents two-dimensional motion; and point 11, three dimensional. The reference code is given in the text.

Figure 5 - Same as Figure 4, except that artificial NO_x is inserted at 17 km.

Figure 6 - A. Optical absorption cross section of ozone as a function of wavelength of radiation. B. Relative biological activity spectrum for DNA and for erythema. C. Transmitted radiation as a function of wavelength for 0.23 cm of O_3 and 25° zenith solar angle. The sharp cut-off near 300 nm is primarily due to absorption by ozone.

Figure 7 - Biological action spectrum for DNA absorption. The area under the curves gives the dose for biological damage. The curves represent equivalent columns of ozone of 0.37 cm, half 0.37 cm, and twice 0.37 cm.

Figure 8 - Increase in skin cancer cases in USA as a function of percentage decrease in the ozone column. The lower curve is based on Green and Mo's erythema action curve and calculated by Urbach (1974). The upper curve is scaled by the ratio of DNA dosage to erythermal dosage. The line is the average of these two curves.

Figure 9 - The percentage decrease of ozone as a function of the number of Concorde aircraft in operation. The lower curve is the global average. The upper curve is the ozone reduction in the temperate zone of all SST's operated in the northern hemisphere. The solid line is an average of the other two, and it is regarded as a reasonable estimate of flight patterns.

Figure 10 - Increase of skin cancer cases in USA as a function of the number of Concorde aircraft. The central line is based on the central lines of Figures 8 and 9. The vertical dashed line represents 375 Concordes, the EPA estimate for 1990.

Figure 11 - Percentage reduction of global ozone⁴³ and the corresponding increase in DNA dosage⁶¹ for the fleets of SSTs projected⁹ from 1990 to 2025. Note that these 1974 projections of future fleet sizes and 1974 calculations of the effect of NO_x on ozone give much larger ozone reductions than a factor of two.

Fig. 1

XBL 751-5616

Figure 2

XBL 751-5615

XBL 751-5614

Fig. 3

XBL748-3837

FIGURE 4

XBL 748-3838

FIGURE 5

Figure 6

XBL 751-5613

00004207986

XBL 748-3839

FIGURE 7

INCREASE IN SKIN CANCER CASES PER YEAR IN USA
AS A FUNCTION OF OZONE REDUCTION

FIGURE 8

REDUCTION OF STRATOSPHERIC OZONE BY NITROGEN OXIDES IN CONCORDE SST EXHAUST

FIGURE 9

INCREASE IN SKIN CANCER CASES PER YEAR IN USA
BY NITROGEN OXIDES IN CONCORDE SST EXHAUST

FIGURE 10

Fig. 11

CBB 7410-7529

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720