CLIMATIC IMPACT ASSESSMENT PROGRAM - CONCLUSIONS AND RECOMMENDATIONS

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Abstract

This report assesses the impact of climatic changes which may occur from operation of aircraft in the stratosphere.

The effects considered involve the geophysics of the stratosphere and the troposphere, the propulsion effluents, the impacts of climatic change on the biosphere, and the economic and social measures of biological and climatic changes.

Technical measures for the improvement of aircraft engines and fuels, by which adverse environmental effects may be avoided, are described.

I. Introduction

In 1971 the U.S. domestic SST program was terminated by congressional action. At about the same time the Department of Transportation developed a new program to ascertain the impacts of climatic changes resulting from pollution of the stratosphere by aircraft, and simultaneously made studies of the noise of SST and other aircraft, to provide basis for answers to questions which were to become important in 1975 and 1976 when the UK/France Concorde requested permission to operate into airports in the United States. The two most important environmental consequences of the SST are the biological and climatic effects of changes in stratospheric composition due to aircraft engine emissions consequences and the effects of the noise (including low frequency vibration) caused by the airplane in the vicinity of the airport. Other environmental questions involve the sonic boom; and the emissions affecting the local air quality in the airport area. My remarks today will address only the first of these subjects.

On the scale of earth-sun dimensions, the atmosphere is essentially a thin veil of air with trace gases that filter the sun's radiation, passing light and life-giving heat in just the right measure to sustain life, while shielding life from massive lethal radiation in the ultraviolet (UV) spectrum beyond. Despite disturbances, the proper proportions of atmospheric components are maintained by complex, natural, self-adjusting mechanisms.

Most manmade impurities are injected into the atmosphere at or near the earth's surface. The atmosphere cleanses itself of these quickly, for the most part. This occurs because in the part of the atmosphere next to the earth (the troposphere), temperature decreases rapidly with increasing altitude up to between 30,000 and 50,000 feet (fig. 1), resulting in rapid vertical mixing, which produces turbulence, storms, and rainfall that remove the impurities. (Exceptions, such as the occasional temperature inversion layer over the Los Angeles Basin, have notably unpleasant results.)

THE ATMOSPHERE'S TEMPERATURE-ALTITUDE PROFILE
(after R. E. Newell, 1969)

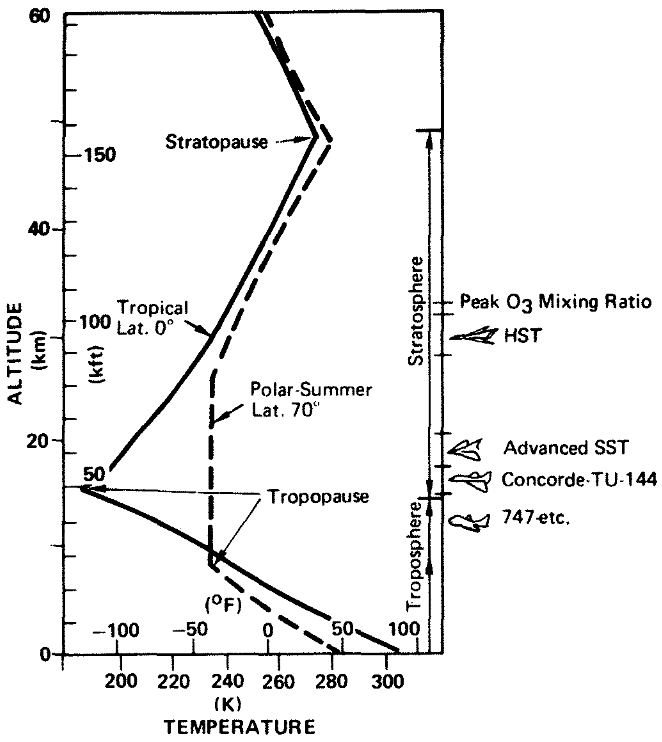

Figure 1

In the stratosphere, i.e., above the altitude of the temperature minimum (denoted as the tropopause in fig. 1), temperature is either constant, or it increases with altitude up to about 150,000 feet, a condition that characterizes the entire stratosphere as a permanent inversion layer.

As a result, vertical mixing in the stratosphere (and, hence, self-cleansing) occurs much more slowly than that in the troposphere. Contaminants introduced at a particular altitude remain near that altitude for periods as long as several years. Herein lies the source of concern: although the turbulent troposphere cleanses itself quickly, the relatively stagnant stratosphere does not.

Effluents from any jet aircraft burning typical jet fuel contain, in addition to large amounts of water vapor: carbon oxides (CO_x), nitrogen oxides (NO_x), and sulfur dioxide (SO_2). These appear initially in the jet plume behind the aircraft. Strong wake vortices wrap them into the familiar pair of narrow strands, sometimes visible at lower altitudes as water vapor condensation trails several kilometers long.

The effluents eventually disperse. In the troposphere, natural turbulence and precipitation remove them. But, in the stratosphere, they persist at the altitude of injection. Moreover, the global dynamics of the upper atmosphere spread them, in a few weeks, throughout the entire latitude zone in which they were injected. Since the altitude of the tropopause varies with latitude (fig. 1) and with time, effluents from flights in the mid and high latitudes at say 10 km (33,000 ft) dwell longer than effluents from tropical flights at the same altitude.

During the four years of the CIAP program, many new measurements of the stratospheric trace constituents were made (as depicted in fig. 2) from balloons, satellites and aircraft, including the Concorde itself. Key constituents, some measured for the first time in that program, are indicated in the figure.

II. Nitrogen Oxide And Ozone

There are two chains of cause and effect, one resulting in change in the ultraviolet radiation at the ground level, and the other affecting the climate (temperature, winds, and precipitation). These radiation and climatic changes affect agriculture and other biological concerns important to the well-being of the world.

Consider first the ultraviolet chain. When fleets of high flying aircraft inject nitrogen oxides (NO_x) into the stratosphere, they add to the NO_x already there in natural amounts. As the NO_x is dispersed globally by the dynamics of the stratosphere, it reacts chemically in a complex way with the atmosphere's other natural constituents, one of which is ozone. In the process, the added NO_x reduces the ozone which normally screens the sun ultraviolet radiation and consequently enhances the UV flux reaching the earth. This UV increase will cause increase

Platforms Used and Atmospheric Characteristics Measured in CIAP

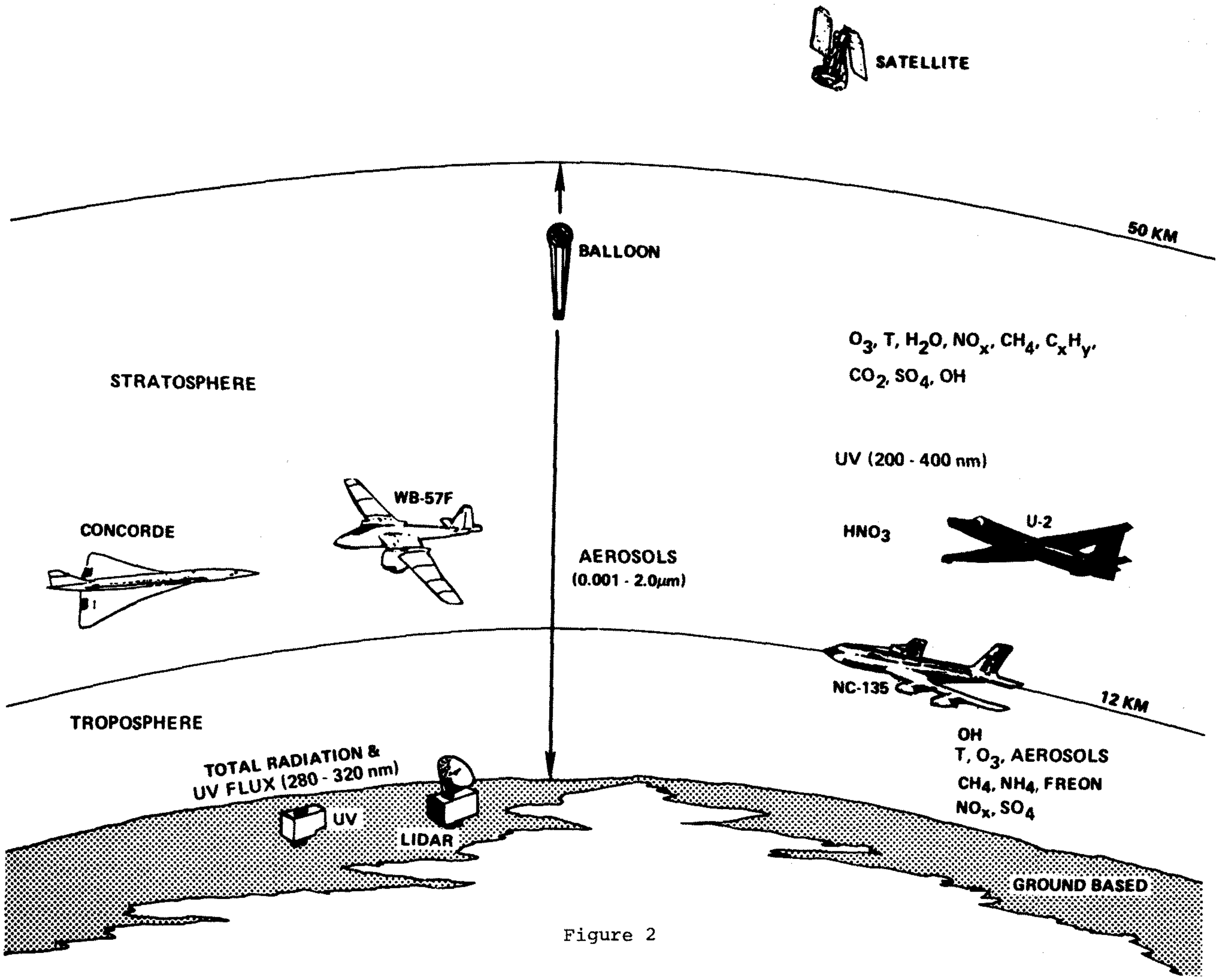

Figure 2

in the adverse effects on micro-organisms, plants and human skin normally attributed to the natural UV radiation. Although the estimation of each step in the chain has large uncertainty, the physical part of the chain (i.e., the link between the postulated operations of a fleet of aircraft with given engine characteristics and the increase of UV flux reaching the earth's surface) is known with greater confidence than the biological part of the chain (that is, the relation between UV flux and effects such as human skin cancer).

Geographically the ozone column on a typical day varies about 300 percent over the globe and about 30 percent, for example, between Minnesota and Texas. Moveover, the distribution changes daily and monthly so that any given locality experiences 25 percent changes from day to day or from week to week. The changes in mean value are perhaps 10 percent from year to year. It is against this natural background that man induced changes in ozone must be measured. From this comes the notion of the "barely discernible change". This is defined, arbitrarily, as the smallest change due to all causes in annual average total ozone that can be discerned, against the background of natural variability, from a comprehensive statistical analysis of 10 years of daily observations by a major global monitoring system, using satellites, aircraft, balloons and ground stations. The barely discernible change in global mean ozone is estimated to be 0.5 percent.

As indicated in Table 1, the estimated change of total ozone in the Northern Hemisphere attributed to current operation of sub-sonic aircraft of more than 1,700 aircraft of the 707, DC-8, DC-10, 747 types is five times smaller than the barely discernible change. One hundred aircraft of the Concorde TU-144 type would cause reduction of the present ozone of about 0.39 percent, which is about four times that produced by the present subsonic fleet.

Within the generally accepted uncertainty (a factor of about three), these results have been corroborated by studies by the U.S. National Academy of Sciences and by the U.K. Committee on Meteorological Effects of Stratospheric Aircraft (COMESA).

Table 2 describes some equivalences of the barely discernable change of 0.5% of total ozone if all the changes taken to be 1/2%, were due

CIAP EQUIVALENCIES

IF BARELY DETECTABLE CHANGE OF WORLD OZONE DUE TO NO_2 FROM STRATOSPHERIC AIRCRAFT IS 0.5%, THIS REPRESENTS:

- Results of 120 Concordes flying 4.4 hr d^{-1}, 365 d yr^{-1} with EI = 18 gm kg^{-1} at altitude 15-18 km (49 - 59 kft)
- Change in U.S. skin cancer incidence 1%
- Change in U.S. skin cancer first appearance 6000 yr^{-1}
- Time of first appearance of skin cancer advanced 4 months after 30 years
- Equivalent of 45 minutes at noon at beach each summer for 30 years
- Equivalent of moving home from Baltimore, MD. to Washington, D.C.

Table 2

Estimated Percent Ozone Reduction per 100 Aircraft

				Percent Ozone Reduction in Northern Hemisphere		
					EI Controls	
Aircraft Type	Fuel Burned Per Year* (kg/yr)	Altitude km (kft)	NO_x Emission Index (EI) Without Controls (g per kg fuel)	Without Controls	1/6 Today	1/60 Today
Subsonic**						
707/DC-8	1×10^9	11 (36)	6	0.0034	0.00070	0.000070
DC-10/L-1011	1.5×10^9	11 (36)	15	0.010	0.0020	0.00020
747	2.0×10^9	11 (36)	15	0.014	0.0025	0.00025
747 – SP	2.0×10^9	13.5 (44)	15	0.079	0.014	0.0014
Supersonic						
Concorde/TU-144	4×10^8	13.5 (44)	18	0.39	0.068	0.0068
	3×10^9	16.5 (54)				
Advanced SST	3×10^8	16.5 (54)	18	1.74	0.32	0.032
	6×10^9	19.5 (64)				

*Subsonics assumed to operate at high altitude, 5.4 hours per day, 365 days per year. Supersonics assumed to operate at high altitude, 4.4 hours per day, 365 days per year.

**The present subsonic fleet consists of 1,217 707/DC-8s, 232 DC-10/L-1011s, and 232 747s flying at a mean altitude of 11 km (36 kft) and is estimated to cause a 0.1 percent ozone reduction.

Table 1

only to NO_x from stratospheric aircraft. This represents the results of 120 Concordes flying nearly 4.4 hours per day, every day in the year. It could cause a change in the incidence of skin cancer in the United States' white population of about 1% or about 6,000 new cases every year. The first appearance of skin cancer would occur roughly four months earlier in life than it normally would. This enhanced occurrence of skin cancer is roughly the same as the result of spending an additional 45 minutes at the beach, once each summer for 30 years, or the result of moving your residence partway from Baltimore, Maryland to Washington, D. C.

The pollution of the stratosphere by NO_x of aircraft emissions can be limited if the design of air-breathing engines limits the maximum temperature of burning gases in the combustion chamber to less than 1800°K. Although engine combustion occurs most readily at about 2500°K there are ways of limiting the maximum temperatures required to initiate burning, without loss of engine efficiency, which is dependent on the temperature of the gases (much lower than 1800°K) as they are introduced into the turbine. Such ways are not in current practice and require development of new engine designs.

Having developed by a deterministic analysis the effects of stratospheric pollution by aircraft in the inducing of skin cancer, it is necessary to estimate how incorrect we may be. Such estimates of uncertainty are shown in Fig. 3.

The values are expressed as fractions indicating the ratios of the standard deviation of observations or calculations to the mean value which is being estimated. For each of the four steps of the estimation the solid bar represents the uncertainty introduced by that step alone, and the cross hatched bar represents the cumulative effect as these effects propagate through the succeeding steps. The estimates of non-melanoma skin cancer incidence rates are expected to have an uncertainty to mean value ratio of about 0.8. This implies that we may be 95% confident that the estimate is accurate within a factor of 3 to 10.

There are, however, many difficulties, one of which is illustrated by the temporal variation of total global ozone as measured from NIMBUS satellite, shown in Figure 4. Satellite measurements have the great advantage that one can get many data points both in space and time, as Figure 4 indicates. The signal of trend is noisy showing a striking variation from day to day. This variation may be in part an artifact of the method of measurement and analysis. However, there is a strong indication that, in addition to the already recognized strong latitudinal and other spatial variation, there is a strong temporal variation of total global ozone. Faced with such strong variation, analysis of trends will call for processing much data. Analysis to sort out the small variation from the annual global mean will be difficult.

Pittock (1974) in Australia has made an attempt to analyze, for the data from one station, how long daily observations from one station would have to be made in order to determine a trend (a certain percent change of overhead ozone in a decade). Figure 5 shows Pittock's data. For 95% confidence, it would take eleven years of daily observations to detect a 5% change in overhead ozone. Pittock's data were derived from the study of observations of a single station at Aspendale. If one used satellite data, one might realize the data from 100 independent

Propagation of Fractional Uncertainty Through NO_x/Skin Cancer Cascade

Schainker et al., 1974

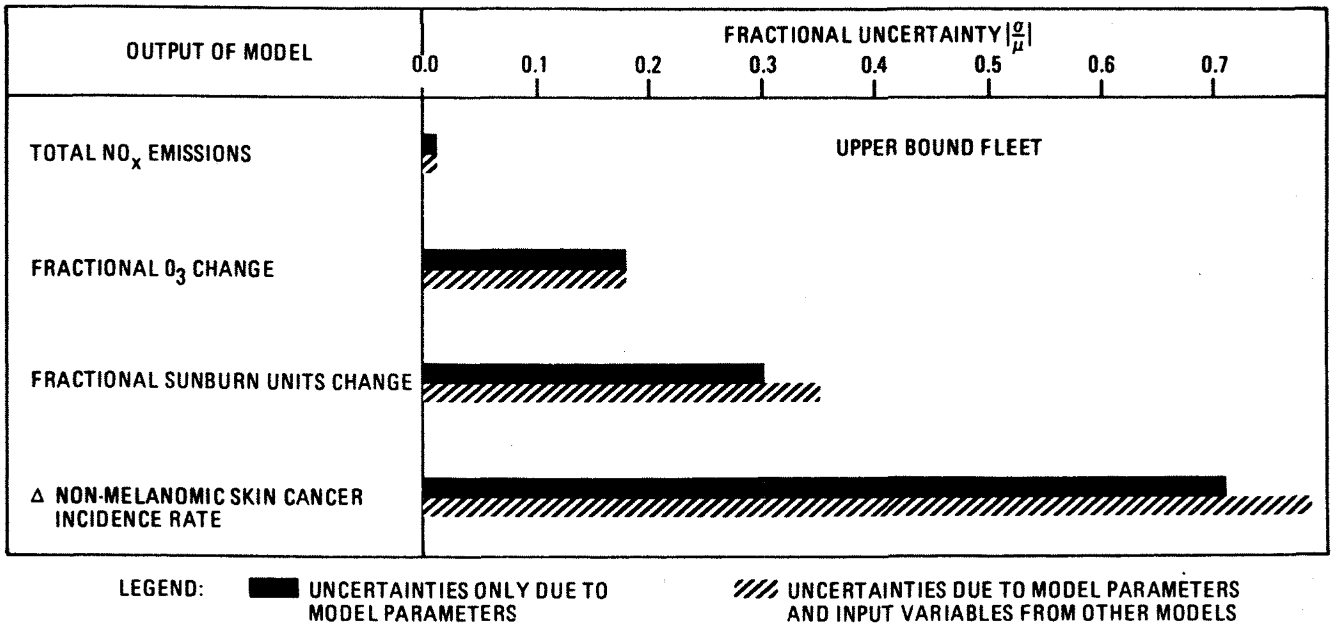

Figure 3

Daily Variation in Total Global Ozone

Lovill, 1974

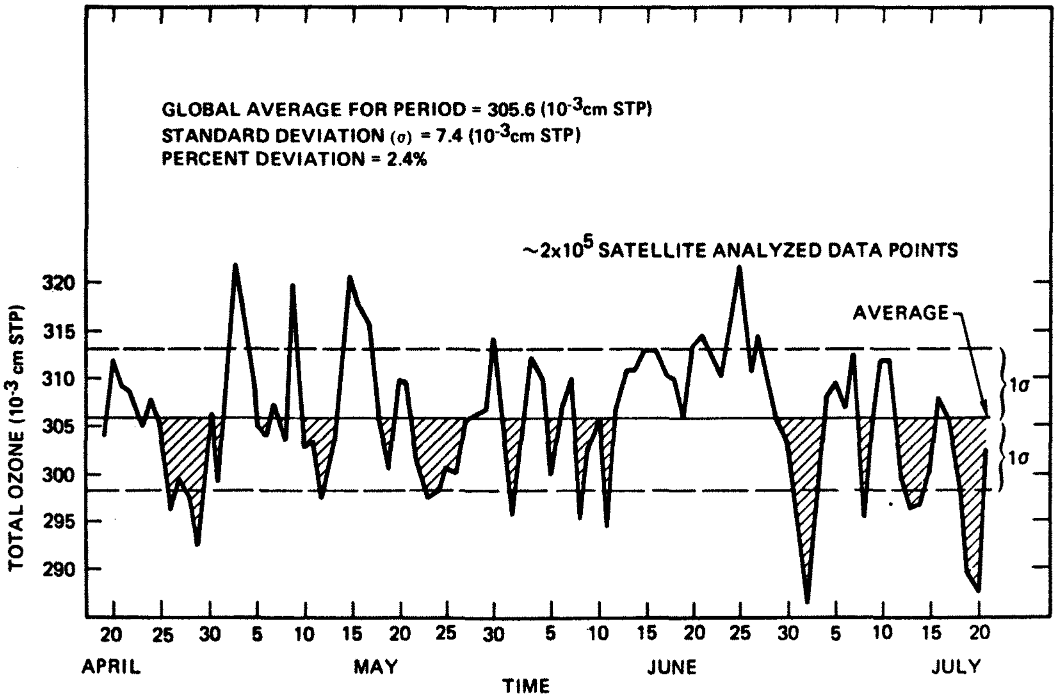

Figure 4

DETECTABILITY OF TRENDS OF CHANGE OF OZONE COLUMN (ADAPTED FROM A. PITTOCK, 1974)

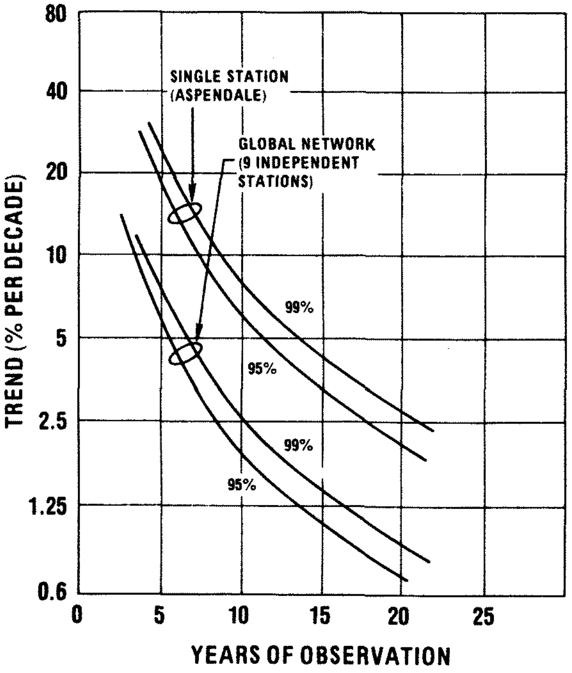

Figure 5

"equivalent stations" around the world. With such data, one could thereby improve the limit of trend predictability to be half a percent (rather than 5%) in ten years of observation. This estimate of the limit of detectability has not been demonstrated nor otherwise proven; it may be over-ambitious.

The difficulties for the monitoring systems of the future which result from the large natural spatial and temporal variability of the measurables (the trace constituent densities, the radiation levels, and so on), are great.

Figure 6 illustrates another problem, the diversity of possible causes of surface ultraviolet change. Shown at the left of the figure is the observable quantity: an increase in UV-B radiation at the ground. Shown to the right in the figure are the various possible causes of that change. There are more than thirty such causes, including volcanism, increase of Freon due to aerosol sprays, atmospheric testing of nuclear weapons, and so on, Only a few of the possible causes are those due to aircraft, such as increased SST operations, increased operations of space shuttles, and so on. At present, it is not hard to establish that the airplanes are not causing much change in the world ozone but fifteen years from now it will be more difficult to determine the contribution of major causes. The monitoring efforts of fifteen years from now will be challenged to define not only that

Simplified Reverse Discrimination Tree for Surface UV-B Increase

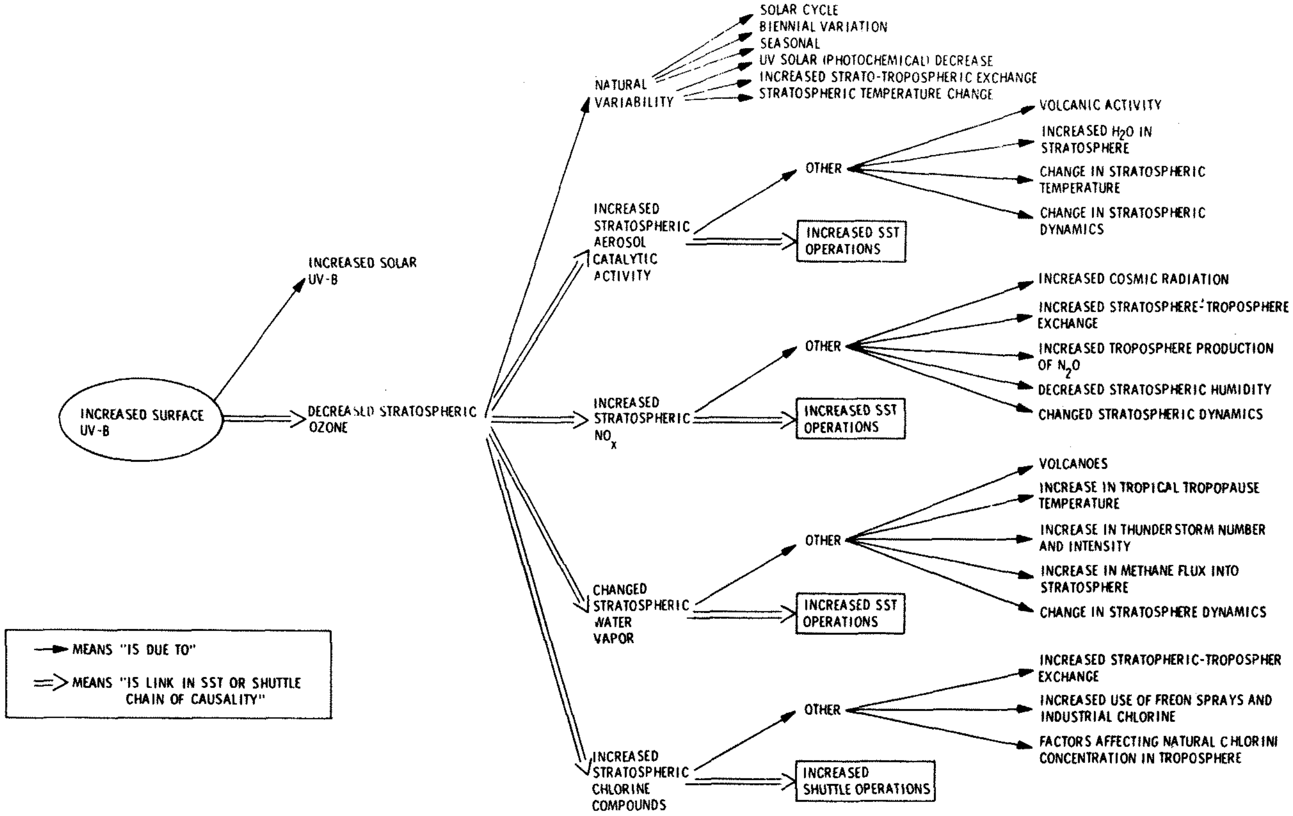

Figure 6

there has been a certain change of world ozone over a time period of considerable duration (like ten years) but how much of that change can be specifically attributed to aircraft flying in the stratosphere.

III. Sulfur Dioxide and Climate

Consider the climate chain of cause and effect by which the aircraft engine effluents (notably sulfur dioxide and to a lesser degree water vapor and nitrogen oxides) affect climate variables such as temperature, wind, and rainfall. The sequence of effects is shown in Figure 7. Chief pollutant likely to cause climate change is the SO_2 created by the combustion of the sulfur in the fuel. If enough particles larger than 1/10th micrometer in diameter were added to the stratosphere, they could alter the radiative heat transfer of the earth/sun system and thereby influence climate. Particles of this size are produced from several gaseous constituents of engine emissions, in particular those of SO_2. When considering the large number of aircraft postulated to operate in the future in the stratosphere and particles developing from the SO_2 engine emissions are potentially serious unless the fuels burnt have sulfur content smaller than at present. The improvement of today's fuels could be realized at a change of fuel cost less than 1%.

THE CLIMATE STUDY

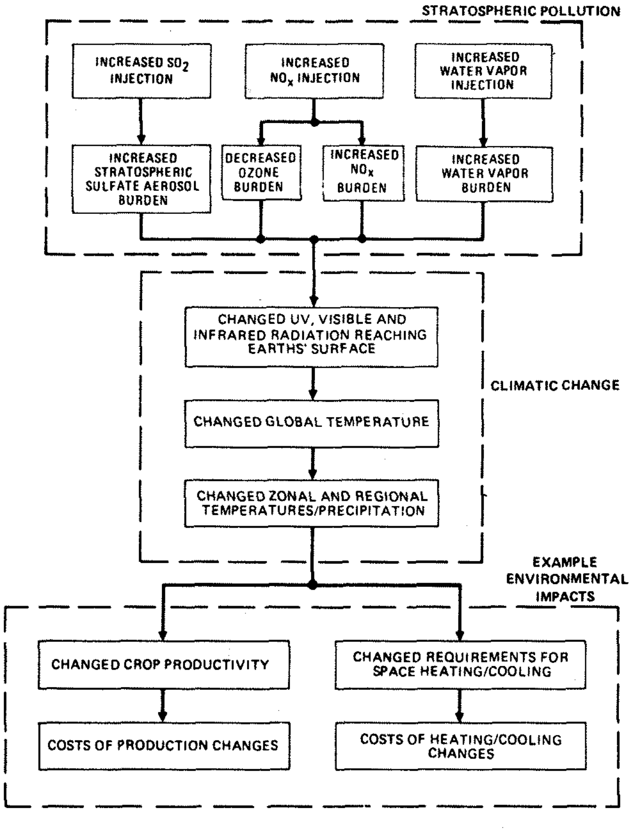

Figure 7

The sequence in the climate cause and effect chain is the following. Stratospheric SO_2 interacts with the abundant water vapor to produce solid sulfuric acid particles that build up with successive collisions to sizes greater than 1 micrometer. These particles disperse within the stratosphere (principally within the hemisphere into which they have been injected) where they remain for periods as long as three years, depending on their altitude. The particles cause the stratosphere's opacity to incoming sunlight to increase slightly, tending to cool the earth's surface. Particles also intercept some radiation reflected from the earth and return to the earth, mitigating the cooling.

Effects of other pollutant gases such as the nitrogen oxide and the water vapor give rise to what is called the "greenhouse effect " and may warm rather than cool. The combined effects of the pollutant gases is a cooling of smaller degree than that due to the SO_2 alone.

The net cooling at the surface changes the global mean temperature. Temperature changes in turn affect the winds and precipitation in complicated ways, and so have effects on agricultural productivity and the need for such measures as warmer clothing, temperature control in dwellings, and snow removal.

Estimated Percent Increase in Stratospheric Optical Thickness per 100 Aircraft

Aircraft Type	Fuel Burned Per Year* (kg/yr)	Altitude km (kft)	Maximum SO_2 EI Without Controls (g per kg fuel)	Percent Change in Stratospheric Optical Thickness in Northern Hemisphere	
				Without Controls	EI Controls 1/20 Today
Subsonic**					
707/DC-8	1×10^9	11 (36)	1	0.023	0.0012
DC-10/L-1011	1.5×10^9	11 (36)	1	0.032	0.0016
747	2×10^9	11 (36)	1	0.044	0.0022
747 – SP	2×10^9	13.5 (44)	1	0.10	0.0050
Supersonic					
Concorde/TU-144	4×10^8 3×10^9	13.5 (44) 16.5 (54)	1	0.44	0.022
Advanced SST	3×10^8 6×10^9	16.5 (54) 19.5 (64)	1	1.9	0.094

*Subsonics assumed to operate at high altitude, 5.4 hours per day, 365 days per year. Supersonics assumed to operate at high altitude, 4.4 hours per day, 365 days per year.

**The present subsonic fleet consists of about 1,217 707/DC-8s, 232 DC-10/L-1011s, and 232 747s flying at a mean altitude of 11 km (36 kft) and is estimated to cause an increase in stratospheric optical thickness of 0.5 percent.

Table 3

CIAP EQUIVALENCIES

IF BARELY DETECTABLE CHANGE OF STRATOSPHERIC OPTICAL THICKNESS DUE TO SO_2 FROM STRATOSPHERIC AIRCRAFT IS 10%, THIS REPRESENTS:

- Results of 2070 Concordes flying 4.4 hr d^{-1}, 365 d yr^{-1} with EI = 1 gm kg^{-1} at altitude 15 - 18 km (49 - 59 kft)
- Decrease in mean global temperature of 0.07°C
- Decrease of mean temperature in U.S. of 0.1°C
- Decrease of U.S. rice crop 2%
- Decrease of world wheat crop value by 9M$ and world rice crop value by 100M$
- Equivalent of 1/3 of world temperature decrease from 1940 to 1960

Table 4

A measure of stratospheric opacity is called "optical thickness," for which the "barely discernible measure of detection" is about 10%. As indicated in Table 3, it is estimated that the present sub-sonic fleet consisting of more than 1,700 large aircraft may cause an increase of stratospheric optical thickness of 0.5 percent. One hundred Concorde TU-144 aircraft would produce an effect of about the same size, about 0.4 percent. Shown in Table 4 are the equivalences to the 10% "barely detectable change" of stratospheric optical thickness assuming it to be solely due to SO_2 from stratospheric aircraft. Ten percent change in stratospheric optical thickness is produced roughly by 2,070 Concordes flying 4.4 hours per day, 365 days per year. That would result in a decrease of mean global temperature of about 0.07 degrees centigrade. The 1/10th of a degree centigrade change in mean U.S. temperature could result in the decrease of the U.S. rice crop productivity by 2% and of the world wheat crop by about $9,000,000 and of the world rice crop by about $100,000,000. This temperature change due to 10% change in stratospheric optical thickness is about one-third of the world temperature decrease during the period 1940 to 1960.

Figure 8 shows the uncertainties of the climatic impact estimation. These are similar to those for the skin cancer case. In the first five steps the uncertainties of the geophysical estimation are shown, leading to a ratio of uncertainty to mean value of surface temperature, estimated to be about 0.7. The largest contribution is that of the step going from the change of radiation to the estimates of surface temperature. In Figure 8, below the surface temperature estimate, the uncertainties of estimating the cost effects on various crops due to temperature change are displayed. Of these, the largest uncertainty is that in the estimation of wheat costs.

Overall, the ratio of uncertainty to the mean estimate is about 0.8. That is to say, there is 95% confidence that estimates are true within a factor of three to ten. Even if one introduces the subjective guesses by modelers of how bad they think their models possibly may be, these factors of uncertainty are not larger than a factor of 5.

Although for science, an uncertainty factor of five is very unsatisfactory, knowledge of climate effects within a factor of five may well be adequate for choice of policy today. However, such uncertainty of estimation will not be satisfactory ten or fifteen years from today. Further investigations should be pursued with sufficient energy that ten or fifteen years from today the effects of climate change are known more accurately. In the future, more monitoring of the cause and effects of climate change is required.

Propagation of Fractional Uncertainty Through SO_2/Temperature/Costs Cascade
Schainker et al., 1974

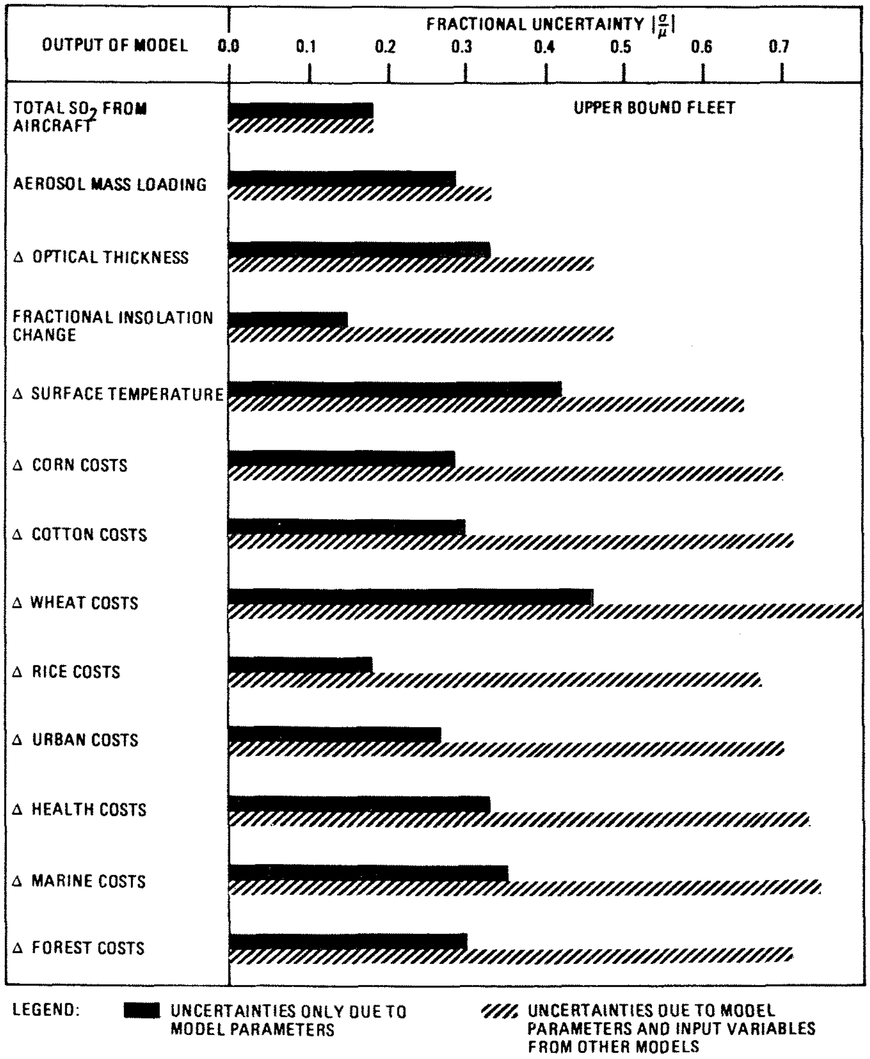

Figure 8

Temporal Variation of Midlatitude Temperature in the Northern Hemisphere
Budyko, 1971; T. Asakura, Japan Meteorological Agency
(unpublished results), for temperature changes after 1959

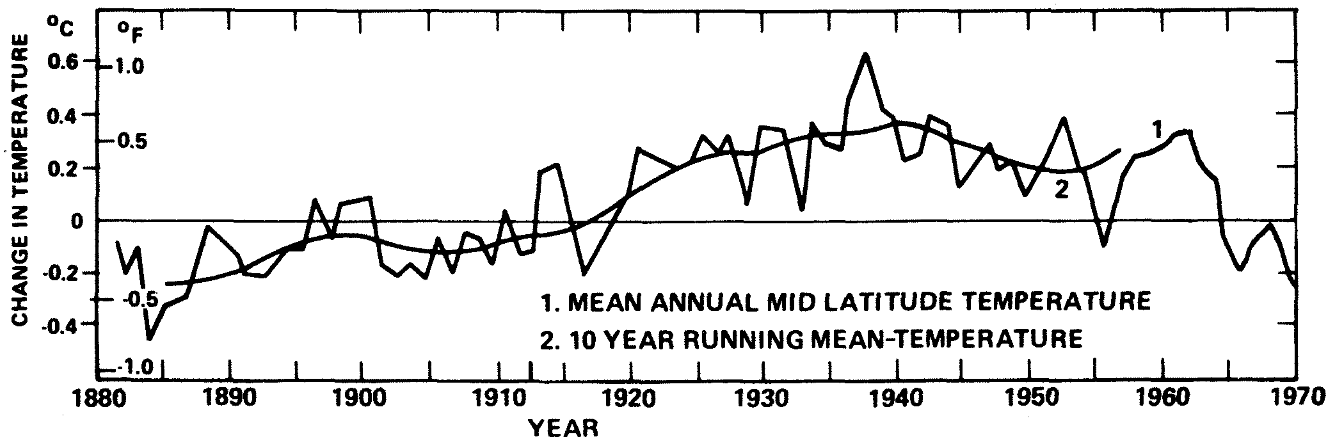

Figure 9

The climatic characteristics themselves are highly variable. Figure 9 shows the temporal variation of mid-latitude temperature in the Northern Hemisphere. The data from 1880 to 1959 was compiled by Professor M. I. Budyko. The most jagged curve, representing the mean annual mid-latitude temperature, shows a strong deviation from the ninety year mean, from year to year. The smoother ten-year-running-mean temperature shows a trend which increased steadily from 1880 to about 1940 and subsequently has declined. From Figure 9 it may be inferred that determining how the world temperature is changing is probably not much easier than determining what's happened to the total ozone.

The problem of determining causes of other climate changes, similar to the change in ozone, is suggested in Figure 10. Shown at the left are the observable changes in mean global climate. Shown to the right are the many causes which could result in these climate changes.

Only a few (indicated in boxes) of the many possible causes of global temperature change can be attributed to aircraft. At the present the knowledge to sort out the causes is lacking. Only newly available are the tools for detecting adequately the long term changes in world ozone or climatic variables. Scientists will be challenged in the next decade to become sufficiently knowledgeable of these processes so that the observed data may be diagnostically analyzed for long term changes of world ozone and climate, and for estimation of the individual contribution of each of the many possible causes.

The projection to the future for nitrogen oxide emission indices is shown in Table 5. The top lines show that, by the current technology, nitrogen oxide emissions of the subsonic aircraft (such as the Boeing 747) produce about 16 grams of nitrogen oxide per kilogram of fuel burned, and that of the supersonic vehicles (such as the Concorde and the TU-144) produce about 18 grams of nitrogen oxide per kilogram of fuel. As a consequence of current efforts to clean up airports, emission indices of future engine designs may be reduced by 50% in the case of subsonics and a smaller factor

PROJECTED NO_X EMISSION INDICES

ENGINE TYPE (AIRCRAFT SYSTEM)	NO_x EMISSION INDEX: $g(NO_2)/kg$ FUEL
CURRENT TECHNOLOGY (OPERATIONAL THROUGH 1985)	
– SUBSONIC (JT97D/B747)	16
– SUPERSONIC (CONCORDE)	18
ANTICIPATED REDUCTION TECHNOLOGY (IMPLEMENTED 1980-1985 TIME FRAME)	
– SUBSONIC	8
– SUPERSONIC	12 - 14
ADVANCED REDUCTION TECHNOLOGY (POSSIBLE BY 1985-1990)	
– SUBSONIC	3
– SUPERSONIC	3
PROJECTED MINIMUM	
– SUBSONIC	0.3
– SUPERSONIC	0.3

Table 5

Simplified Reverse Discrimination Tree for Tropospheric Temperature Changes

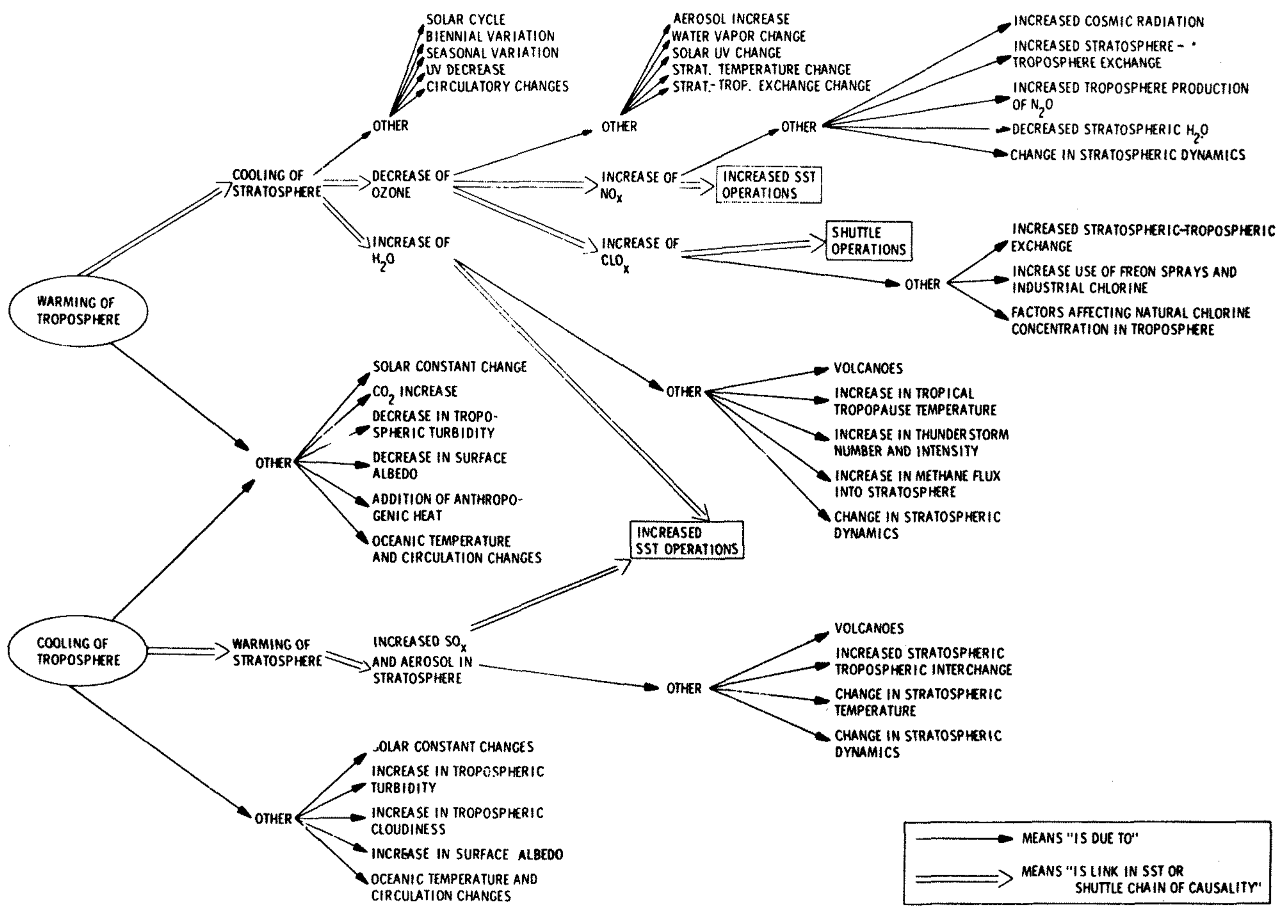

Figure 10

in the case of supersonics. But the goal for 1985 and 1990, which has not yet been demonstrated but is the subject of energetic efforts by NASA and by the aircraft engine manufacturers, is that the NO_x emissions of subsonics and supersonics be reduced by a factor of almost 6 by 1990.

Although the direction this improvement will take is known and has been demonstrated in the laboratory, we are a long way from having an engine which has been tested and certified for flight operations. Testing and certifying a new combustor represents a task of about a $50,000,000 magnitude at the very least. It has not yet been done, and needs to be done. It will not be done for any other reason that we know except concern for the environment. The projected minimum emission index described in Table 5, about 60 times smaller than that of present technology is a theoretical limit.

Introducing a comparison of costs, Figure 11 shows the present value of some aerosol pollution effects, projected in years ahead under the exaggerated assumption that numbers of aircraft were to increase by maximum conceivable growth without benefit of technological improvement. The items shown are incomplete in a list of all effects. The dashed lines show, at the top of Figure 11, the discounted annual cost of a monitoring program, and the total cost of desulfurization. The latter represents about a half a cent per gallon, or 20 cents per barrel, and is a relatively small fraction of the cost of aviation fuel. At the bottom of Figure 11 are two examples of crops (corn and wheat in the U.S.) that would benefit by the cooling due to increased aerosols.

The costs of the two remedies are an order of magnitude smaller than the several ecologic consequences estimated. The economic consequences which are shown here have uncertainties indicated by error bars. One can choose the most pessimistic or the most optimistic or, as we have done, the middle value for his prediction. Presumably, the total of all ecologic effects of stratospheric pollution is greater than the sum of the few examples that we have shown here, and much greater than the cost of remedies.

The arguments which I have described so far lead to the conclusions of CIAP.

IV. Conclusions of CIAP

The principal scientific conclusions of the CIAP Program are the following five, quoted from the 1974 CIAP Report of Findings:

"1. Operations of present-day SST aircraft and those currently scheduled to enter service

ESTIMATED PRESENT VALUE (1974) OF ANNUAL COST OF AEROSOL EFFECTS (5% DISCOUNT RATE)

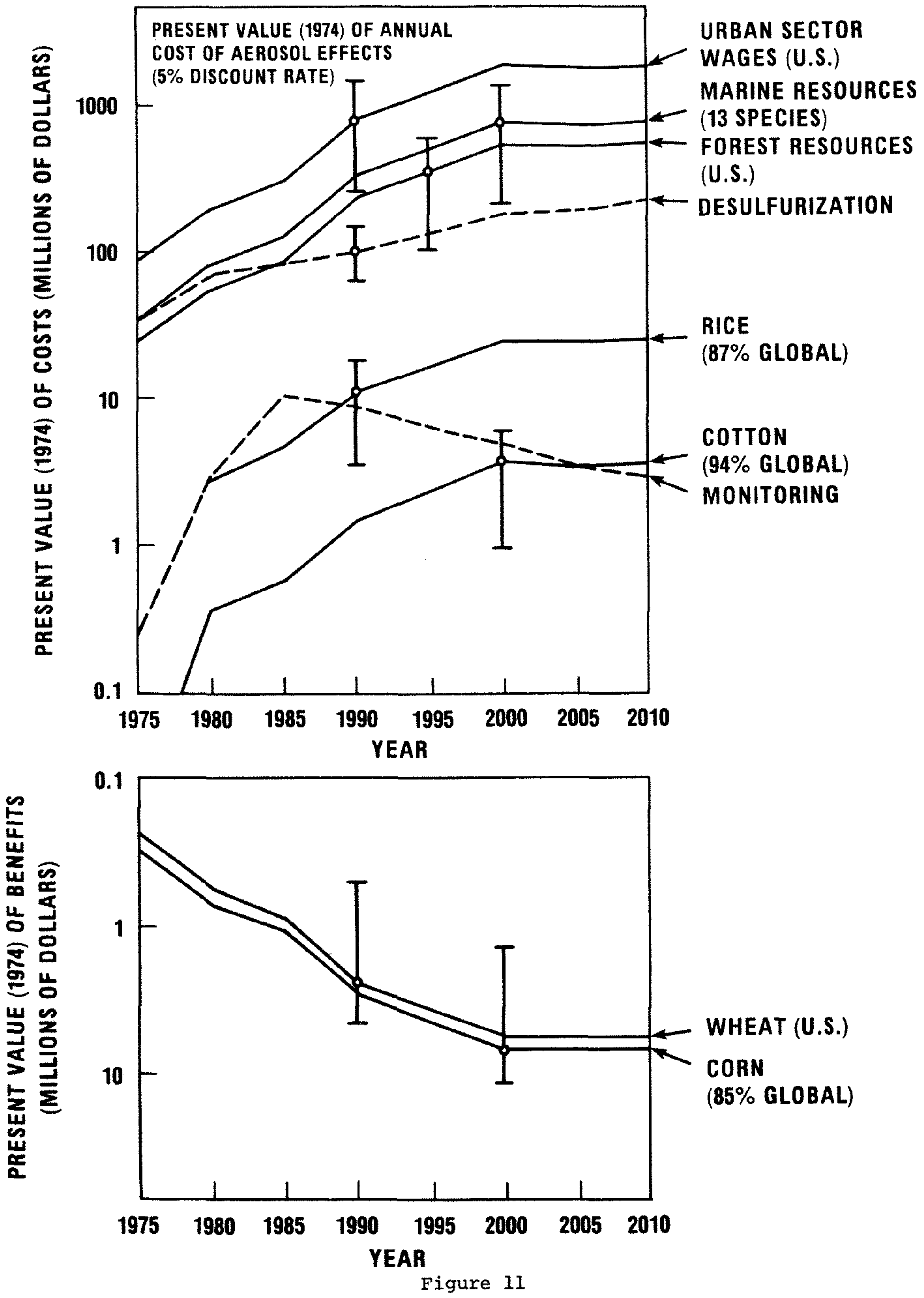

Figure 11

(about 30 Concordes and TU-144's) cause climatic effects which are much smaller than minimally detectable.

"2. Future harmful effects to the environment can be avoided if proper measures are undertaken in a timely manner to develop low-emission engines and fuels in step with the future growth of stratospheric aviation. These measures include:

"a. The development of new engine technology leading to lower levels of nitrogen oxide emissions (which involves a lead time of 10 to 15 years for development, fabrication, certification, and introduction into service of the new engines).

"b. Use of jet fuels having a sulfur content smaller than that in current fuels, through the application of state-of-the-art desulfurization processes.

" 3. If stratospheric vehicles (including subsonic aircraft) beyond the year 1980 were to increase at a high rate, improvements over 1974 propulsion technology would be necessary to assure that emissions in the stratosphere would not cause a singificant disturbance of the environment.

" 4. The cost of carrying out the measures in conclusion 2, including the operational cost of compliance, is small compared to the potential economic and social costs of not doing so.

"5. A continuous atmospheric monitoring and research program can further reduce remaining uncertainties, can ascertain whether the atmospheric quality is being maintained, and can minimize the cost of doing so."

V. Recommendations of CIAP

The scientific conclusions of CIAP suggest the following four courses of action quoted from the 1974 CIAP Report of Findings:

"1. Develop in the next year a plan for a proper program for international regulation of aircraft emissions and fuel characteristics for whatever stratospheric flight operations may evolve in the future.

" 2. Accelerate combustion research and engine development programs needed to make stratospheric flight possible with specified nitrogen oxide emission standards.

"3. Use low-sulfur fuels. Study the implications of utilizing low-sulfur content aviation fuels for stratospheric flight.

"4. Develop a global monitoring system to ensure that environmental protection is being achieved. Continue research (drawing on the monitored data) to reduce the uncertainties in the present knowledge of the stratosphere and improve the methods for estimating climatic change and the biologic consequences. "

Considering the future, Figures 12 and 13 describe relationships of necessary actions. As indicated in Figure 12, CIAP has uncovered the science naming many of the problems of stratospheric pollution by aircraft, and of the possible technical solutions.

The first step, already initiated, is development of non-polluting aircraft engines and fuels. In order of urgency, the next step is the establishment of appropriate standards for the air quality. Standards, while based on a scientific understanding of the consequences of pollution, must also respond to the subjectively derived criterion of public acceptability. "What is

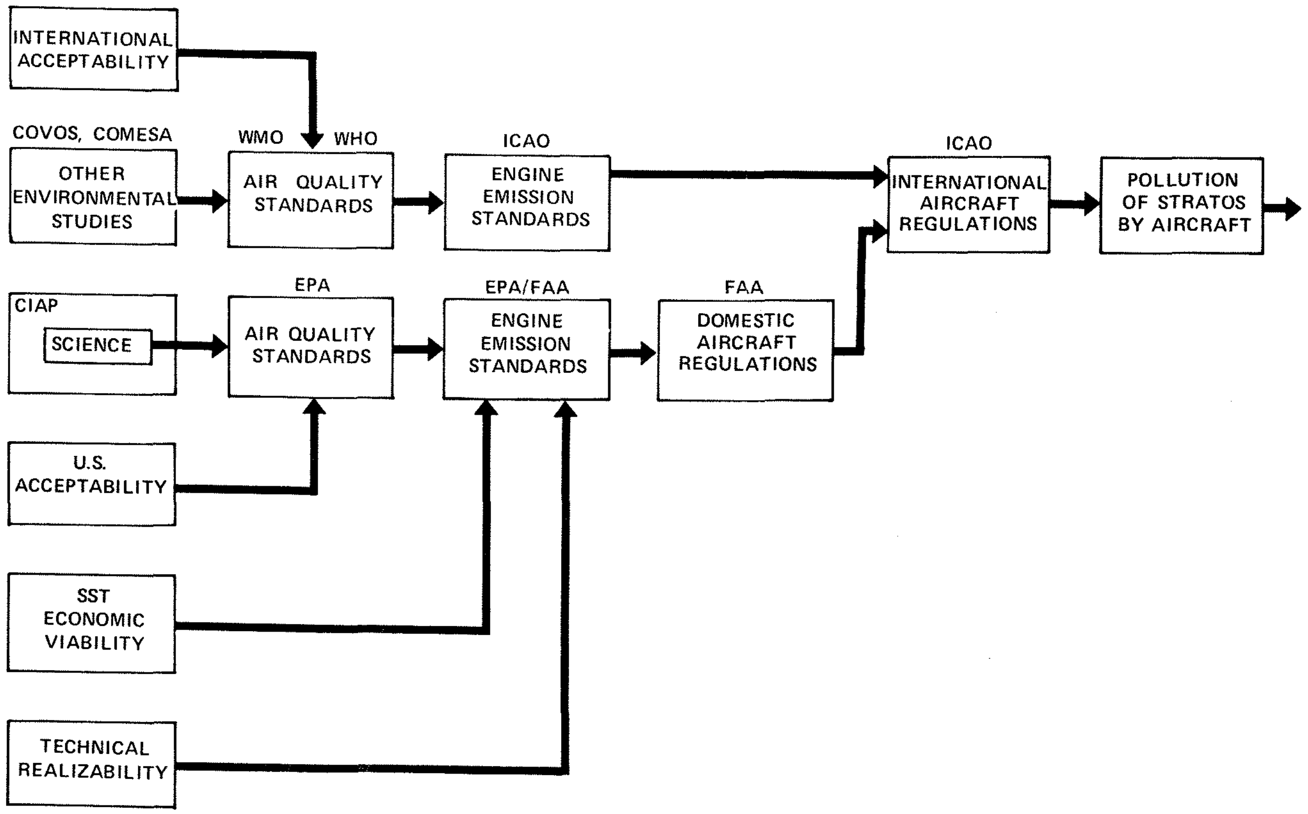
REGULATION OF POLLUTION BY AIRCRAFT

Figure 12

Monitoring of Pollution by Aircraft

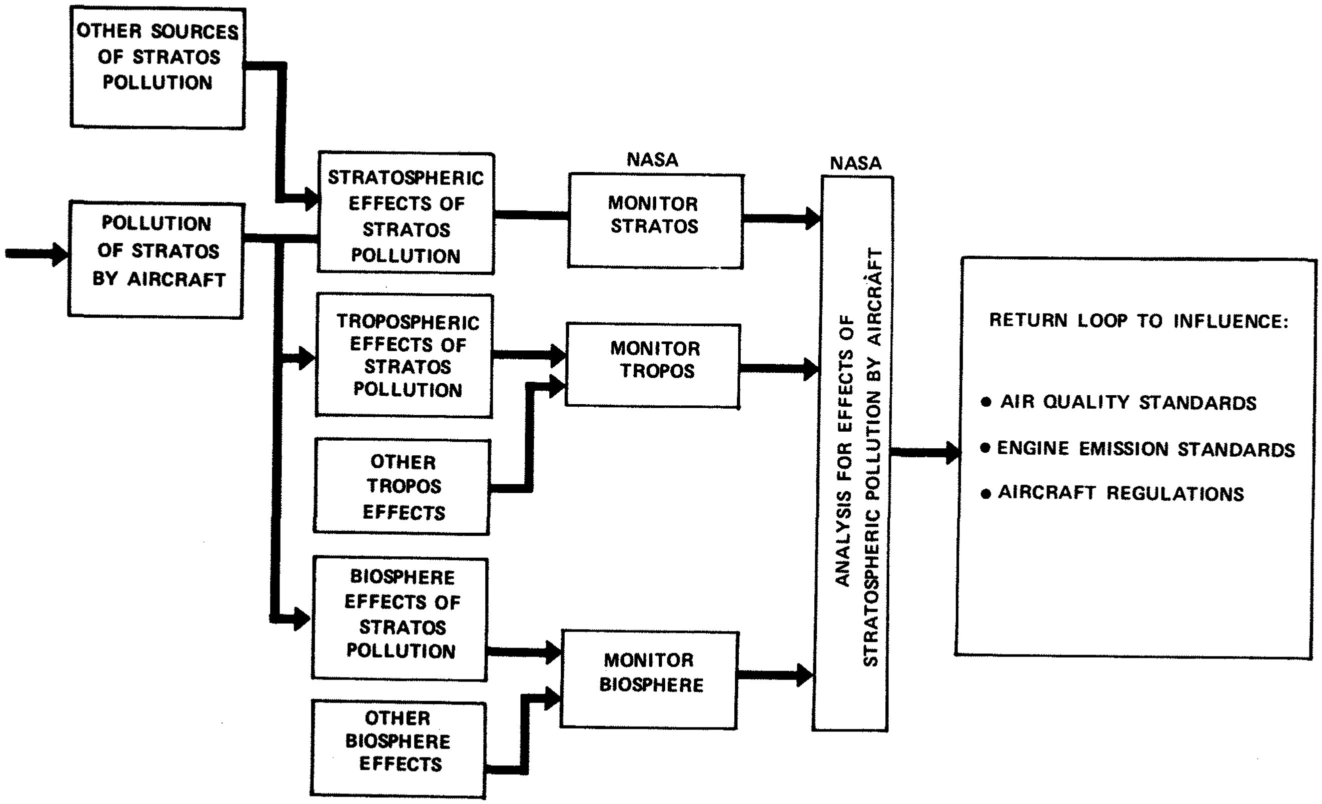

Figure 13

acceptable" might be phrased in this case: "What is the acceptable deviation from the present annual mean of total overhead ozone? Is a 1% change acceptable? A 1/2% change? A tenth of a percent change? A 50% change? The choice must be determined first by the Environmental Protection Agency (EPA), and approved by Congress, and the people.

Logically dependant on the determination of acceptable standards of air quality is the decision as to what are appropriate standards for aircraft engine emissions. In this, in addition to the chosen air quality standard, one must consider the number of sources of pollution. The number of airplanes that will be flying and the time of flight of each in the stratosphere become considerations quite as important as emission characteristics of the individual aircraft. Moreover, engine emission standards have to be technically realizable; one should not prescribe infeasible standards.

In the U.S., the determination of engine emission standards is the joint responsibility of the EPA and the Federal Aviation Administration (FAA). Domestic aircraft regulations based on the standards are established by the FAA in the United States.

Wherever the source of stratospheric pollutions its effects are felt everywhere. Stratospheric pollution by aircraft is an international problem, for the regulation of which the International Civil Aviation Organization is legally competent. In parallel with the U.S. efforts described in Figure 12, there must be analogous activity in the international community. Already there are extensive programs in half a dozen countries; they include the U.K. Committee on the Meteorologic Effects of Stratospheric Aircraft (COMESA), and the French Group d'Etudes des Consequences du Vols Stratospherique (COVOS). By means of these and similar studies in Canada, Japan, Australia, and the Soviet Union, and the activities of the World Meteorologic Organization (WMO), the World Health Organization (WHO) and the International Civil Aviation Organization (ICAO), the world nations may join in a multilateral agreement on air quality standards and the appropriate regulatory action.

Accomplishing the regulation on an international basis is only the first part of a sensible solution. The second part (closing the loop), as indicated in Figure 13, requires determining the true results of the preceding ten or fifteen years of regulated aircraft activity. To be successful ten or fifteen years from now in identifying the effects of pollution of the stratosphere by aircraft, the effects of non-aircraft sources of stratospheric pollution (for example, Freon, volcanism, and atmospheric testing of nuclear weapons) must also be recognized so that confusion as to the source of change may be avoided. In addition to the stratospheric effects of stratospheric pollution, there are also tropospheric effects (which may also be confused by multiple causes) and biospheric effects.

Proper monitoring for changes in the stratosphere, the troposphere and the biosphere requires diagnosis as to cause of change. In the U.S. the National Aeronautics and Space Administration (NASA) and the National Ocean and Atmosphere Administration (NOAA) are the agencies which will lead in accomplishing this necessary function. Whoever leads, it is important to the Department of Transportation that the future analysis of the effects of stratospheric change properly identify the effects attributed to aircraft. With such analysis, then, there will be basis for future reevaluation of air quality standards, of engine emissions standards, and of aircraft regulations.

In addition to the reports of CIAP studies other important steps have been the completion and publication of reports of the U.S. National Academy of Sciences (1974), of the U.K. Committee on Meteorological Effects of Stratospheric Aircraft (COMESA) (1975), and of the World Meteorological Organization (1975).

The most recent step in considering the environmental impacts of the SST's was the decision of the Secretary of Transportation concerning the Concorde Supersonic Transport, published on February 4, 1976. In the Secretary's decision, he considered the legal framework (that is, the effect of international obligations and requirements of domestic law), the policy framework, the environmental consequences (including effects on local air quality, energy, the stratosphere, and noise) and the benefits of the Concorde both technically and with respect to international relations.

Bearing in mind that the benefits of an environmentally sound and commercially viable SST would be substantial, the magnitude (and its uncertainty) of the environmental consequences did not warrant the restriction of operation of about six Concordes into the United States. He ruled that operation should be permitted for a sixteen-month demonstration period during which time the consequences of operation might be further evaluated.

Other important steps have been the completion and publication of reports of the U.S. National Academy of Sciences (1974), of the U.K. Committee on Meteorological Effects of Stratospheric Aircraft (COMESA) (1975), and of the World Meteorological Organization (1975).

ACKNOWLEDGEMENTS AND REFERENCES

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