

V. UPPER ATMOSPHERE POLLUTION MEASUREMENTS (GASP)

Richard A. Rudey and James D. Holdeman

The past 5 years have seen an increasing awareness of the potential problems that may occur due to the discharging of certain pollutants into our atmosphere. The EPA has taken regulatory action to control the level of certain emissions from industrial sources and transportation vehicles in the United States. In the case of air transportation, paper IV describes the principal aircraft engine pollutants, their related effects on both the low and high altitude environment, and the EPA regulations for low altitude emissions.

For the high altitude environment (or the upper atmosphere) no such regulations exist. The potential upper atmosphere problem is complex and worldwide, and the data needed for its assessment are difficult to obtain and to evaluate. Because of this, both national and international environmental impact programs will be needed in the future. An example of a national program is the NASA Stratospheric Research Program that is now being organized. The Lewis program described in this paper is an important part of this NASA effort.

THE POTENTIAL UPPER ATMOSPHERE PROBLEM

Two recent climatic impact studies, the Climatic Impact Assessment Program (CIAP) and a study conducted by the National Research Council (NRC), arrived at the conclusion that, if future large fleets of aircraft were to cruise in the upper atmosphere (stratosphere), certain engine effluents could have an adverse effect on our environment. This conclusion was based on several factors that are related to the chemical composition of the engine exhaust and to certain atmospheric properties.

Atmospheric Properties

One important atmospheric property, the static air temperature, is illustrated in figure V-1. That portion of the atmosphere where the temperature decreases with altitude is the troposphere, which can extend to an altitude varying from approximately 25 000 to 50 000 feet. This variation is both seasonal and geographical. The troposphere can be generally characterized as a turbulent region with a large amount of both vertical and horizontal mixing. This turbulence, along with associated rainfall, allows the troposphere to rapidly cleanse itself of most impurities. Pollutants injected into it normally have short residence times - on the order of days or weeks. The region of the atmosphere where the temperature-altitude relationship changes from decreasing to increasing is known as the tropopause. It is generally characterized by an altitude band rather than a discrete point. Above the tropopause is the stratosphere where the temperature increases with altitude. This increasing temperature characteristic is similar to the temperature inversions that contribute to our urban smog problem when they occur over large cities. In the stratosphere, the increasing temperature inhibits vertical mixing, thus the region is quite stable and any pollutants injected into it have long residence times - on the order of months and possibly years. However, horizontal dispersion around the globe is quite rapid - on the order of weeks. Thus, the effect of a pollutant injected into the atmosphere at one geographical location can be worldwide.

Two other important properties of the upper atmosphere, ozone and particulates, are illustrated in figure V-2. The ozone layer, which has its peak concentration at approximately 70 000 feet, absorbs short wave ultraviolet solar radiation. This absorption capability allows life to exist on Earth in its present form; hence, any change in the concentration level of the ozone layer could produce biological effects on the Earth's surface.

The particulate (aerosol) layer, which is composed of both solid and liquid particles, has a significant effect on the heating of the atmosphere and influences the radiation balance of heat at the Earth's surface. Any change in the thickness, composition or extent of this layer could produce climatic changes. There is a natural variability in both of these layers which is not clearly understood and which contributes to much uncertainty in climatic impact studies.

Aircraft Engine Effluents

Those aircraft engine effluents of most concern in the upper atmosphere and their associated potential environmental effects are listed in table V-1. Oxides of nitrogen (NO_x) are highly reactive with ozone (O_3) and may cause a reduction in the ozone layer. This reduction could result in an increase of short wave ultraviolet radiation on the Earth's surface, thus producing possible biological effects. The other three effluents, sulphur dioxide (SO_2), water vapor, and particulates, could contribute to a change in the density and composition of the atmospheric particles. The result could be a change in the Earth's radiation balance and, potentially, the climate. Of these engine effluents, the amount of NO_x emissions are considered the most important from an environmental viewpoint. This is the principal reason for the concentrated effort to reduce cruise NO_x that is discussed in paper IV.

If these potential environmental effects are of concern, the question arises as to why there are no regulations governing the injection of these effluents into the upper atmosphere. One reason is that the potential effect was only recently recognized (about 1971). Another reason is the high degree of uncertainty involved in assessing the effects of these aircraft effluents as distinguished from the natural variability of atmospheric properties and the effects of other man made pollutants injected at ground level. (One of these ground level pollutants will be discussed later.) A principal contributor to the uncertainty is the lack of comprehensive, long term upper atmosphere data.

UPPER ATMOSPHERE MEASUREMENTS

There are several programs currently underway to obtain the necessary data, and they include a variety of measurement techniques. The ultimate future system will probably utilize remote sensing devices aboard satellites to provide continuous global monitoring. Even though an operational satellite system is not likely within this decade, an experimental system is scheduled for launch on the Nimbus G satellite in the late 1970's. Until the time when a satellite system becomes operational, most upper atmosphere data will be obtained by using airplane, balloon, and rocket instrument carriers. Of

these three techniques only airplanes have both independent altitude and location flexibility.

One airplane currently in use for making atmosphere measurements is the U2 (fig. V-3). This aircraft is being flown out of the NASA Ames Research Center to measure NO_x , water vapor, carbon monoxide (CO), ozone and chlorofluoromethane concentrations in the atmosphere from altitudes of 20 000 to 70 000 feet. The air sampling instruments and an inlet probe are located in the lower part of the fuselage. Another aircraft currently in use for making atmospheric measurements is the WB-57F aircraft being flown out of the NASA Johnson Space Center in cooperation with the Department of Transportation (fig. V-4). Measurements of NO_x , particulates, ozone, and water vapor are being made with this aircraft up to altitudes of 60 000 feet. Air sampling instruments are located in the fuselage, and inlet probes are located in the nose. Both aircraft have large, lightly loaded wings and can easily penetrate the stratosphere. However, they are dedicated research vehicles and are used on an as-required and relatively local basis. As such, they do not provide a continuous, global data gathering capability.

Global Air Sampling Program

About 3 years ago the use of commercial airliners as instrument carriers on a continuous global basis was considered. A study was initiated by Lewis with commercial airlines and aircraft manufacturers to determine the feasibility of this approach. The feasibility question was answered in the affirmative and out of this study came the now operational Lewis Global Air Sampling Program (GASP). The objectives of GASP are to provide baseline data of selected atmospheric constituents in the upper troposphere and lower stratosphere (from 20 000 to 40 000 ft) and to assess potential adverse effects between aircraft exhaust emissions and the natural atmosphere. The approach being used is to install and operate automated instrument systems on commercial Boeing 747 aircraft, to acquire global air quality data during routine airline operation, and to document and analyze these data for 5 to 10 years. The 747 aircraft was selected because it has the space available for locating a measurement system, it has an inertial navigation system for determining geographical location, and it operates on a global route structure.

Atmospheric constituents of concern. - The upper atmosphere constituents to be measured and related information needed for data analysis were also determined during the feasibility study and are shown in table V-2. The constituents are divided into two major groups - particulates and gases. In the particulate group the number density and the size distribution will be measured on a continuous basis. Mass concentration and chemical composition will be obtained by periodically collecting a filter sample. Laboratory analysis techniques will then be used to determine the presence of sulfates, nitrates, and carbon. The gases will be measured continuously using a dedicated instrument for each constituent except for the chlorofluoromethanes, which will be determined from laboratory analysis of air samples periodically collected in cylindrical containers. Chlorofluoromethanes are one form of inert gas used as a propellant in many aerosol spray cans. Recently, these species have been the subject of a controversy regarding stratospheric ozone destruction. This has led to the inclusion of this measurement in GASP even though it is not related to aircraft emissions. The list of measurements contains most of the constituents that are known to be important for determining the potential effect of aircraft emissions on the upper atmosphere plus others, such as chlorofluoromethanes, which are pollutants injected at ground level.

In addition to the air sample measurements, geographical information (such as latitude and longitude), meteorological information (such as temperature, pressure, wind direction, and velocity), and aircraft operational information (such as altitude, flight Mach number, and time) are obtained from aircraft systems. These data will be recorded along with the air sample data to precisely describe conditions when a data point is recorded.

The 747 measurement system. - The design, fabrication, and installation of the 747 air sampling systems have been contracted to United Airlines. The constituent measuring part of the system is shown in figure V-5. The instruments for measuring CO, O₃, water vapor, and particles were developed by Lewis from commercially available units. The flow control unit was also developed by Lewis and was provided along with the instruments as government furnished equipment (GFE) to United. United integrated the GFE with a data management and control unit (DMCU), a flight data acquisition unit (FDAU), a cassette tape recorder, and all the supporting wiring and aircraft interconnects. The equipment is packaged to fit on standard ARINC (Aeronautical Radio, Inc.) approved racks and has been certified by the FAA

for flight operation. A small, portable system development panel (SDP) is used to periodically check the operation of the system between flights. It can also be used in-flight on properly equipped aircraft.

The entire air sampling system is installed directly below the first class compartment of the aircraft (fig. V-6). The constituent measuring system is located adjacent the nose gear wheel well. (See fig. V-6 insert.) Air samples are collected by probes located under the nose of the aircraft and delivered to the gas measuring instruments through a 1-inch line and to a particulate collecting filter located on the opposite side of the aircraft through a 3-inch line.

A photograph of the probe installations on the United Airlines 747 is shown in figure V-7. The main probe has two inlets. The top inlet collects the air sample for the gaseous and filter measurement systems. The lower inlet is designed for isokinetic sampling at aircraft cruise speeds and collects the air sample for the particle size and distribution measuring system. Isokinetic sampling is obtained when sample velocity inside the probe inlet matches the free-stream velocity. This provides optimum collection of all particle sizes. The main probe cap automatically opens by rotating into the slot when the aircraft exceeds an altitude of 20 000 feet, at which time the system begins to take data. The separate probe located at the top right of the insert contains the water vapor measuring sensor. The entire system operates automatically without attention by the flight crew and in no way interferes with the normal operation of the aircraft. Data can be recorded for up to 24 days under normal operation. The GASP equipped 747 shown in figure V-7 has now been taking data for approximately 6 months.

The 747 route structure. - Current plans call for installing four systems in 747 aircraft from the three airlines shown in figure V-8 plus one additional aircraft yet to be selected. In addition to the United aircraft, a GASP equipped Pan American World Airways aircraft has been in operation on a global basis for about $2\frac{1}{2}$ months. With the addition of a Qantas Airways aircraft in late 1975, global data acquisition will be available over the routes illustrated in figure V-9. A desired route structure for atmospheric analysis as proposed by the National Oceanic and Atmospheric Administration (NOAA) is also shown in this figure. NOAA and NASA will be collaborating on data analysis throughout this program. The route structure of the participating airlines provides data acquisition around the globe in the northern hemisphere

and into portions of the southern hemisphere. The lack of acceptable 747 routes is the reason for the missing coverage of some of the desired routes. The bulk of the data will be obtained in the heavily traveled routes of the northern hemisphere where aircraft emission effects are likely to be the greatest.

The near polar route of Pan Am is of special interest because much of the data will be obtained in the stratosphere, which is extremely important in terms of potential environmental problems. The southern hemisphere routes of Qantas are important because the air there is generally much cleaner than in the northern hemisphere. This is because atmospheric flow circulation patterns near the equator act as a barrier to prevent the pollutants discharged into the northern hemisphere from being transported to the southern hemisphere. The Qantas routes will provide data to compare the air qualities of the two hemispheres. The frequency of the United flights over the continental United States and Hawaii will provide a good statistical data base for this region.

Examples of GASP data. - An example of one type of data obtained during a United Airlines flight from Chicago to Honolulu is shown in figure V-10. The upper plot shows the aircraft's geographical location. An outline of the continental United States is shown for reference purposes. The lower plot shows the ozone readings that were obtained during the flight as a function of longitude. The ozone levels were very low at the beginning of the flight which was at a cruise altitude of 31 000 feet. This is a normal ozone level for the troposphere. When the aircraft climbed to a 35 000-foot cruise altitude, the ozone readings rose sharply to a level which is characteristic of readings in the lower stratosphere. An extremely rapid rise and high level of ozone was encountered at 124° W longitude even though the aircraft cruise altitude was constant. Ozone concentrations this high are normally associated with flight operation well into the stratosphere. The data shown in figure V-11 can be used to determine the cause of this ozone level change. At the point where the high ozone concentration began (indicated by the arrows in fig. V-11), a rise in static temperature occurred along with significant changes in both wind direction and wind velocity, indicating that the aircraft encountered significantly different meteorological conditions at this geographical location. A plausible explanation for the ozone rise would be the existence of a polar air mass which normally has higher ozone concentra-

tions at a given altitude (lower tropopause altitude). Regardless of the cause, the data in figure V-10 clearly illustrate some of the natural variability in ozone that was previously mentioned.

Another type of data being obtained is shown in figure V-12. The plot shows a correlation between the number density and size distribution of particles measured during a flight between San Francisco and Honolulu at an average altitude of 39 000 feet. The slope of the distribution curve is similar to that observed at ground level but the density of particles of a given size range is much lower, showing the increased cleanliness of the air at high altitudes. Similar data in less and more heavily traveled air traffic routes will be compared to determine if a correlation exists between air traffic density and particle density and size.

Off-Route Data Acquisition

In addition to the on-route GASP data that will be obtained from the four commercial 747's, two NASA aircraft are being used to help develop measurement and analysis techniques and to obtain off-route and supplemental data. The Ames Research Center CV-990 (fig. V-13) has been used extensively to flight test all of the instruments currently used on the 747's. A typical instrument installation used for flight testing is shown in the lower photograph. This aircraft will continue to be used for development of improved instruments when they become available. An automated GASP system will be built and installed on this aircraft on a semipermanent basis. This will allow off-route data to be obtained during normal aircraft flight experiments and during dedicated flights to specific localities. The aircraft shown in figure V-14 is one of the two Lewis F-106's which are primarily used for propulsion research flight testing. For supporting the GASP work, the aircraft is equipped with two particle sampling filter systems located in removable pods that are attached to the lower surface of the wings as shown in the lower left photograph. The current configuration carries a single filter cartridge in each pod as shown in the lower right photograph. With these pods installed, particulate samples are being obtained up to altitudes of 45 000 feet. This F-106 aircraft is also being equipped to carry a cylindrical container system for obtaining high altitude "grab" samples which will be analyzed for chlorofluoromethanes.

DATA REDUCTION AND ANALYSIS

With all of these measuring systems in operation, a considerable quantity of data will be obtained. Under normal conditions, each 747 operates an average of 10 hours per day, and the GASP system takes a data point every 5 minutes above 20 000 feet. The 747 data and the off-route and supplemental data obtained by the NASA aircraft will be processed as illustrated in figure V-15. The Lewis computer center will compact the data and format it to provide a consistent basis for subsequent analysis. Then, the data will be distributed to three places (see fig. V-15). NASA/NOAA will analyze the data to assess potential pollutant emission effects on a case-by-case basis. (A case may be defined as a particular flight or a group of flights.) NOAA will also perform studies related to meteorology, climatology, and atmospheric chemistry. An independent procedure will be established at Lewis to maintain a complete documentation of all data obtained as a function of time, altitude, and geographical location. Specialized analyses will be performed on particulate mass concentration and composition and on selected gaseous constituent variations. Another flow path for the data will be to a NOAA data storage center at Asheville, North Carolina (National Climatic Center) where it will be available to other atmospheric research programs and to independent researchers on request. NASA Lewis will periodically publish reports describing the type of data available and how it can be obtained from this source.

CONCLUDING REMARKS

Data such as that being obtained in the NASA Global Air Sampling Program will help provide a basis for understanding the complex potential pollution problems in the upper atmosphere. With respect to the work described in this paper, the current status in this quest for understanding can be summarized as follows:

1. The effect of aircraft emissions on the upper atmosphere is presently uncertain. However, the potential reaction of certain species in a jet engine exhaust with ambient atmospheric constituents, such as the NO-O₃ reaction, is factual, and is reason for concern. Also, because of certain properties

of the atmosphere, the possibility of environmental impact will likely increase when cruise altitudes go higher into the stratosphere and that the effect, if it occurs, will be worldwide.

2. A comprehensive global air quality data bank must be established on a long term basis. This will be necessary to ferret out the effect of aircraft emissions from the natural variability of the atmosphere and from other man made pollutant sources. For the next decade the bulk of the data will come from aircraft, rocket, and balloon systems. Eventually, satellites using remote sensors should provide a global atmospheric monitoring system.

3. The Lewis Global Air Sampling Program will provide an important continuous input to this global data bank for at least the next 5 to 10 years. These data will be valuable for general atmospheric studies as well as for aircraft emission impact studies.

4. The interest and assistance of United and other airlines and of aircraft manufacturing companies, such as Boeing, has been invaluable. Allowing NASA to install and operate GASP systems on in-service 747 aircraft demonstrates the interest and concern of the airlines in defining the effects of air transportation on our environment. In addition, the interest and participation of the aircraft engine manufacturers in the emission reduction programs (described in paper IV) indicates their concern for reducing engine emissions and minimizing the potential adverse effect of aircraft on our environment.

TABLE V-1. - UPPER ATMOSPHERE EMISSIONS

ENGINE EFFLUENT	POTENTIAL ENVIRONMENTAL EFFECT
OXIDES OF NITROGEN SULFUR DIOXIDE WATER VAPOR PARTICULATES	REDUCTION IN OZONE INCREASE IN SULFATES INCREASE IN CLOUDS INCREASE IN PARTICLES

TABLE V-2. - GASP MEASUREMENTS

PARTICULATES	GASES	RELATED INFORMATION
DENSITY SIZE DISTRIBUTION MASS CONCENTRATION CHEMICAL COMPOSITION SULFATES NITRATES CARBON	OZONE WATER VAPOR OXIDES OF NITROGEN CARBON MONOXIDE CARBON DIOXIDE CHLOROFLUOROMETHANES	GEOGRAPHICAL LOCATION METEOROLOGICAL CONDITIONS AIRCRAFT OPERATING CONDITIONS

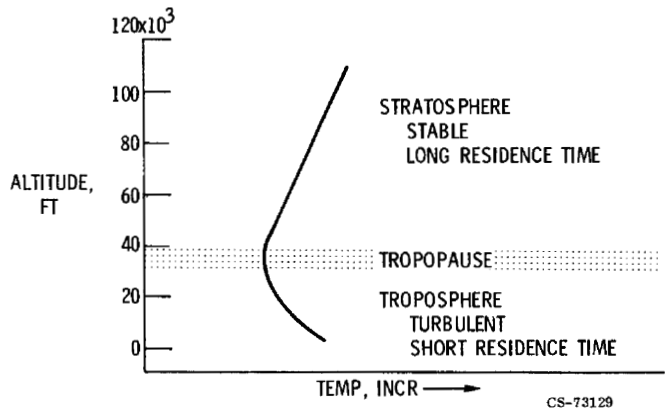


Figure V-1 - Variation of static air temperature with altitude.

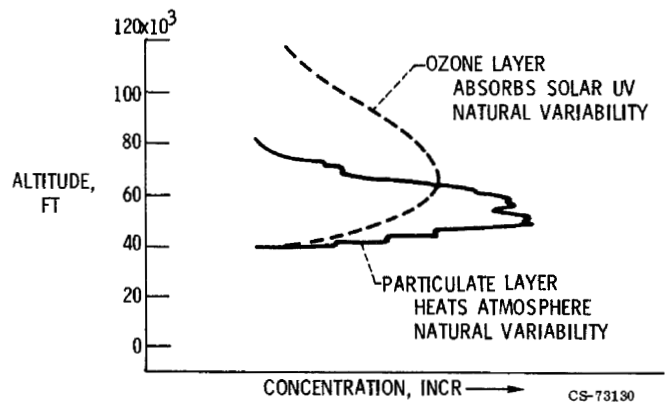


Figure V-2 - Variation of ozone and particulates with altitude.

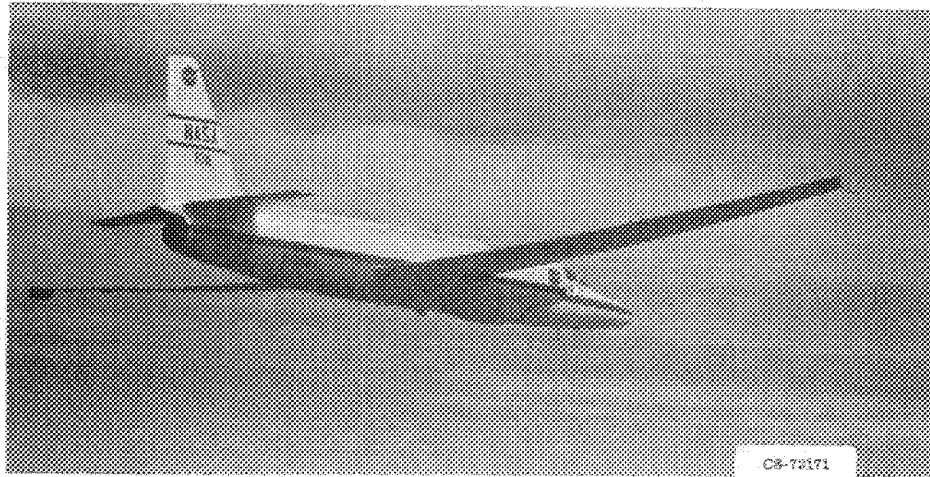


Figure V-3. - U2 aircraft used for atmospheric air quality measurements.

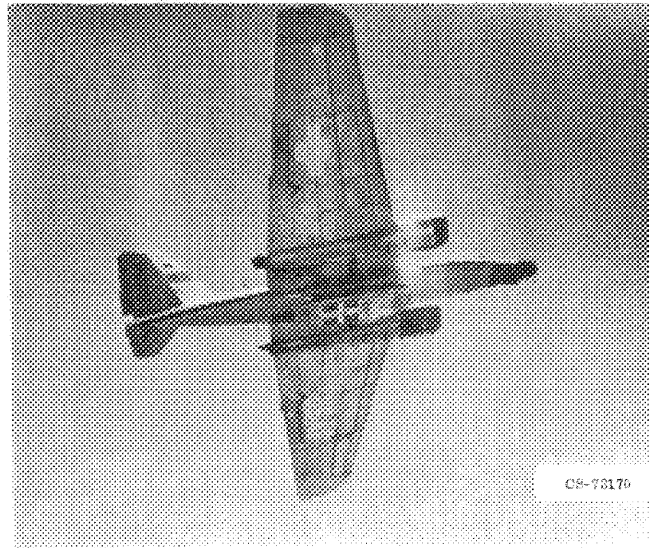
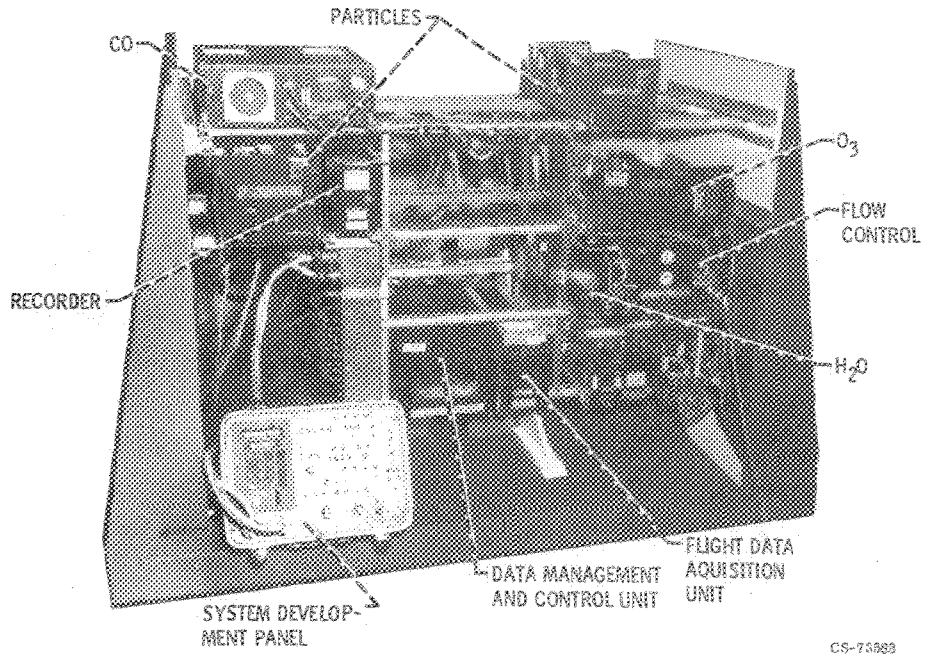


Figure V-4. - WB-57F aircraft used for atmospheric air quality measurements.



CS-73583

Figure V-5. - GASP constituent measuring system.

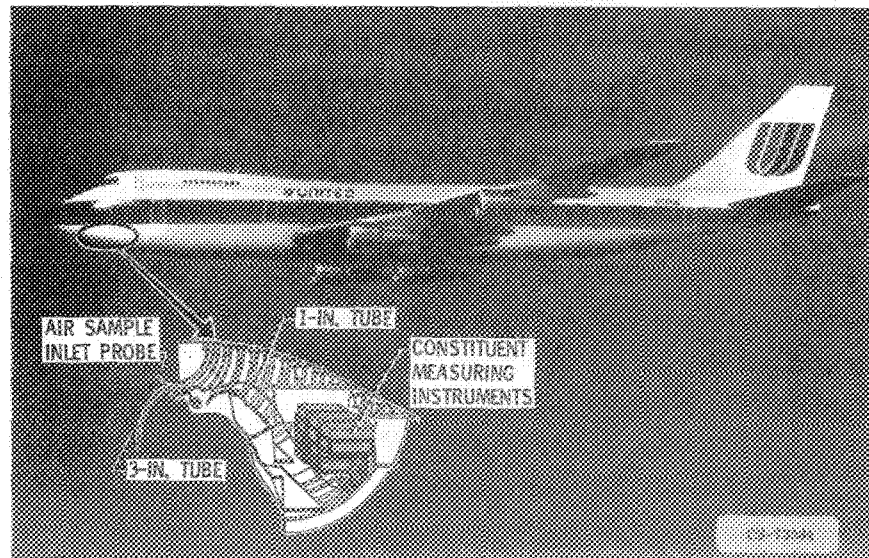


Figure V-6. - GASP system installation.

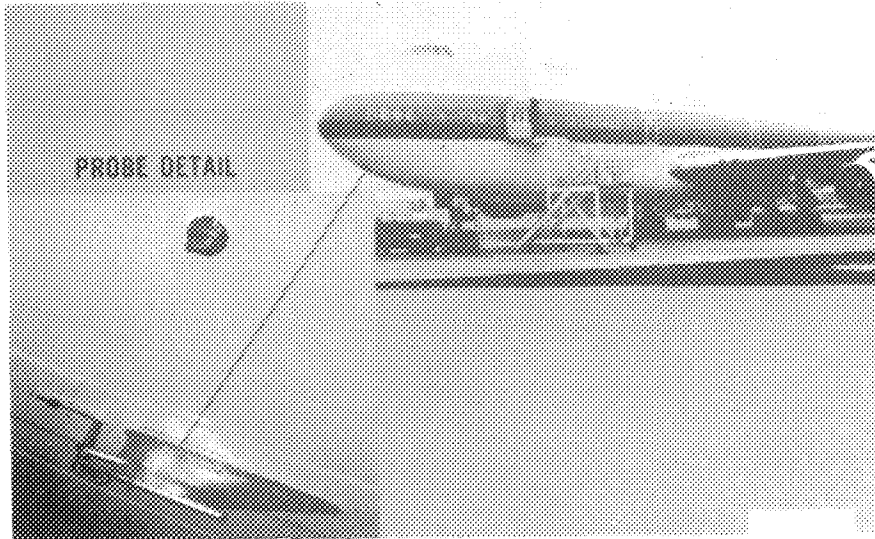


Figure V-7. - First operational GASP aircraft rollout at United Airlines (Dec. 10, 1974).

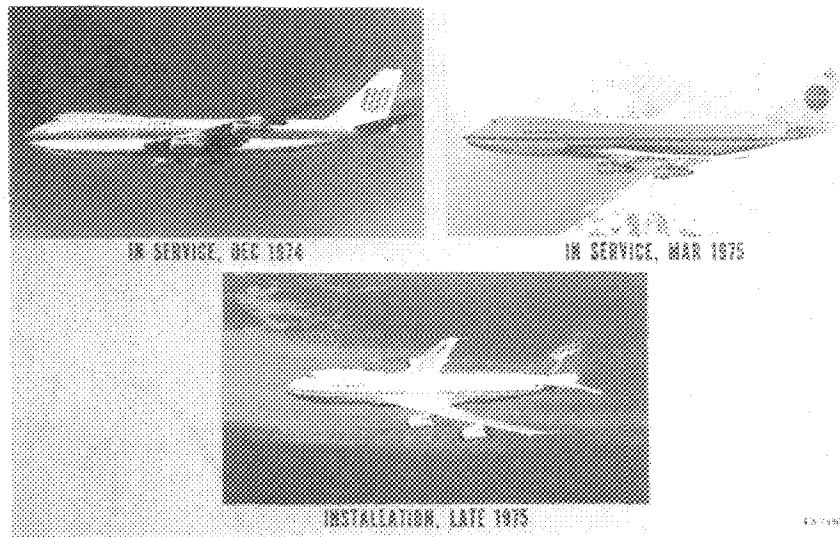
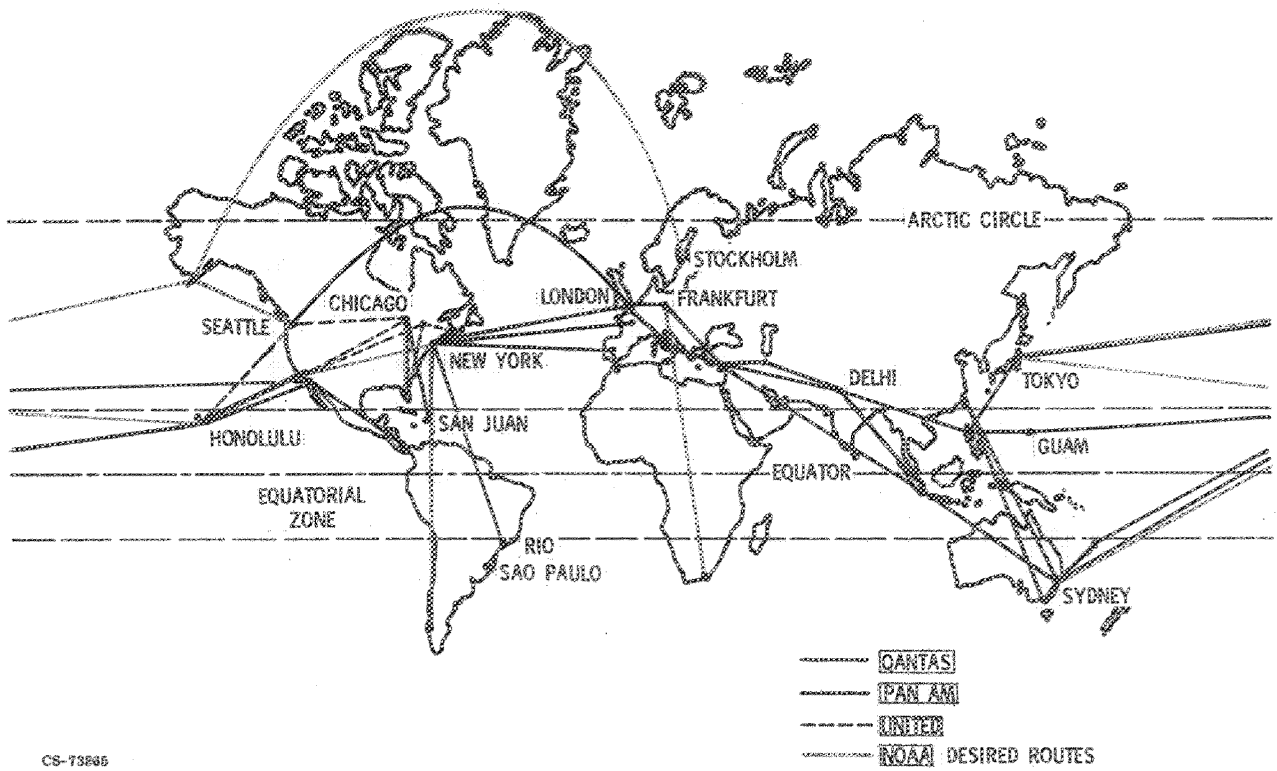


Figure V-8. - Airlines currently participating in GASP.



CS-73R06

Figure V-9. - GASP route structure.

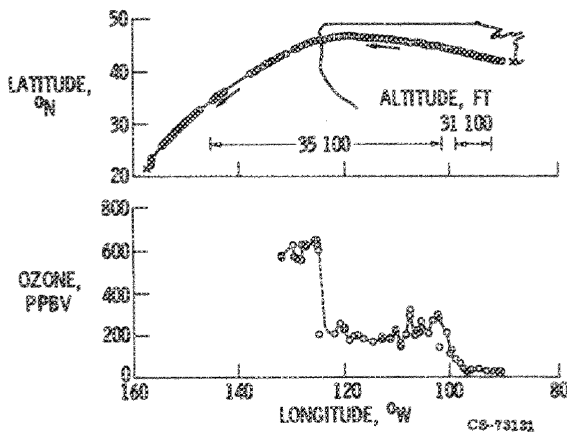


Figure V-10. - Aircraft location and ozone data for Chicago to Honolulu flight on United 747.

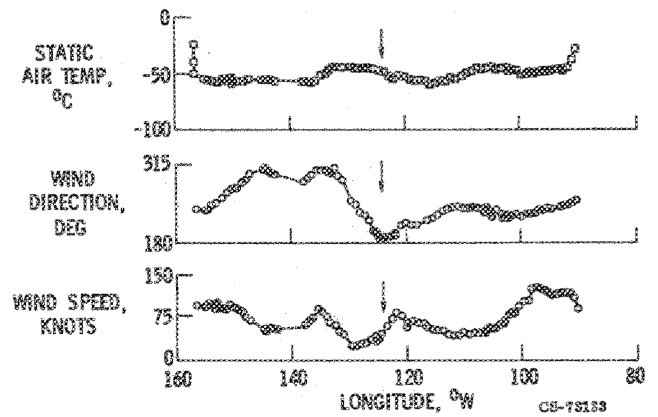


Figure V-11. - Meteorological data for the flight in figure V-10.

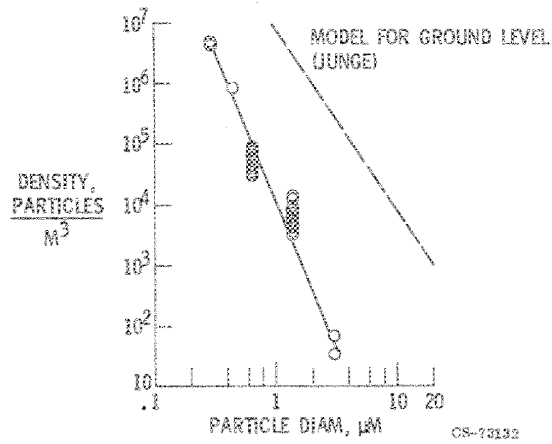
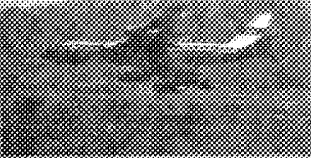
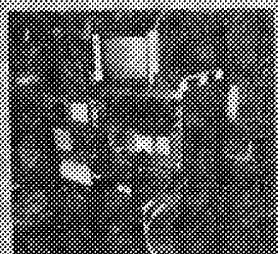


Figure V-12 - Particle size distribution on flight from San Francisco to Honolulu at 39 000 feet.



AMES CV-990 AIRCRAFT



GASP INSTRUMENT INSTALLATION

PURPOSE

TEST AND EVALUATE CANDIDATE INSTRUMENTS AND PROTOTYPE SYSTEMS IN AIRCRAFT ENVIRONMENT AT ALTITUDES BETWEEN 20,000 AND 40,000 FEET AND OBTAIN OFF-ROUTE DATA FOR GASP.

Figure V-13. - GASP instrument evaluation on Ames CV-990.

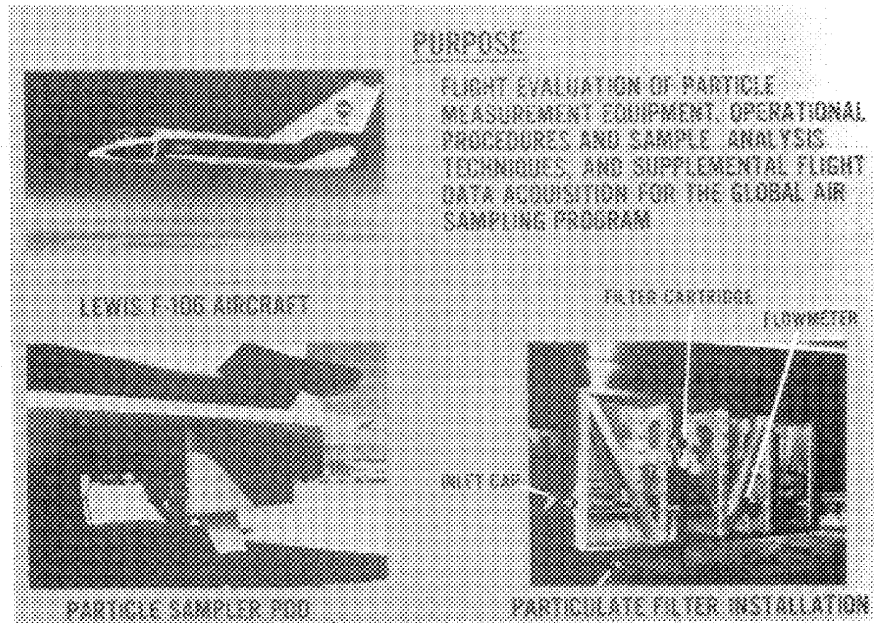
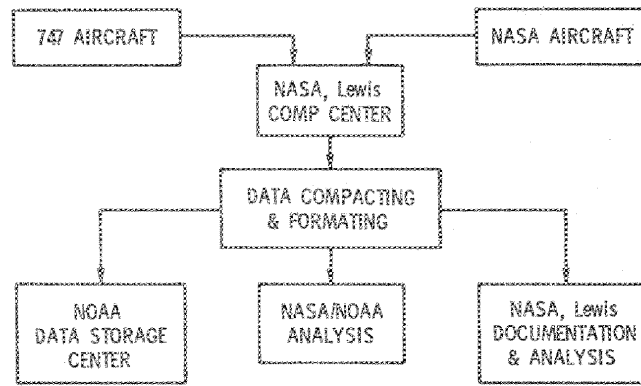


Figure V-14. - Upper atmosphere particle sampling with F-106.



CG-72125

Figure V-15. - GASP data flow chart.