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Protection of Our Fragile Upper Atmosphere

Clayton Clark

Utah State University

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CLAYTON CLARK

46TH HONOR LECTURE
Winter 1973

Faculty Association
Utah State University
Logan, Utah

FORTY-SIXTH HONOR LECTURE DELIVERED AT THE UNIVERSITY

A basic objective of the Faculty Association of Utah State University, in the words of its constitution, is:

> to encourage intellectual growth and development of its members by sponsoring and arranging for the publication of two annual faculty research lectures in the fields of (1) the biological and exact sciences, including engineering, called the Annual Faculty Honor Lecture in the Natural Sciences; and (2) the humanities and social sciences, including education and business administration, called the Annual Faculty Honor Lecture in the Humanities.

The administration of the University is sympathetic with these aims and shares, through the Scholarly Publications Committee, the costs of publishing and distributing these lectures.

Lecturers are chosen by a standing committee of the Faculty Association. Among the factors considered by the committee in choosing lecturers are, in the words of the constitution:

> (1) creative activity in the field of the proposed lecture; (2) publication of research through recognized channels in the field of the proposed lecture; (3) outstanding teaching over an extended period of years; (4) personal influence in developing the character of the students.

Clayton Clark was selected by the committee to deliver the Annual Faculty Honor Lecture in the Sciences. On behalf of the members of the Association we are happy to present Professor Clark's paper:

Protection of Our Fragile
Upper Atmosphere

Committee on Faculty Honor Lecture

Protection of Our Fragile Upper Atmosphere

Clayton Clark

Introduction

Termination of U.S. government support for the Supersonic Transport, SST, may eventually cost the United States its leadership in aviation and billions of dollars in international trade losses, yet if the world wide SST program is allowed to continue, the costs to mankind as a result of damage to environmental resources could be much higher. The decision to terminate the project was heavily based upon concern for possible changes in the properties of the upper atmosphere as a result of SST operations in that realm, with consequent danger to plant and animal life on the Earth below.

Briefly, the concern over atmospheric modification stems from pollution from the SST's and possibly other sources. The SST's must operate within the stratosphere to reduce the danger from sonic booms and to obtain high operating efficiency. Because that region is very stable (little mixing occurs), pollutants from the SST exhausts, will accumulate in the stratosphere and impurities will remain in that region for at least a year and possibly several years.

Two very great dangers can be visualized from stratospheric pollutants. First, the temperature of the Earth may be increased or decreased by greater or lesser retention of solar energy—a change either way could change the Earth's ability to support life. Second, and perhaps most important, the ozone within the atmosphere, which now blocks most of the Sun's ultraviolet rays, could be reduced by pollutants thus allowing the rays to penetrate to the Earth's surface causing skin cancer, blindness, and other serious biological effects.

Proposed and existing supersonic transport aircraft are illustrated in figures 1, 2 and 3 respectively, the Boeing SST, the British-French

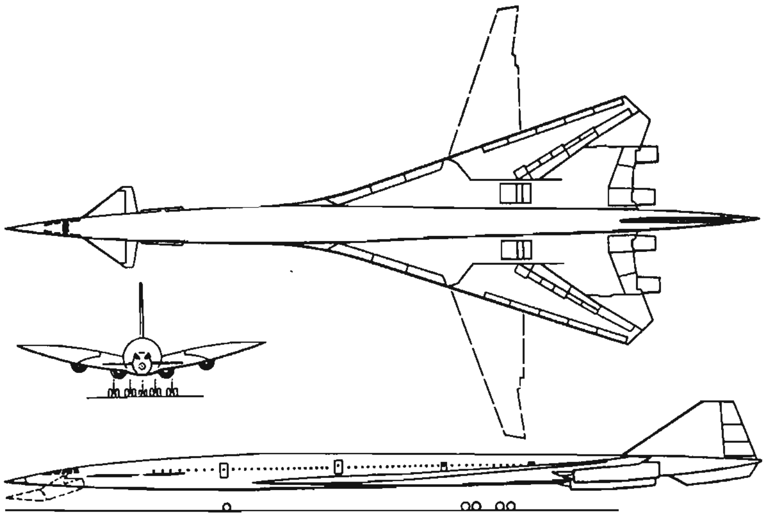

Figure 1.
Outline drawing of the swing wing model of the Boeing supersonic transport. The cover picture is an artist's rendering of the fixed wing model of the Boeing SST at the time the program was terminated.

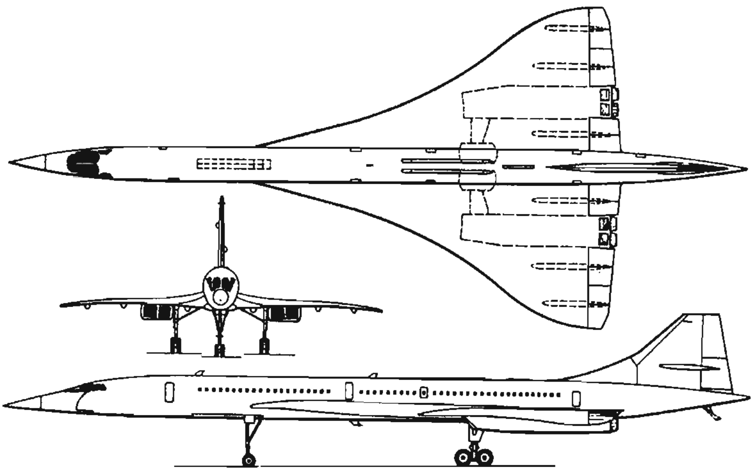

Figure 2.
Outline drawing of the British-French Concorde supersonic transport.

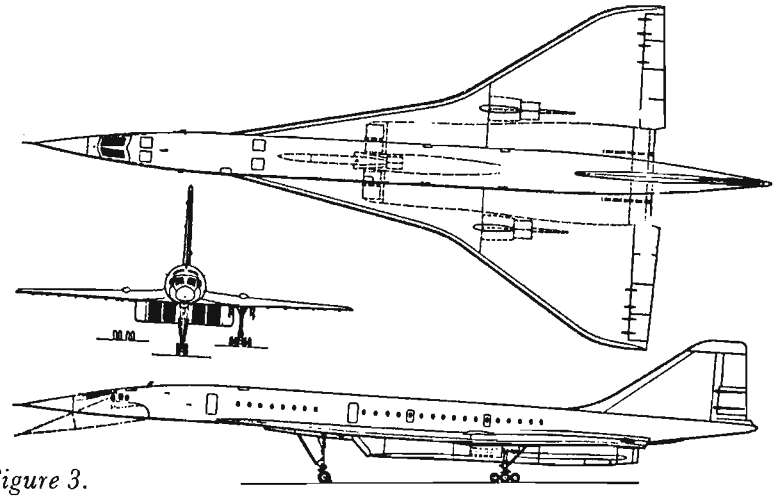

Figure 3.
Outline drawing of the Russian Tu-144 supersonic transport.

Concorde and the Russian Tu-144. The Concorde and Tu-144 are now operational. Figure 4 indicates the weekly routes proposed for 1990 (not including the Russian routes). It is estimated that by 1990 the SST fleets could reach 600 planes. This adds up to potential deposits of more than 82 million tons per year of pollutants. Concentrations of such impurities have been calculated assuming they remain in the stratosphere for two years and are uniformly mixed. The results are frightening to the scientist because the resulting concentration, one pollution molecule per million natural molecules, approaches the same order of concentration as that of ozone in the stratosphere and thus could cause vast changes in our environment. These pollutive exhaust products will be in the form of gases such as ionized water vapor, oxides of carbon, nitrogen and sulfur, plus aerosols such as soot particles. The oxides of nitrogen and the hydroxyl ions from the water vapor function as catalytic agents which can destroy ozone without themselves being destroyed. Consequently, stratospheric behavior could be greatly altered by such concentrations of pollutants.

The U.S. government's withdrawal of SST support does not divert the danger. Already, military aircraft and some foreign SST's are operating within the stratospheric region. Over the polar regions the stratosphere dips earthward so that polar commercial jet flights

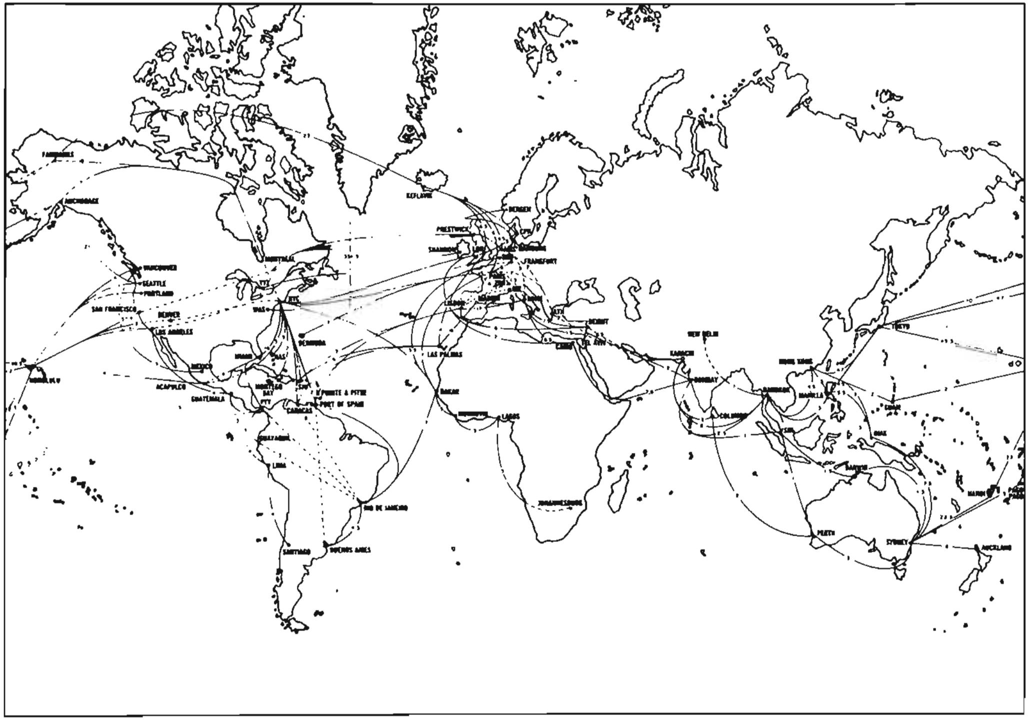

Figure 4.
Proposed daily round-trip flights for the Boeing and Concorde SST fleet by 1990, before cancellations of the American SST program.

currently penetrate the region for a part of their journey. Apparently, the number and duration of these flights are not great enough to have yet produced significant influence, but continuing future flights of commercial SST's could be of real danger.

Completely accurate assessment of the extent of the problem is not yet possible because certain vital information is unknown. A crash effort to obtain reliable information on atmospheric processes and reaction rates, and natural pollutant concentrations is underway. Congress has allotted $11 million to study this problem, part of which provides for a Utah State University experiment to measure nitric oxide in the stratosphere.

We hope the alarmist view presented here will not be justified when natural concentrations of nitric oxides and hydroxyl ions are known. Perhaps natural concentrations are so large that man-made changes will be insignificant, but we must be sure. Prudence dictates a careful study be completed before man has irreversibly modified his environment. The SST appears to be the most eminent danger; but all such threats to the fragile upper atmosphere are the concern of the USU Center for Research in Aeronomy.

The Atmosphere

The public thinks of the atmosphere mainly as the air we breathe, a few clouds, and a jet stream bringing storms from Alaska. Little thought is given to the one or two percent of the air that is above the 14 kilometers, (10 miles) altitude. However, this upper region is extremely important to us.

Figure 5 illustrates the regions of the atmosphere. As an example of the variations within any particular region, we could not live on the top of Mount Everest without supplementary oxygen, yet that is a mile or more below the altitude we fly in today's jet aircraft and five miles below the altitude SST's are expected to fly.

The Troposphere

This region which we inhabit and which contains the most dense portions of the atmosphere, extends from ground level upward to about 12 km. Cloud processes and moisture transport occur in

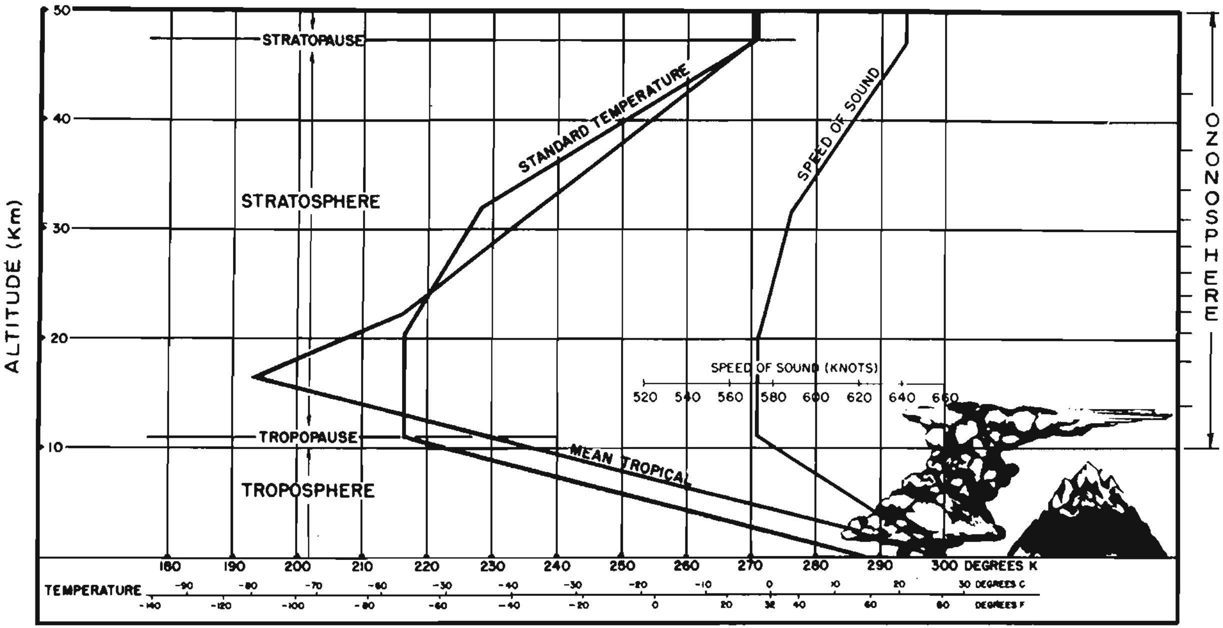

Figure 5.

Regions of the atmosphere. Temperature variations with height for different seasons and altitudes are shown. Note that the ozonosphere lies within the stratosphere.

this region, mostly below 8 km above sea level. The jet stream lies at 7 to 10 km altitude and accounts for much of the transport of energy about the northern hemisphere. The troposphere is characterized most prominently however, by a decreasing temperature with increasing height. This temperature gradient causes convection currents producing vertical mixing. These convection currents aid in removal of pollutants. Occasionally, a portion of the troposphere will have an abnormality in which the temperature increases with increasing altitude for a short distance. This is called an *inversion* and when it happens normal mixing of the air is blocked and impurities collect below the inversion, causing smog and sometimes heavy fog in winter. We see this often in our mountain valleys. Los Angeles and Salt Lake City have serious smog due to inversions. Logan also faces this potential problem.

To understand the nature of a temperature inversion, consider the undisturbed air of your living room. Cool air settles to the floor and hot air rises to the ceiling. Temperature stratifications lie between. This is the normal distribution and the air will remain still if nothing stirs it, but if air at the ceiling were cooled by a cold water pipe for example, the cool air would settle to the floor and cause air currents.

Likewise in the atmosphere, cooler upper air plus rising air, heated by the Earth's surface, cause mixing in the troposphere. Because of this natural mixing in the troposphere pollutants are removed relatively rapidly and inputs from aircraft exhausts represent a lesser problem than stratospheric pollution sources. SST flights in the troposphere present no great problem other than adding to the general aircraft pollution, but if they fly in the stratosphere the problem begins.

The Stratosphere

At about 10 km height the temperature no longer decreases, but in fact begins increasing with altitude. This is a crucial factor in the behavior of the atmosphere, and marks the beginning of the stratosphere which continues to a height of about 50 km. The temperature rise within this region is caused by ozone absorption of ultraviolet rays from the Sun. Because the temperature is always rising with

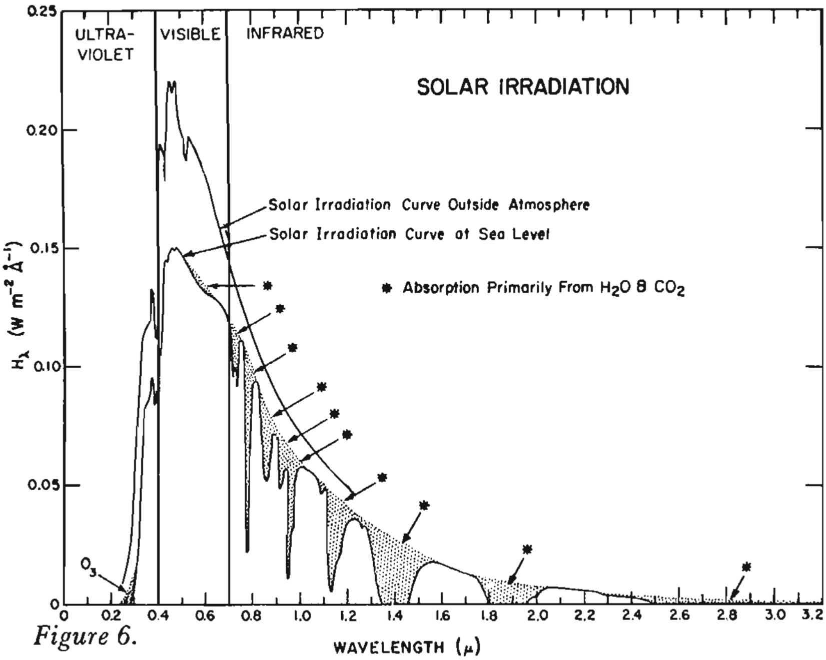

Figure 6.

Solar Irradiation. Much of the sun's energy is in the visible wavelength region. The ultraviolet irradiation and the small absorption of ozone (O_3) seem to be a small part of the total on this diagram, but the ozone is probably the most important protection we have from the sterilizing ultraviolet rays.

increasing height in the stratosphere, an effect similar to an inversion over our valleys occurs and particles are trapped in this region. Mixing is very slow between this region and the troposphere below. Therefore, this boundary is called the *tropopause.*

Pollutants deposited into the stratosphere may remain there for months or years. The number of molecules per cubic meter within the stratosphere is only about one-thousandth of that at sea level, so foreign particles introduced there tend to comprise a larger part of the total than equivalent amounts at sea level.

For computational purposes assume that mixing between the stratosphere and other parts of the atmosphere is so slow that particles remain in the stratosphere for two years, and that there are 600

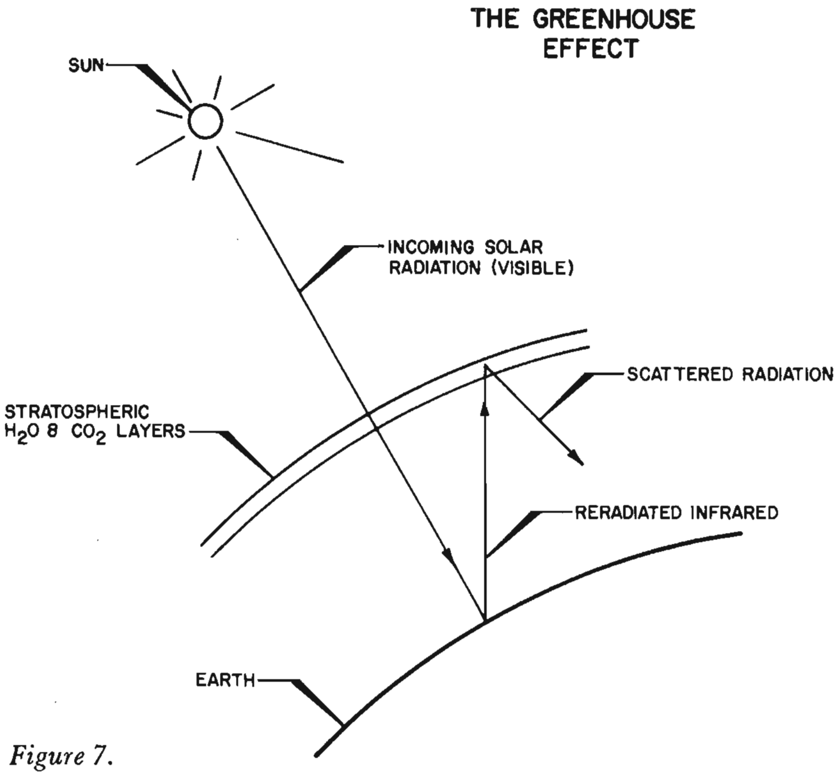

Figure 7.

Simplified illustration of the "greenhouse effect." Carbon dioxide and water vapor in the upper atmosphere admit light rays from the sun in the visible part of the spectrum and retain within the atmosphere the infrared heat rays produced when the "visible" rays heat the earth.

SST's making five flights per day each. The resulting pollution could accumulate to more than 160 million tons as a steady-state load. This amounts to a concentration of at least one part per million throughout the stratosphere, approximately the same concentration as that of ozone in the stratosphere.

Pollution in the stratosphere could cause two dangerous conditions. First, the "greenhouse effect" could be modified, either increased or decreased, causing a corresponding increase or decrease in earth surface temperature. The "greenhouse effect" results from energy entering the atmosphere by radiant heat primarily in the visible portion of the spectrum. This heat is then absorbed by the Earth's surface and lower atmosphere which is heated in the process. Reradiations from these heated areas are at a lower temperature than the Sun and therefore occur at longer wavelength. These longer wavelengths are infrared radiations. They are retained within the lower atmospheric regions because the carbon dioxide and other gases in the atmosphere prevent their escape. The process is complicated but acts effectively to reflect and absorb the energy. This process is extremely important in determining the surface temperature of the earth. As an example of the "greenhouse effect," your car windows reflect heat back into the interior of the car so it becomes hot while standing in the sun.

Only a few degrees of temperature change, resulting from dust or high water vapor clouds reflecting heat away, could bring another ice age; on the other extreme, increased heat retention could melt the polar ice caps and increase the sea level enough to cover our coastal lands. Who is to say that changes initiated by a few degrees of increase in temperature would not be progressive with the Earth eventually becoming so hot that carbon dioxide would be released from our rocks, perhaps even becoming like Venus where the surface is as hot as melted lead and the atmosphere is mostly carbon dioxide at a pressure 100 times greater than the Earth's atmosphere?

Mars is a dead planet with only one hundredth as much atmosphere as ours, mostly carbon dioxide. It is a little smaller than Earth, and therefore cannot hold its atmosphere as well, but size and distance from the sun are not alone sufficient reasons for the differences between Venus, Mars, and Earth. Titan, a satellite of Saturn, is smaller than Mars yet has more atmosphere. Why? What are the crucial and perhaps sensitive factors that make Earth habitable? We hope to find out before we blunder into irreversible changes.

The second, and perhaps greatest danger, from stratospheric pollution is that it may cause a reduction of the ozone layer, allowing the ultraviolet rays from the sun to penetrate to the surface of the Earth. Most of the ultraviolet is now blocked and converted to heat high in the atmosphere. Strong ultraviolet intensity on the surface

Figure 8.
Earth, taken from space showing Africa, Egypt, and clouds over Antarctica. Clear and cloudy areas move around the Earth allowing sunlight to reach the surface. A delicate balance of temperature exists here.

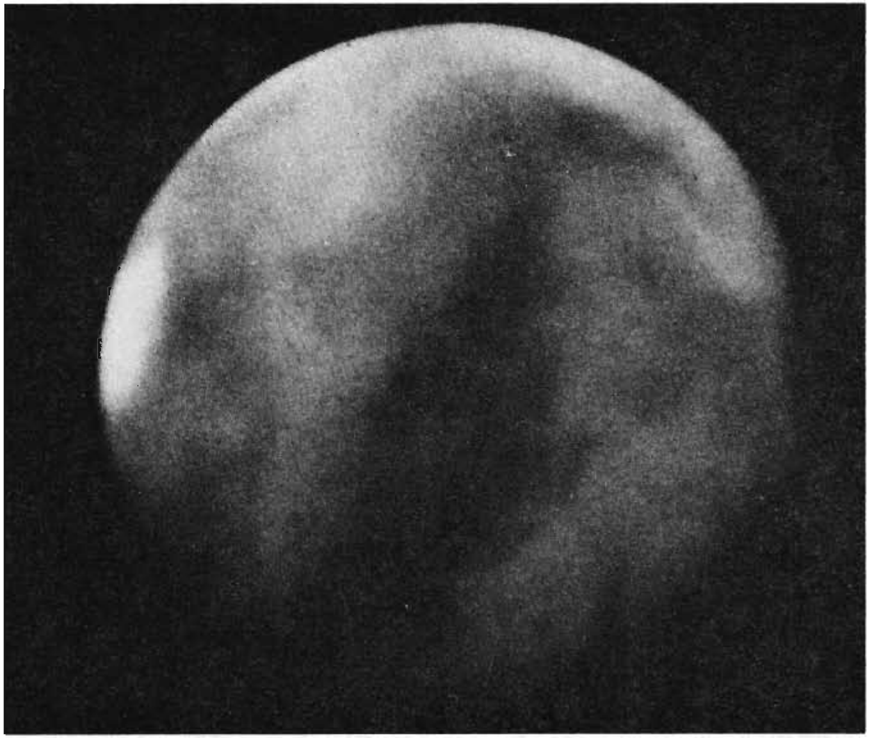

Figure 9.
Mars, from Earth. Surface markings by meteors on Mars, shown in pictures taken from spaceships, and other evidence show the atmosphere of Mars to be only one-hundredth of that on earth. Probably no life of any kind exists there.

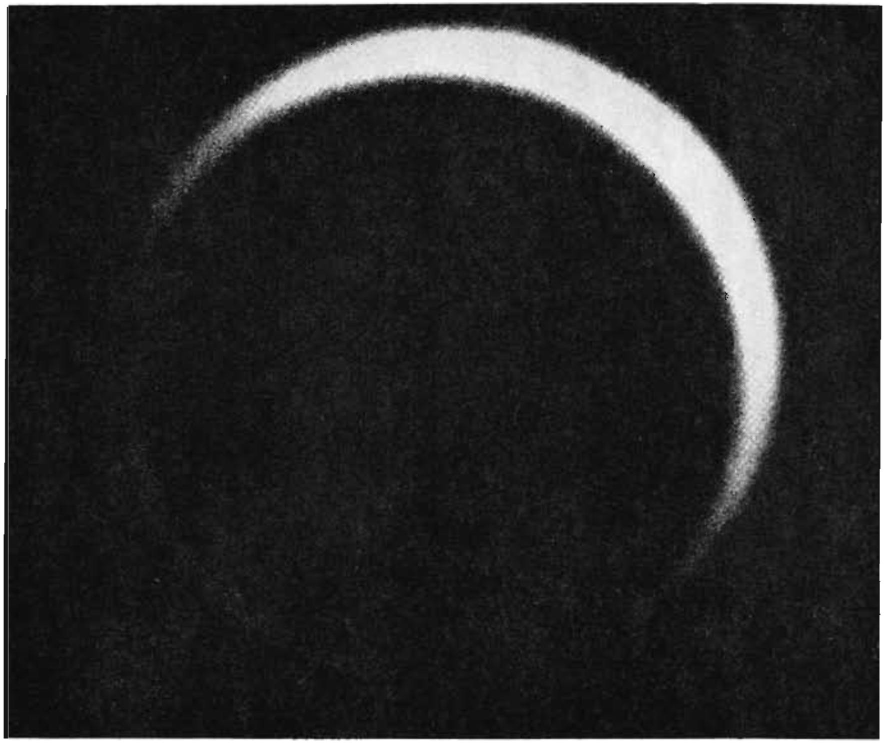

Figure 10.
Venus. The atmosphere is 100 times as dense as that of Earth. The surface temperature exceeds that of melted lead. The "greenhouse effect" in the dense atmosphere contributes to the extreme heat. Because Venus is between Earth and the Sun, it appears as a crescent. Note that light entering the Venusian atmosphere on the far side emerges on all sides due to ray bending in the dense atmosphere.

of the Earth could be very damaging to life, for even if the intensity is below the total sterilization levels such radiation is harmful.

As a brief summary of biological effects Kendric C. Smith, M.D., of the Stanford School of Medicine, in a study for the U.S. Department of Transportation on the SST dangers, has pointed out that even though the ozone allows less than one ten-thousandth of the ultraviolet energy to reach the Earth, living things are in a delicate balance between the photochemical destruction of cellular components by solar radiation and their biochemical repair. The organism may die or mutations may appear in offspring. Blindness, skin cancer, sunburn, and chronic skin changes will occur. In addition to the physical injuries to man, the effects on life due to a change in behavior of insects (who see by ultraviolet) may be even more damaging. if insects could not pollinate plants our source of food would be severely affected.

Some scientists believe the ultraviolet danger to be much greater than that of temperature change. Consequently, a detailed study with somewhat more detail of the processes that are sensitive to pollutants is in order.

Stratospheric Physics and Chemistry

The chemical and physical processes in the stratosphere are extremely complex even in the natural state. A complete discussion is beyond the scope of this paper but an attempt will be made to point out the processes and factors that are considered to be the most likely to cause changes in life on Earth if the stratosphere becomes significantly polluted.

One process that is giving great concern at present is the destruction of ozone by the oxides of nitrogen. Ozone (O_3), the strange gas you "smell" around sparking electrical apparatus, lies in a thick layer in the stratosphere. While this layer extends down toward the Earth and reaches far out into the regions above the stratosphere, the natural formation process causes the ozone to be centered in the stratosphere at about 25 km height with only a few percent of the ozone below 10 km and above 60 km. Ozone absorbs most of the ultraviolet radiation from the sun, thus reducing the damaging effects of those rays to the inhabitants of Earth, and providing a heat absorption process thought to be extremely important in the Earth's heat balance. While no one knows how much ozone reduction might be expected from SST effluents, calculations indicate dangerous depletion to be very probable.

More than 60 chemical reactions take place simultaneously in the high atmosphere. The following are a few of the reactions most important to this study of possible pollutant disturbance of the natural balance.

$$O_2 + h\upsilon_1 \rightarrow O + O \qquad (1)$$

where υ_1, are photons of wavelengths less than 2000 Å

$$O + O_2 + M \rightarrow O_3 + M \qquad (2)$$

$$O_3 + h\upsilon_2 \rightarrow O + O_2 \qquad (3)$$

where υ_2 are photons of wavelengths less than 3000 Å

$$O + O_3 \rightarrow O_2 + O_2 \qquad (4)$$

Equation (1) indicates that normal molecular oxygen is broken into atomic oxygen by absorption of solar radiation at wavelengths shorter than about 2000 angstroms. Equation (2) is the principal formation process for ozone. One atomic oxygen atom joins an oxygen molecule to form an ozone molecule (O_3) providing the collision occurs simultaneously with a third molecule M in the air (such as N_2) to balance momentum and energy.

Equation (3) shows that the ozone molecule is immediately subject to destruction by a photon of wavelength 3000 angstroms or shorter. Thus, ozone molecules are formed and destroyed. Solar energy is absorbed in processes (1) and (3). More than 99% of the solar ultraviolet radiation is blocked from reaching the Earth's surface by the ozone absorption (and by molecular oxygen at even shorter wavelengths). This accounts for a considerable part of the solar energy input into the upper atmosphere. Equation (4) indicates that ozone is also being removed by collision with atomic oxygen to form O_2, the usual oxygen that we breathe.

Certain chain reactions occur with hydroxyl molecules (HO), and nitric oxide molecules acting as catalysts.

$$HO + O_3 \rightarrow HO_2 + O_2$$
$$O + HO_2 \rightarrow HO + O_2$$

or

$$HO_2 + O_3 \rightarrow HO + 2O_2$$
$$O + HO \rightarrow O_2 + H$$
$$H + O_3 \rightarrow O_2 + HO$$

also

$$O + HO \rightarrow O_2 + H$$
$$H + O_2 + M \rightarrow HO_2 + M$$
$$O + HO_2 \rightarrow HO + O_2$$

Another destructive chain involves nitrogen:

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O \rightarrow NO + O_2$$

None of these chain reactions produce ozone, but ozone is destroyed without loss of the catalytic agents: NO, HO, HO_2, or H. This chain could proceed and destroy all of the ozone unless the catalytic radicals are transported out of the stratosphere. The production rate of ozone is dependent upon solar radiation intensity and is therefore relatively constant. It will not increase to compensate for destructive processes due to pollutants. More information is needed on rates of all of these reactions to determine the build up times and ultimate concentrations.

Other Regions of the Atmosphere

Other regions in our atmosphere are important to our well being but apparently are not directly threatened by the SST program. To put the stratospheric studies in the proper context with other portions of our fragile upper atmosphere, the USU research programs at other altitudes are briefly mentioned here.

The *ionosphere* lies above 90 km where solar rays reacting with atmospheric molecules release electrons. They remain free for long periods of time in large numbers. Our radio waves enter this area

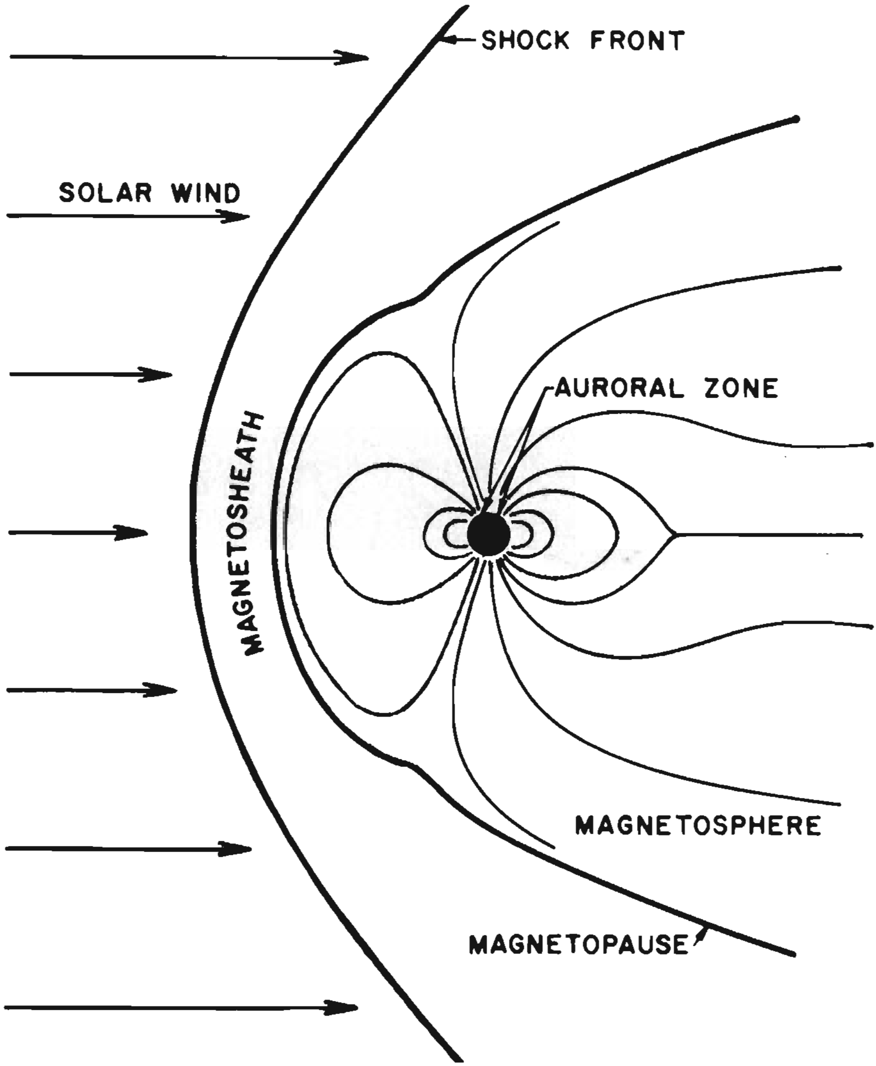

Figure 11.
The magnetic field about the Earth is distorted by the ionized particles (called the Solar Wind) streaming from the Sun. Some of these particles follow the magnetic field lines and reach the Earth in the polar regions causing the aurora.

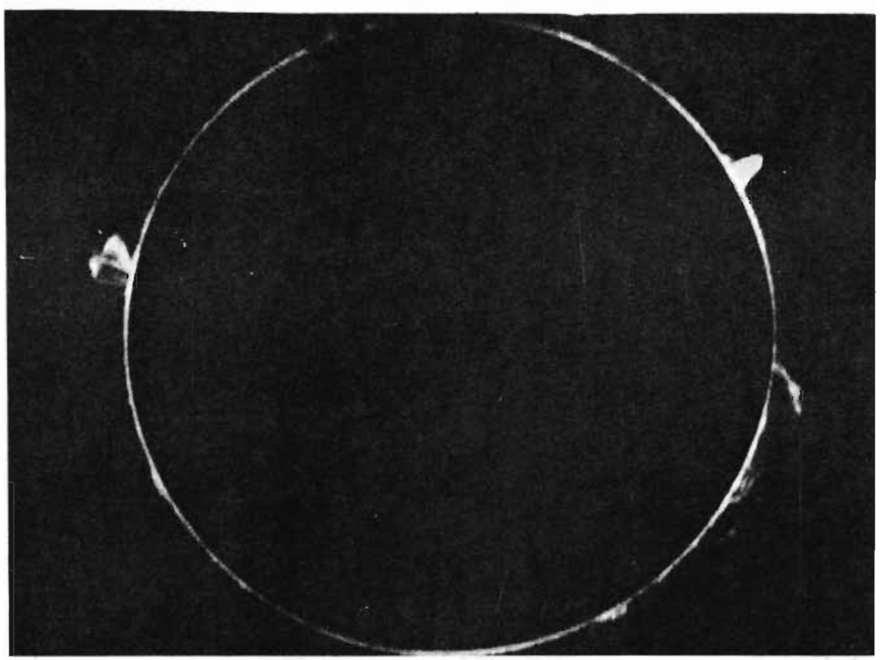

Figure 12.
A picture of the Sun with the main part of the disk blocked out to show the intense surface activity. These flares and prominences produce high speed particles that stream out into space. The Earth is about the size of a pin head on this scale.

and are absorbed, reflected, or changed in direction, depending on their frequency. As a result we cannot hear California broadcast radio stations in the daytime but can hear them at night. Amateur and commercial shortwave (high frequency) stations transmit around the world using the ionosphere but television and F.M. stations cannot use the ionosphere because the frequencies are too high, requiring us to provide nearly line-of-sight paths for those stations. The ionosphere is studied partly because of its radio-wave reflection properties but, more importantly, because it's a region of high physical and chemical activity.

Outside of the ionosphere is the magnetosphere where the reactions occur between the atmosphere of the Sun (the solar wind) and the Earth's magnetic field. This important region protects us from damaging effects of countless very high speed particles sent out by solar flare eruptions on the Sun and from cosmic space. These particles striking the Earth's magnetic field move around the Earth in paths controlled by the terrestrial magnetic field and enter the atmosphere in the polar regions. These high speed particles bursting into the atmosphere cause the aurora and the resulting chemical and physical changes occurring there. They provide a rich display of color in which nature reveals many of her atmospheric secrets for those who brave the Arctic land to measure them with instruments on rockets, balloons, and on the Tundra.

Research Plans and Activities

The National Program

To ascertain potential stratospheric pollution and radiation hazards associated with proposed supersonic aircraft, a panel was formed by the U.S. Department of Commerce at the request of the U.S. Department of Transportation to study the situation and report on the research necessary to assess the danger. The charter of the panel was:

To determine whether supersonic aircraft would create significantly increased world weather and climatic hazards with particular (but not necessarily exclusive) reference to the following:

an increase in upper air water content

a decrease in upper air ozone content with subsequent increase in ultraviolet radiation

a change in atmospheric temperature through disturbance of the thermal radiation balance

an increase in cloud cover through contrails

To determine whether SST passengers and crew will experience ionizing radiation exposure problems.

For each of these questions, and other related environmental questions which the Panel may identify, advice and recommendations should be given concerning:

Whether enough information is available to provide definite answers at this time.

Whether adequate research programs are underway, in the U.S. or in foreign countries, to cover subjects for which inadequate information exists.

Whether planned research programs are designed to produce definitive answers prior to appropriate decision points in the SST program of the United States.

The report was issued in May of 1972 and included the following recommendations (each item has approximately equal urgency):

a. Measurement of the distribution in the stratosphere of trace constituents, in particular, H_2O, NO and NO_2, and of the solar spectrum as a function of altitude and latitude. Measurement of the ultraviolet spectrum striking the Earth's surface.

b. Evaluation and measurement of chemical rate constants and quantum yields appropriate to the stratospheric environment. Determination of jet engine exhaust composition applicable to stratospheric flight.

c. Development of computer models capable of describing stratospheric transport properties and of jointly describing stratospheric transport and chemistry.

d. Evaluation of the biological and climatological consequences of changes in the distribution of ozone in the stratosphere.

The last paragraph of the report summary issues this urgent warning:

> Finally because of increasing numbers of military and commercial flights (viz., the Concorde and the Tu-144 SST's) which will be occurring in the stratosphere, it is imperative that measurements of the trace constituents of the stratosphere and of the intensity of ultraviolet light reaching the Earth's surface begin immediately.

Many programs have been funded in various agencies and institutions throughout the United States and Canada. Each is gathering data as fast as possible in the recommended areas of study.

The Atmospheric Research Program at Utah State University

In December 1972, USU scientists and engineers using a balloon as a vehicle to transport instruments into the stratosphere above White Sands, New Mexico, made the first measurements of nitric oxide (NO) ever accomplished directly within the stratosphere. The continuing experiment is a joint program with York University of Toronto, Canada, and is funded by the Department of Transportation as a part of the continuing SST pollution study. Repeated flights will be made including flights in Japan in cooperation with Dr. Takao Tohmatsu of the University of Tokyo. These will aid in determining the world-wide distribution of the important trace constituents in the stratosphere.

This is one recent accomplishment of the research program which has been carried out by USU scientists and engineers for more than twenty years concerning our atmospheric resource. The programs now exceed $2 million in annual expenditures. Except for the current program (mentioned above) to measure nitric oxide in the strato-

Figure 13.
The aurora as it is typically seen by USU field groups in Alaska. Colors are spectacular in the aurora—mainly green, but occasionally red may also be observed.

sphere, and assist in SST pollution studies, the fields of study have been in basic research on the science of the atmosphere and in the engineering of new measurement and instrumentation techniques. These include measurements of solar radiation intensity at the surface, meteorology applied to agriculture, weather modification and atmospheric water resources, general atmospheric circulation, physical and chemical processes in the stratosphere and mesosphere, including the airglow, theoretical and applied studies of the ionosphere, and studies of the interaction of the solar wind with the Earth's magnetic field and the outer atmosphere including the aurora. USU studies have included measurements from ground observation from aircraft, balloons, rockets flying to appropriate altitudes and from satellites orbiting the Earth.

The USU research program on the high atmosphere was developed because of the vital need for more information on the detailed processes that go on there. An understanding of those processes will lead us to wise use of the high atmosphere for transportation and radio communication without endangering that region. The U.S. Government has recognized this need and has provided funds to the USU program to support experimentation and theoretical interpretation of atmospheric models.

In the past ten years the USU program has gained an international reputation for excellence in the engineering development of unique instrumentation for atmospheric research and for efficiency in conducting difficult experiments in hostile environments such as the Alaskan winter. In recent years, gains have been made in balancing the acknowledged engineering excellence with solid analytical competence in the chemistry and physics of atmospheric reactions, the meteorology of general circulation, the solar particle interaction processes evident in auroral displays, and the computer-aided simulation of atmospheric models.

The USU meteorology Group in the Soils and Biometeorology Department has been concerned with surface radiation, agricultural aspects of the atmosphere, and microscale-mesoscale energy interactions. Significant contributions have been made by this group for many years in the area of plant and animal dependence on low altitude meteorology. In addition this team has assisted other groups as meteorological consultants in atmospheric circulation and low altitude problems.

The Atmospheric Water Resource Group in the Utah Water Research Laboratory has developed an instrumented range for monitoring precipitation data, hundreds of miles in extent, with automatic, computer-controlled readout into a central location on the USU campus. Normal precipitation is quickly measurable over large areas. Data have been accumulated over several seasons for comparison with man-made modifications in the weather.

The Electro-Dynamics Laboratories specialize in the creation of techniques, instruments, and instrumentation systems for the remote

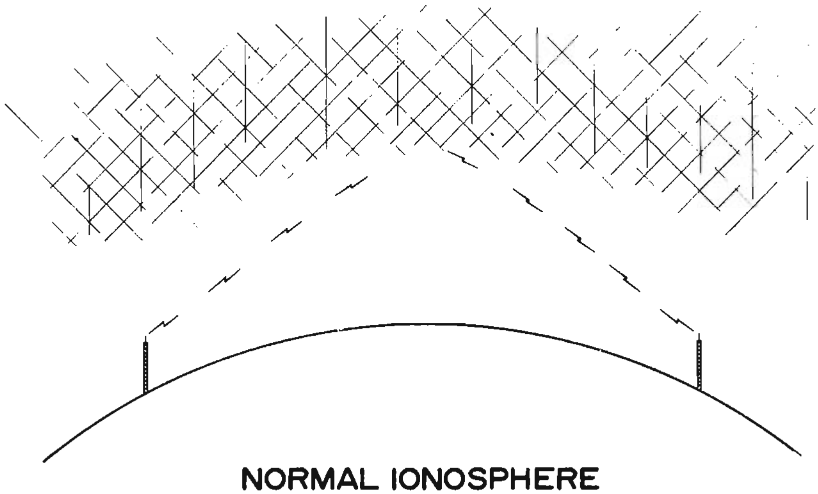

Figure 14.
Simplified diagram of radio waves reflecting from the ionosphere.

measurement of electromagnetic energy in the visible and infrared. The most recent advances in optical, electronic, mechanical, cryogenic, vacuum, and aerospace technology are adapted into the engineering of instruments for obtaining data required for the study of environmental resources. Examples of recent unique creations of EDL which are being used in the study of the upper atmosphere, are liquid-helium cooled rocketborne spectrometers and liquid-nitrogen cooled field-widened interferometer-spectrometers.

The Space Science Laboratory has concentrated on measurements of phenomena in the upper atmosphere, particularly within the ionospheric regions. The techniques of exploration have involved the use of sounding rockets to place instruments within the prescribed atmospheric region to sample the local environment. Although much remains to be learned about the normal atmosphere, the major emphasis thus far has been placed upon making measurements in conditions of disturbed atmospheres that may cause communication blackouts and related problems. Examples of problems specifically explored are the auroras and solar flare induced radio blackouts.

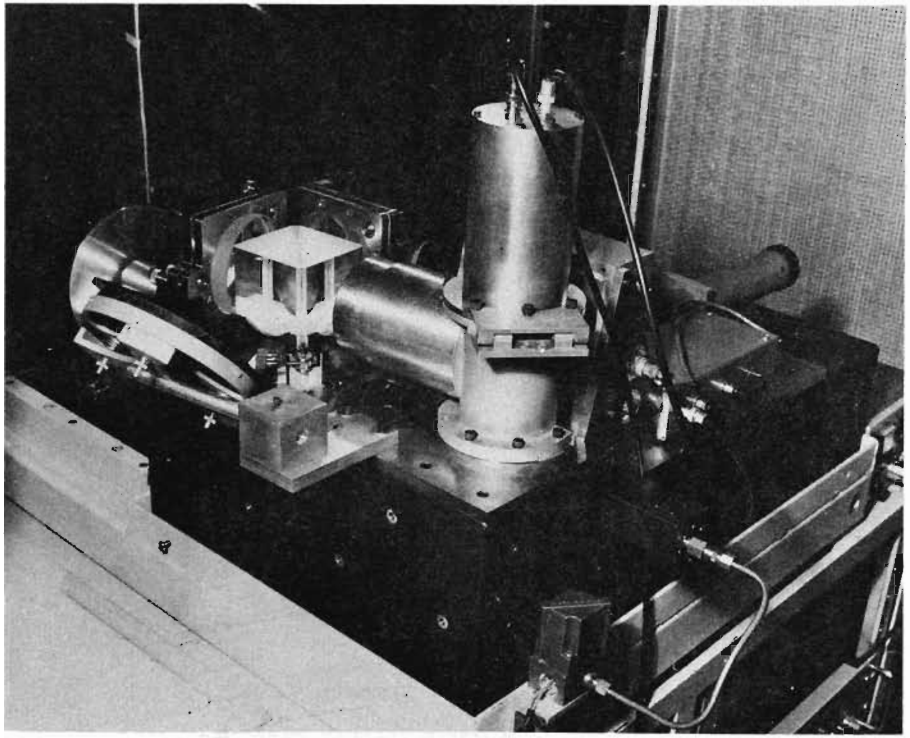

Figure 15.
The Field Widened Interferometer. This instrument was developed at USU with support from the National Science Foundation. It has increased by at least one-thousand times the ability to measure weak radiations from the atmosphere.

The Space Science Laboratory team is involved in developing measurement techniques, installing the instruments into rocket payloads, conducting the measurement program at a suitable launching site, and analyzing the results.

The Theoretical Aeronomy Group was organized to provide a stronger analytical science effort to balance the excellent experimental programs. The work of TAG consists of computer-aided modeling of the atmosphere, specialized modeling of the ionospheric layers and measurement of trace gases in the upper atmosphere. This group is also conducting the experimental program for measurement of nitric oxides in the stratosphere. The objective is to determine the natural level of nitric oxide in the stratosphere so that later measurements made in the wake of aircraft may be adequately evaluated for stratospheric pollution.

The USU workers deserve commendation for their excellent accomplishments and for their cooperation with each other in some very difficult programs. Credit to individuals is not possible in the limited space appropriate for this paper but the appendix includes names of individuals and the organizations with which they affiliate. Major accomplishments are seldom the work of any one individual so credit is most properly shared by all in a group.

The Center for Research in Aeronomy coordinates and assists the research of the various component groups and individuals in ways appropriate to each situation. The center was organized in 1969 and serves as an interdisciplinary administrative group to focus the atmospheric science research in five academic departments and five organized research laboratories in three colleges of USU.

Discussion

Summary of Evidence

The dangers from disturbance of the fragile upper atmosphere, particularly the SST pollution, are so great that they must not be ignored or minimized even though evidence as to their certainty or the existence of any possible compensating mechanisms is still incomplete.

The purpose of this discussion is to attempt to put the danger

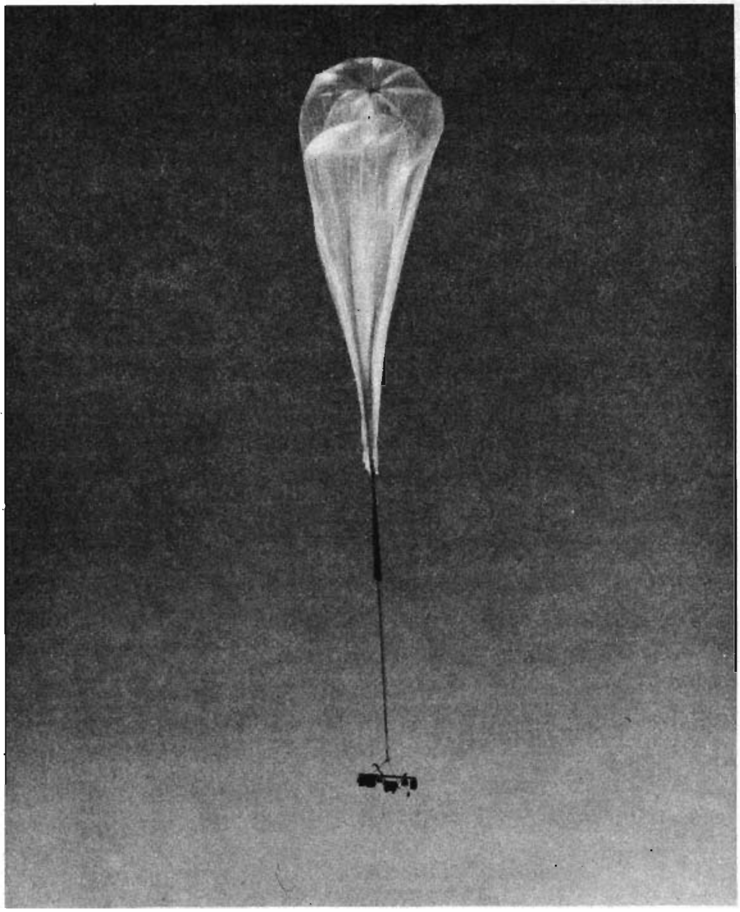

Figure 16.
Balloon carrying USU developed instruments beginning ascent from White Sands, NM, Dec. 12, 1972. This USU program is a part of the U.S. effort to determine stratospheric air pollution. These instruments measured nitric oxide at the altitude SST aircraft are designed to fly, after which the parachute lowered the instruments gently to the ground. (Note the 15 ft. radius parachute attached under the balloon with cords extending to the instrument mounting bar.)

in perspective—balancing the alarming calculations with moderating information as far as possible.

The few measurements that have been made of the oxides of nitrogen concentrations in the natural stratosphere and the ozone concentrations therein indicate that some unknown mechanism in addition to the oxides of nitrogen must be in operation in nature to suppress ozone. For example, the ozone level is less than known radiation levels indicate that it should be and oxides of nitrogen do not appear to be present in sufficient quantity in the undisturbed stratosphere to account for the reduction. Measurements of water, hydroxyl radicals, and other molecules and particles have not yet supplied adequate information concerning their suppression of ozone. Perhaps further study will indicate that the SST pollution inputs will be less damaging than calculations now indicate.

At this point in time no conclusion can be drawn with certainty but present incomplete theory indicates that the danger may be extreme. Opinions differ but many scientists tend to believe, from the indications of the limited theory, that the danger is too great to allow any further SST flights until all evidence is in. Some proponents of the SST program have a disregard for the theoretical studies and continue their belief that nature is too vast to be disturbed by man made pollution.

Risk Versus Benefit Considerations

As population and affluence rise, more attention must be given to risk versus benefit in each new activity. We have always faced the need to weigh the risk in every new activity. Until recently it was mostly an individual matter but now risks have increased to the point where all life forms may be involved. When man first mounted a horse he faced possible injury or death but considered it worth the risk. We drive cars or fly in airplanes knowing that they are dangerous. Governmental involvement regarding safety is increasing in an attempt to reduce risk with even more stringent safety laws, for example, seat belts, air bags and antipollution devices in cars. Some of the laws are opposed by large segments of the population as being limitations to their freedom, but the majority of the people believe such laws to be necessary for the general good.

New plants are needed for electrical power generations. These also involve pollution and attendant health risks but some people believe the need for power justifies far greater risks than are posed by the new plants. Others oppose this view with cries of environmental destruction.

Environmental impact studies are required in most new construction of public works or large scale private activity. The studies disclose only the effects expected to be produced and often cannot put a value on the benefits or on the degradation of life that might ensue. The science of risk-benefit assessment is very difficult and subject to opinions on values but a quantitative scale of risks versus benefits would be an aid in decision making.

We must find ways to properly compare the true total costs with the actual risks so that decisions can be made for the best interests of the most people. To do this we must have more agreement on basic values.

Comparison of Values and Opinions in the SST Program

For the SST	*Against the SST*
1. The U.S. world leadership in aviation rests on this aircraft and with it, billions of dollars in balance of trade.	1. Pollution will be large and may be intolerable, for example the Earth may heat or cool, resulting in a change of area climate. Also, more ultra-violet will endanger health.
2. High speed is needed for the world-wide activities of businessmen, government workers, and others.	2. The sonic boom may be damaging to ecology.
3. Sonic booms are tolerable when the aircraft is at cruise altitude.	

4. There is no firm evidence that the stratosphere will not be able to accept the pollution without harm to life below. Natural contaminants in the stratosphere may exceed the SST input.

5. Foreign SST's are flying anyway and we can't stop them. We might as well go along. The total number will be the same either way.

3. High speed is not needed. Subsonic speeds satisfy all real needs, as load-unload is the time consumer already and will be even worse for large SST's.

Obviously, the number of items listed has no bearing on the total weight, for or against.

Opinion

This study has led to some opinions even though much remains controversial. While these opinions are based on reading and conversations with leading scientists and engineers, supporting experimental evidence is very limited.

1. I was sorry to see the United States SST project killed before the evidence of danger was assessed. It cost nearly as much to terminate it as it would have cost to finish two pilot models. A few flights with the U.S.-SST prototypes would have established the economic factors, proved the technology, measured the pollutants and reaction rates needed to assess the danger, and kept our options open for continuing our world leadership in aviation. If our leadership had been established with an aircraft far superior in speed and payload, as the U.S. aircraft appeared to be, we would then be in a position to say: "We will limit our flights to the number consistent with safety," and we would have been a strong influence in the world. Now that cancellation of the U.S.-SST program has, in effect, caused us to abdicate our leadership, we must take other measures to restrain the increase of flights in the stratosphere until the problems are understood and controlled.

2. We must not allow more than a few research stratospheric flights until we have more evidence that the reduction in the ozone concentrations by pollution predicted from theory will not occur. Also our climate is sensitive to forces that move the jet stream southward or northward from its average position. Those forces may relate to stratospheric temperature. This year, because the jet stream brought cold air from Northern Canada, Utah experienced one of the coldest winters and the heaviest snowfall, in many decades. The dangers from climate change that could be caused by stratospheric pollution are so great that we must not allow extensive disturbance until climatic factors are well understood.

3. I believe that large projects pay off well in economic advantages for all of the people, in spin-offs valuable for many things not foreseen in the beginning, and in an increase in morale with a difficult job well done. I believe the space program has and will continue to pay for itself many times over. I see no benefit in closing down large projects, putting many thousands of people out of work and then giving them welfare payments with the money saved. People tend to forget that the money spent on the space program, for example, actually went mostly to wages for our people. I would like to see a U.S. program continue that would develop a safe, clean SST. Other large projects such as development of good mass transportation systems on the surface, large scale water management programs, and new clean power generation and distribution networks would benefit all of the people.

As a final word, I feel we must vigorously seek international agreements to limit flights in the stratosphere. Closing our air space alone will not help because pollutants will be distributed world wide. We have a strong economic lever through denial of access to our airports. Without U.S. business the SST program would probably not be economically viable. Repeated pressures are being applied to reactivate the SST program and to permit foreign SST's to land in this country. Neither of these must be allowed to happen until the scientific and risk-benefit studies are completed.

Our upper atmosphere, invisible, fragile, yet vital, is unlike anything we have found on other planets in the reachable expanses of space. We must protect it before damage, possibly irreversible, is allowed to begin.

Appendix A

Utah State University

Atmospheric Research Organizations and Professional Staff

College of Agriculture—D. J. Matthews, Dean
- Soil Science and Biometeorology—R. L. Smith, Head
  - Inge Dirmhirm
  - Gene L. Wooldridge
  - Gaylen L. Ashcroft
  - E. Arlo Richardson
  - Geoffrey E. Hill

College of Engineering—D. F. Peterson, Dean
- Utah Water Research Laboratory—J. M. Bagley, Director
  - Geoffrey E. Hill, Project Leader
  - William N. McNeill
  - Don L. Griffin
  - Frank W. Haws
- Electro-Dynamics Laboratories—D. J. Baker, Director
  - Clair Wyatt
  - Alvin M. Despain
  - Ronald J. Huppi
  - Ralph H. Haycock
  - Allan J. Steed
  - Larry R. Smith
  - Ralph D. Briscoe
  - Gary Frodsham
  - John Kemp

Blaine Anderson
Brent Bartschi
Arthur Corman
Don Goode
Clair Jones
David Morse

CENTER FOR RESEARCH IN AERONOMY

Director—Clayton Clark
Assistant Director—K. D. Baker
Scientific Advisor—L. R. Megill
Council—R. M. Johnson, Chairman
D. F. Peterson, Member
E. N. Hatch, Member

Individual Affiliates with the Center for Research in Aeronomy
William Moore, Chemistry Dept.
Larry Thorne, Chemistry Dept.
R. D. Harris, Electrical Engineering Dept.
M. Ray Johnson, Electrical Engineering Dept.
Vern L. Peterson, Physics Dept.
William R. Pendleton, Physics Dept.

Space Science Laboratory—K. D. Baker, Director
David A. Burt, Electrical Engineering Dept.
Earl F. Pound, Electrical Engineering Dept.
L. Carl Howlett, Electrical Engineering Dept.
Larry L. Jensen
Gary LeBaron
Richard Mitton
Hsiao-Yen (Becky) Han
William Grieder

Theoretical Aeronomy Group—L. R. Megill, Director
Alan W. Shaw
Richard H. Bishop
Howard LeVaux
Ruey-Yuan Han

Aeronomy Center Observatory—Gene A. Ware, Supervisor
Howard Pollard
Norton Thurgood

Appendix B

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