Good (morning or afternoon), my name is [signature].

and I would like to welcome you to the new wing of the Propulsion System Laboratory and to our display entitled "Cleaner Skies."

What we will show today are NASA's efforts in studying air pollution problems as it relates to jet aircraft. Today, pollution from aircraft is a concern primarily in the vicinity of airports. However, the projected increase in air traffic indicates that unless steps are taken now to minimize pollutant emissions, aircraft will become a major source of pollution worldwide.

At Lewis we are studying ways of applying advanced technology to reduce aircraft pollution.

Here in the new Propulsion Systems Laboratory we can test full scale engines at various flight conditions. The testing includes measurements of all engine performance parameters as well as measurements of engine emissions at altitude conditions.

Here we have a cutaway of an aircraft jet engine. High pressure air, supplied by the compressor enters the combustion chamber where fuel is sprayed and continuous combustion occurs. The hot gases then exhaust into the turbine which drives the compressor and fan and finally exhaust from the engine to provide thrust. It is during this combustion process that pollutants are formed. Our first slide shows a schematic of an aircraft jet engine combustor. Here we have identified the principle emissions due to combustion. In addition to the normal products of combustion,
which are water vapor and carbon dioxide, pollutants are emitted such as HC, CO, Oxides of Nitrogen, and Smoke. It is these pollutants which are of primary concern.

The gas turbine operates at very nearly 100 percent combustion efficiency at all operating conditions except idle. At idle, with lower combustion efficiency, levels of carbon monoxide and hydrocarbon emissions. The effects of these two pollutants are different. Carbon monoxide is an odorless invisible gas.

Extended exposure to high concentrations of carbon monoxide can be very dangerous. This is a potential problem for airport personnel that service jet transports. Hydrocarbons which are primarily unburned or partially oxidized fuel cause the odor characteristic of all airports. When hydrocarbons mixed with air and other pollutants and exposed to sunlight, they slowly react to form new compounds - generically named photochemical smog. This smog is an irritant to eyes and lungs and is damaging to plant life.

The oxides of nitrogen are primarily emitted during high power operation of the engine - during take-off and climbout. The oxides of nitrogen are formed by the reaction shown on the next slide. At full power, high temperatures and pressures, generated within the engine, promote the reaction of the oxygen and nitrogen in the air to form nitric oxide. This occurs within the hottest portions of the flame zone. The nitric oxide formed is
very reactive in the atmosphere. To demonstrate this, we have an experiment to show the oxidation of NO to NO$_2$. This chamber has air on one side and a dilute mixture of nitric oxide and nitrogen on the other. When we open the valve (opens valve) and allow the gases to mix, you will see the slow formation of a brown gas which is nitrogen dioxide.

The oxides of nitrogen are the principal compounds which reach with hydrocarbons in the lower atmosphere to produce the components of photochemical smog.

The next question to be answered is how can the levels of the pollutants generated by aircraft be reduced. First, we will consider idle conditions, then full power. The next slide illustrates techniques for reducing idle pollutants. Recall that the pollutants at idle are primarily CO and HC which result from incomplete combustion. One reason for poor combustion efficiency at this condition is that the fuel, when sprayed into the combustor, is not finely atomized. Due to the low fuel flow rates at idle, a coarse tulip shaped spray pattern occurs. Fuel atomization can be improved by fuel scheduling, use of an air blast nozzle, or an air assist nozzle. In fuel scheduling, the fuel is supplied to only a small number of nozzles thus increasing the fuel flow rate per nozzle. The air blast nozzle is a new technique which uses the combustor air to atomize the fuel. Air assist uses a conventional nozzle with externally supplied high pressure air injected through a secondary fuel passage.

We can demonstrate the effects of air assist using this jet engine fuel nozzle (flip light switch) and measuring emissions during idle operation of a combustor. Behind this window, we have mounted a single combustor can from a present-day jet engine. The gas analysis instruments to your left
to measure the pollutant levels. These will be indicated by the dials above.

We can demonstrate the type of fuel spray in the combustor by flowing water, rather than fuel, through this nozzle at a typical idle fuel flow rate. (Start water flow in fuel nozzle) I think you can see the rather coarse spray formed under these conditions. If we now add air through the secondary fuel passage, I think you will see a dramatic difference. (Adds air - waits - turns off experiment).

Now we will run the combustor at an idle condition without air assist so that you can observe the readings, and then we will add the air assist and you will see a drop in the levels of carbon monoxide and hydrocarbons.

Data indicating the effectiveness of air assist is shown on the next slide. We have found that as little as 1/4 of 1% of the total engine air flow injected through the fuel nozzles as we have demonstrated, can reduce idle emissions by more than a half.

As an example of what this might mean, the application of the air assist technology would reduce emissions of CO and NO by approximately $9,000,000$ pounds per year at the Cleveland Airport.
Now let's consider the full power condition. Recall that the primary pollutant emissions during full power operation of the engine are smoke and oxides of nitrogen.

The most easily identifiable pollutant from gas turbine engines was smoke. Black smoke trails across the sky from low flying airplanes were very common only two years ago. Today, only a few of the smoky engines on most jet transports remain to be retrofitted with new smokeless combustors.

The next slide shows how smoke reduction has been accomplished. By adding more air in the primary combustion zone, the fuel rich condition which produced smoke in earlier combustors was eliminated. This modification had to be made without compromising altitude flight capabilities.

The benefits of smoke reduction can be seen at every major airport. The next slide illustrates both the old and the new in regard to smoke emissions. Here are photographs of two aircraft taking off. You can see that there is no visible smoke from the aircraft having the modified engines.

The primary gaseous pollutants at full power are the oxides of nitrogen formed during high temperature combustion. The next slide illustrates some of the basic concepts employed to reduce these emissions. Since the oxides of nitrogen are formed in the hottest portions of the flame zone, these emissions can be reduced by lowering the flame temperature and reducing the time the gases reside in the
hottest portions of the flame. This can be accomplished by leaning on the fuel-air mixture, premixing the fuel and air, and segmenting the flame zone. Leaner mixtures are achieved by directing most of the combustion air into the primary burning zone. In the premixing method, the fuel and air are mixed prior to entering the combustion zone.

Breaking the flame zone into a large number of segments is the approach used in the modular swirl-can combustor invented at Lewis. The next slide illustrates the basic features of the swirl-can concept. These are premixing the fuel and air, small burning zone, and rapid mixing with bypass air. The illustration on the board shows how the individual modules are assembled to make the full-scale combustor on display. We have been extensively testing this combustor design and have shown it to significantly reduce oxides of nitrogen emissions. The next slide shows these reductions at engine operating conditions typical of today's narrow and wide bodied jet transports. The oxides of nitrogen emissions from the swirl can combustor are approximately half of that of current combustors. Based on these results,

the amount of oxides of nitrogen produced by aircraft flying over the United States, by approximately 240 million pounds per year. As current air transport increases both chemical & fuel power consumption

To achieve the reduced emissions, we have discussed, we must transfer laboratory technology to practical engine use. This is the goal of the Experimental Clean Combustor Program. This program is a contracted as well as an in-house effort to investigate new combustor designs that have the potential of significantly reduced emission levels. The Clean
Combustor program will require all of our skill and knowledge plus that of the major commercial engine manufacturers if we are to achieve our reduced emission goals and meet the standards of the EPA for 1979. These standards require that emissions of He, CO, and NOx be reduced to approximately 1/3 of current levels. We have contracts with two of the major commercial jet engine manufacturers to explore a variety of new combustor designs. The final phase of the CCP will include testing of the best combustor designs installed in engines to demonstrate the reduced emission levels. We expect to complete this program during 1976. We have some charts showing the combustor designs being studied arranged along the right side of this area.

At present, the Environmental Protection Agency Standards for aircraft emissions only apply at altitudes below 3000 feet. But, there is growing concern over emissions at all altitudes. Because of this concern, the Department of Transportation is conducting the Climatic Impact Assessment Program.

The purpose of this program is to measure pollutant concentrations within the upper atmosphere and determine what effect, if any, an increase in those levels by jet aircraft would have upon the atmospheric balance. This program is a national cooperative effort between government and industry.

At Lewis, we are involved in measuring the concentration of pollutants at all levels of the atmosphere. Our monitoring of pollutant
levels in the urban atmosphere uses a wide variety of data gathering instruments. Some of these instruments can be seen on the display tables.

A major atmospheric measurement effort is our Global Air Sampling Program. This program is concerned with measuring the constituents of the atmosphere at the 20 to 40 thousand foot altitudes where most present-day jet transports cruise. To make these measurements, we are installing instrument packages in some 747 aircraft, at the location shown on the next slide. In flight, air samples will be ducted to the instruments through the sampling probe. We will continuously record the levels of atmospheric constituents as well as the position of the aircraft. As the quantity of these data grow, we hope to determine if pollutant concentrations in the upper atmosphere are changing due to air traffic.

The routes to be covered by our first two instrumental aircraft are shown on the next slide. Extensive sampling over the United States will occur during our initial flights starting in December of 1974. Global coverage will begin with the flights of the second instrumented aircraft. 

Another contribution by Lewis to the Climatic Impact Assessment Program is to determine engine emissions at flight conditions. These measurements are made in test facilities such as these you see here to your left and right. The engine on your left is the Quiet Engine which you have heard about or will hear about at another stop. This engine is being tested to determine the effect of the low noise features on altitude performance. Emission measurements will also
be made at simulated altitudes from 20 to 40 K ft. On your right, we have a J-58 engine installed and instrumented to measure emissions. Emissions measurements will be made on this engine at simulated altitudes up to 70,000 ft. and flight Mach numbers up to 3. These tests will give us information as to the levels of pollutant emissions generated during high altitude supersonic flight.

During this brief presentation, we have shown you what Lewis is doing to apply advance technology to minimize pollutant emissions from jet aircraft and touched briefly on what we are doing to measure pollutant concentrations in the atmosphere. This concludes our presentation.

Thank you.
1973 Inspection and Show

Stop #2 "CLEANER SKIES"

Demonstrations during talk:
1. JT8D Engine Cutaway
2. Parts per million demonstration
3. Oxides of Nitrogen demonstration tube
4. Fuel nozzle--air assist demonstration
5. Mock-up of Global Air Sampling Instruments in 747
6. Advanced low emissions combustor technology
7. Full scale combustors
8. Combustor demonstration of low emissions technology
9. Emissions measuring instruments

Additional Static Displays
1. Air monitoring equipment and instruments (Fordyce)
2. Global Air sampling display of instruments, charts etc.
1) AIRCRAFT ENGINE EMISSIONS 40x60
2) OXIDATION OF NITROGEN
3) EMISSIONS REDUCTION AT IDLE
4) IDLE EMISSIONS REDUCTION BY AIR ASSIST
5) SMOKE REDUCTION
6) AIRCRAFT SMOKE REDUCTION
7) EMISSIONS REDUCTION AT FULL POWER
8) SWIRL-CAN CONCEPT
9) COMPARISON OF NO, NO\textsubscript{2} EMISSIONS
10) CLEAN COMBUSTOR PROGRAM
11) GLOBAL AIR SAMPLING PROGRAM (CHART)
12) GLOBAL AIR SAMPLING (747)
13) GLOBAL AIR SAMPLING ROUTES (MAP)
AIRCRAFT ENGINE EMISSIONS

- Water vapor
- Carbon dioxide
- Hydrocarbons
- Carbon monoxide
- Oxides of nitrogen
- Smoke

SLIDE 1

OXIDATION OF NITROGEN

DURING COMBUSTION:
AIR \( (N_2 + O_2) + \text{HEAT} \rightarrow \text{NO} \)

IN ATMOSPHERE:
\( \text{NO} + \text{AIR (O}_2) \rightarrow \text{NO}_2 \)

SLIDE 2
EMISSIONS REDUCTION AT IDLE

ATOMIZED SPRAY

TULIP SPRAY

FUEL SCHEDULING

AIR ASSIST NOZZLE

AIR BLAST NOZZLE

SLIDE 3  (CS-67565)

IDLE EMISSIONS REDUCTION
BY AIR ASSIST

SLIDE 4  (CS-67566)
SMOKE REDUCTION

FUEL-RICH PRIMARY ZONE

LEANER PRIMARY ZONE

SLIDE 5  (CS-67567)

AIRCRAFT SMOKE REDUCTION

SLIDE 6  (CS-67568)
EMISSIONS REDUCTION AT FULL POWER

EMISSIONS REDUCED BY:
- LOWER FLAME TEMPERATURE
- REDUCED TIME IN FLAME

CONVENTIONAL COMBUSTORS

LEANER MIXTURES
PREMIXING
SWIRL CAN

SLIDE 7 (CS-67569)

SWIRL-CAN CONCEPT

FUEL-AIR PREMIXING
Rapid mixing with bypass air
SMALL, UNIFORM FLAME ZONE

SLIDE 8 (CS-67570)
COMPARISON OF NO, NO₂ EMISSIONS

WIDE BODY JETS (E.G. 747, DC-10)
PRESENT DAY COMBUSTERS
NASA SWIRL-CAN
NARROW BODY JETS (E.G. DC-8, 727)

LBS NO, NO₂
1000 LB FUEL

INLET TEMP, °F

CLEAN COMBUSTOR PROGRAM

- ADVANCE LABORATORY TECHNOLOGY TOWARD BENEFICIAL USE
- BEST OF NASA AND INDUSTRY TECHNOLOGY
- MEETS 1979 EPA STANDARDS
- TWO CONTRACTORS
- COMBUSTORS TESTED IN ENGINES
GLOBAL AIR SAMPLING PROGRAM

PURPOSE: TO DETERMINE CHANGES IN THE CONCENTRATION OF POLLUTANTS IN THE WORLD AIRWAYS.

- DUE TO AIR TRAFFIC
- OVER A 5 TO 10 YEAR PERIOD

SLIDE 11 (CS-67573)

GLOBAL AIR SAMPLING

[Diagram of an airplane with sampling probes and atmospheric measuring instruments]

SLIDE 12 (CS-67574)
GLOBAL AIR SAMPLING ROUTES

SLIDE 13

(CS-67545)
GLOBAL AIR SAMPLING PROGRAM

For the past ten years, all aircraft traffic in the upper atmosphere has been increasing at a rapid rate. The exhaust emissions from jet aircraft engines are increasing the air content in the upper atmosphere. Other sources of pollutants are being studied to determine the extent to which man’s activities on the ground and at sea are contributing to this. The Global Atmospheric Research Program attempts to answer whether the increase in all the various natural sources affecting the upper atmosphere was 2.35 in 1975.

Qualify the upper atmosphere sample by measuring the instruments on board regularly and analyzing the data only 31st of May. The data will be used because the atmosphere is the ultimate test of the instruments and the method used in each part of the world. Tens of thousands of people have contributed to this project and will continue to do so.