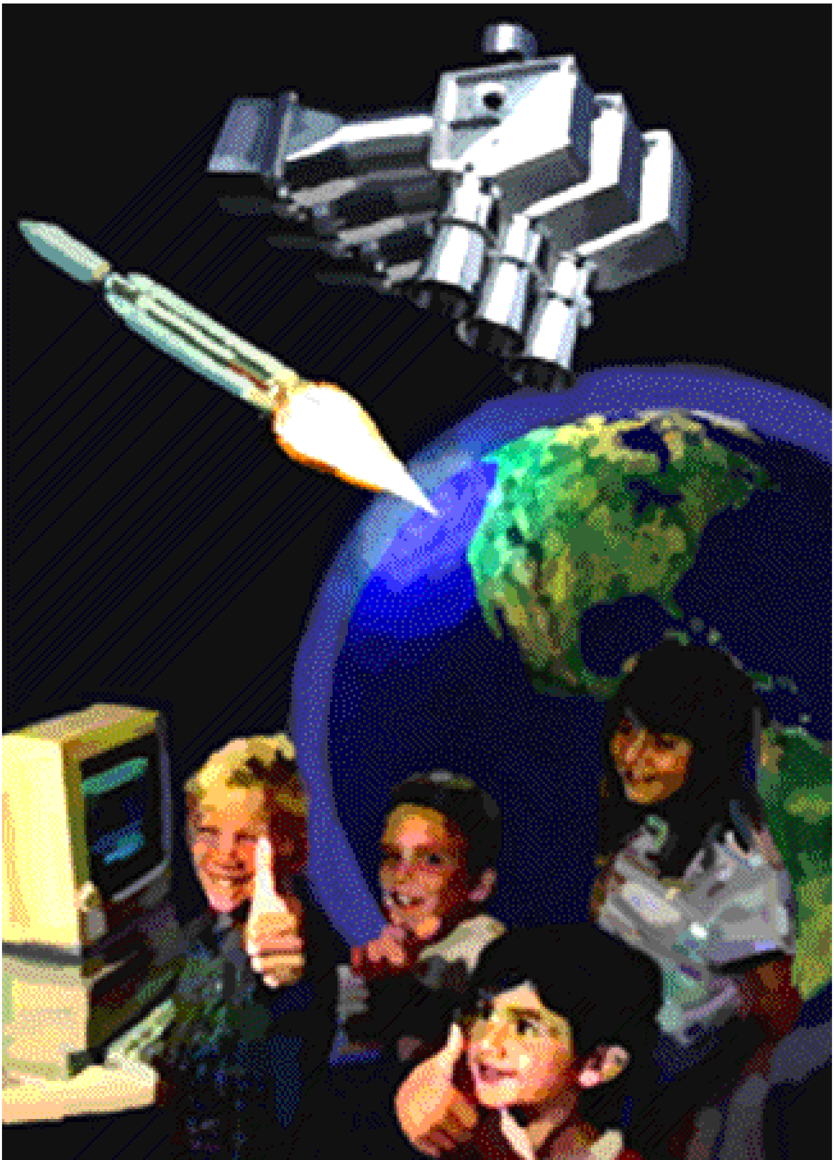
SPACE AND MISSILE SYSTEMS CENTER



H I R O I G

High Resolution Ozone Imager

PROFILE

ENVIRONMENTAL LEADERSHIP

The United States Air Force (USAF) and Space and Missile Systems Center (SMC) have clear environmental goals and missions.

As stated on 7 January 93 to all Major Air Force Materiel Command (AFMC) Commanders:

"The Air Force is committed to environmental leadership. Our goal is to prevent future pollution by reducing use of hazardous material and releases of pollutants into the environment to as near zero as feasible."
General Merrill A. McPeak
Air Force Chief of Staff

Brig. Gen. Eugene L. Tattini
Chairman, SMC
Environmental Protection Committee

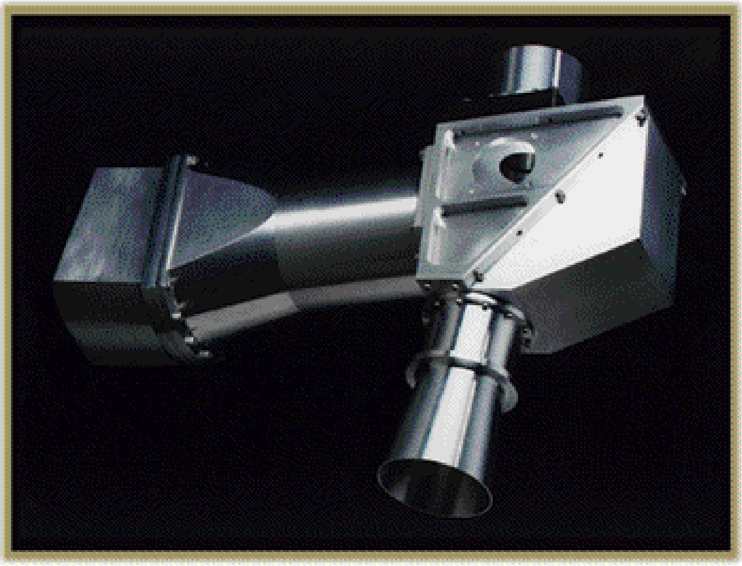
Brig. Gen. Tattini provided seed funding to initiate High Resolution Ozone Imager (HIROIG) development through The Aerospace Corporation's support.

CONTENTS

...As a center of acquisition excellence, we quickly and
efficiently respond to the needs of the operational
commanders and employ visionary thinking
to keep US space and missile systems
on the leading edge of technology.

SMC Mission Excerpt

WHAT IS HIROIG?



A prototype of one of the three elements of HIROIG.

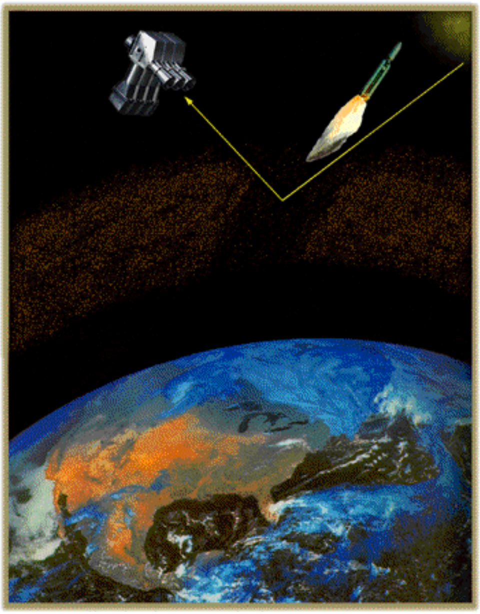
Instrument:	Imaging Polarimetric Spectrograph
Approximate Size:	1.5 x 1.5 x 1.5 feet
Approximate Weight:	100 pounds

The High Resolution Ozone Imager (HIROIG) is a state-of-the-art sensor designed to measure ozone depletion resulting from rocket launches. When operational, HIROIG will be mounted on a satellite in a polar orbit about 800 km above the earth. It will monitor the area of the atmosphere affected by a rocket's exhaust (i.e., the launch corridor) within one to three hours after the launch, during which the concentration of ozone is predicted to reach its lowest level. It will be able to measure and compare ozone loss resulting from various launch vehicles.

HIROIG will measure the depletion of stratospheric ozone by monitoring changes in the intensity of solar ultraviolet (UV) light which is backscattered from the stratosphere after the rocket launch (see artist's rendering on the following page). Existing instruments lack sufficient resolution to measure ozone loss in a rocket's relatively narrow launch corridor. HIROIG is specifically designed to be able to measure ozone depletion in the area of the launch corridor. HIROIG is also designed to give a full altitude profile of the ozone loss. This will provide the data needed to perform three-dimensional analysis of ozone depletion in the launch corridor.

HIROIG BACKGROUND

SMC first assessed ozone depletion in 1988 for Titan Centaur launches, relying heavily on NASA's Environmental Impact Statement for the Space Shuttle, which uses similar solid-fueled rockets. Subsequent data showed problems with the model predictions on which NASA's analyses were based. In 1991, SMC initiated several additional studies to quantify the effect that launches have on stratospheric ozone. These studies concluded that available measurements and models were not adequate for such quantification. The best available data was from NASA's Total Ozone Monitoring Spectrometer (TOMS). However, since TOMS was built to measure global ozone changes, it lacked sufficient resolution to measure ozone loss in a narrow launch corridor.



Artist's rendering of HIROIG measuring ozone depletion resulting from rocket launches. Solar UV light is backscattered by the atmosphere.

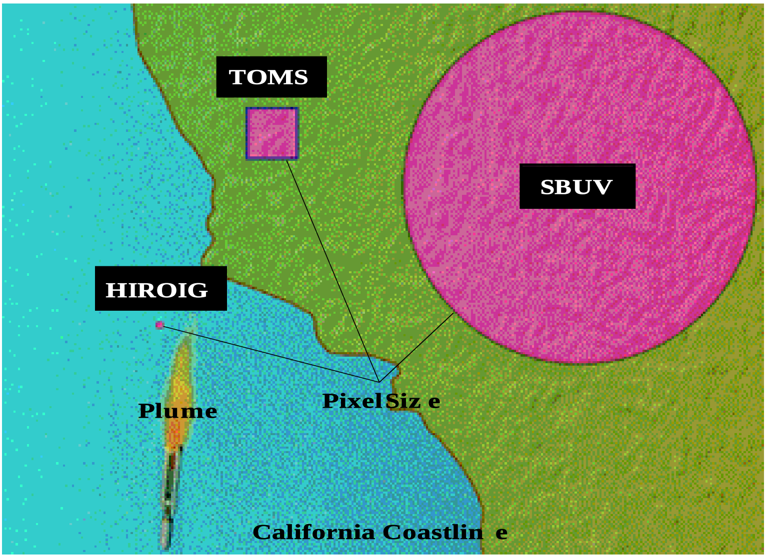
To respond to the lack of data, an instrument capable of making these measurements was designed by members of the Space and Environment Technology Center of The Aerospace Corporation. The performance requirements were based on models of rocket exhaust composition, mixing of the effluents in the stratosphere, and specifications for previous ozone measurements by space instrumentation. The requirements were met in a device that became known as HIROIG, which stands for "High Resolution Ozone Imager". It basically consists of a series of polarizing telescopes with state-of-the-art spectrographs (devices which split light into different wavelengths and measure their intensities).

In addition to HIROIG, on-going studies include ground-based infrared imaging of launch plumes to estimate ozone depletion magnitudes and laboratory studies of the various rocket exhaust products that can cause the depletion of ozone. Computer modeling is used to integrate the information resulting from these studies. Aircraft-based measurements will also be obtained by aircraft flying through a rocket's launch corridor.

WHY DOES SMC NEED TO MEASURE OZONE DEPLETION?

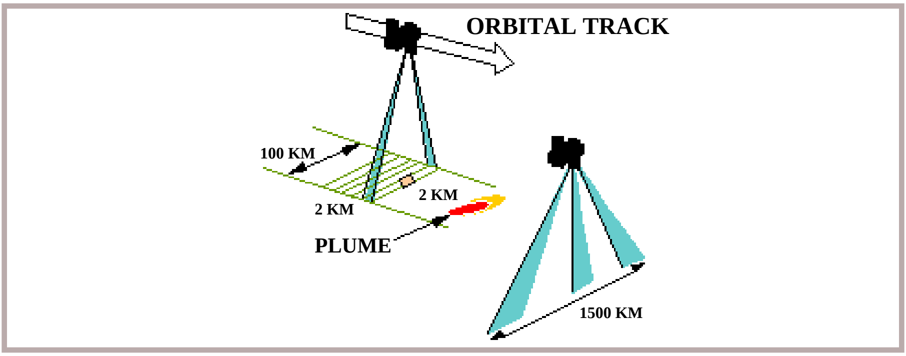
The Air Force is committed to environmental leadership. In recent years, it has taken aggressive steps to understand the environmental impacts of its activities.

The National Environmental Policy Act (NEPA) requires SMC, as a government agency, to analyze the environmental impacts of its programs. Since space launch programs contribute to depletion of stratospheric ozone, SMC is required to characterize this effect. In addition, the relative impacts of liquid-fueled and solid-fueled rockets and alternative propellants need to be quantified for the design of future launch systems.



Comparison of the resolution of HIROIG with the NASA Total Ozone Monitoring Spectrometer (TOMS) and Space-Based Ultraviolet (SBUV) instruments. Smaller pixel size implies greater resolution and detail.

Solid rocket exhaust products deplete ozone in the stratosphere in the following way. Solid propellants, which contain large amounts of chlorine, have the potential to chemically destroy ozone in the stratosphere. Normally the release of active chlorine from the solid-fuel exhaust would be slow and most of the harmful substance would leave the atmosphere through natural processes such as rain. However, a series of chemical reactions at the extremely high temperatures in the rocket plume cause the immediate release of large amounts of active chlorine into a small area of the stratosphere. Each chlorine atom released eventually causes the destruction of many thousands of ozone molecules in what is known as a catalytic cycle. Rocket exhaust also contains aluminum oxide particles that may further accelerate ozone depletion, like that which occurs over Antarctica due to polar stratospheric clouds. This effect of aluminum oxide is based on theory and requires further study.



Scanning resolution and range of HIROIG.

The Montreal Protocol established policy and requirements controlling the industrial use of ozone depleting chemicals (ODCs). Each year, the parties to the protocol meet to identify additional industrial materials which deplete ozone, and, as appropriate, establish timetables for their curtailment or phase-out. In the United States, the Clean Air Act Amendments of 1990 implement this protocol and call for an elimination of the worst "Class I" ODCs within several years. While rocket exhaust has not been listed as a Class I ODC, it could be. We now know that annual chlorine loading in the stratosphere from launch vehicles is double that of CFC-115 (chlorofluorocarbon-115), a Class I ODC, and more than 10 times greater than all other Air Force CFCs combined. The Ozone Depleting Potential (ODP) of launch chlorine in the stratosphere is well above the threshold for regulation.

In view of these requirements, and in keeping with the Air Force's commitment to environmental leadership, there is an urgent need to characterize and reduce the environmental impact of the ozone depleting substances released by launches.

WHY DO WE NEED HIROIG?

There are two principal reasons why a space-based instrument such as HIROIG is needed to measure ozone depletion by launch vehicles:

Space-based UV backscatter measuring instruments can not only measure the area of ozone depletion, but also obtain altitude profiling of ozone loss. Thus, space-based instruments such as HIROIG can provide a three-dimensional image of ozone depletion in the launch corridor. The vertical information allows for a better understanding of the specific mechanism by which ozone loss is occurring and whether upward or downward transport of air parcels is involved. In addition, HIROIG will be capable of achieving a 2 km x 2 km spatial resolution , which is necessary to measure ozone depletion in the narrow launch corridor. This resolution is greater than 1000 times better than any existing instrument.

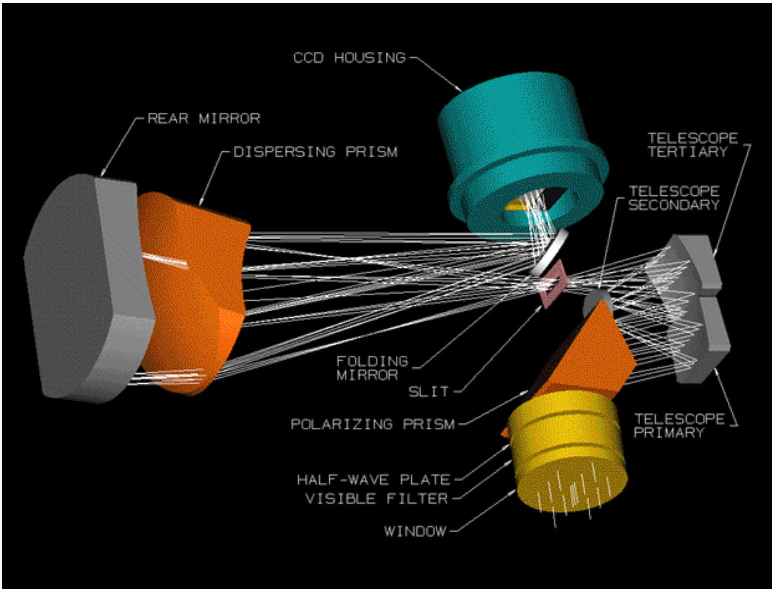
The second reason for space-based measurements is that a space-based instrument in a polar orbit, such as HIROIG, will be able to monitor launches occurring from any location on Earth. HIROIG is expected to observe the ozone depleting effects of between one-fourth and one-third of the launches that take place during its mission without the cooperative launch scheduling required by balloon-based or aircraft measurements. Thus, HIROIG can determine effects on the stratospheric ozone layer from both U.S. and international launches, which use a wide variety of propellants. This is important for assessing the environmental impacts of alternative launch propellants and launch vehicles. This is also important for the development of propellants that will not cause ozone depletion. Phillips Laboratory at Edwards AFB, California, is currently developing such alternative "clean" propellants.

HOW DOES HIROIG WORK?

HIROIG determines ozone depletion by measuring the intensity of backscattered solar UV light. In the undisturbed stratosphere, the depth to which UV light can penetrate before being completely absorbed by ozone is dependent upon the wavelength of the light. If there is an "ozone hole" at a particular altitude, light that normally penetrates to that altitude is able to reach lower altitudes where the atmospheric density is higher and the light is more strongly scattered, resulting in more intense backscattered light. Light that does not normally penetrate to the hole's altitude is unaffected. Therefore, the wavelengths at which the backscattered light is intensified are correlated with specific altitudes at which the ozone has been depleted.

By observing different intensities of solar UV light at many different wavelengths, HIROIG is able to determine the stratospheric ozone concentration at altitudes up to 50 km in 7 km intervals. HIROIG utilizes a state-of-the-art charge coupled device (CCD) detector to achieve it's uniquely high spatial resolution of 2 km x 2 km. The resulting three-dimensional data obtained from HIROIG will provide a detailed profile of ozone loss in the atmosphere due to launch vehicles, even if the loss occurs in a localized region.

HIROIG uses three spectrographs that measure the components of the backscattered solar UV radiation in three different polarization directions. Because the light that is reflected by atmospheric molecules is polarized in a well-known and predictable manner, and the light that is scattered by aerosols from rocket exhaust is very weakly polarized or unpolarized, HIROIG can eliminate the unwanted component of backscattered light due to the exhaust aerosols. Due to further processing of the light within the instrument, the response of the spectrographs does not depend upon the polarization of the incident light, allowing HIROIG to be calibrated very reliably. Each spectrograph also incorporates filters to assure that light outside the wavelength band of interest does not reach the detectors, thereby diminishing background "noise".



Filters and prisms in the HIROIG, with ray traces to show the path of the light as it travels through the instrument.

The polarized, filtered UV light is dispersed by a prism onto a detector that records a spectrum in a direction perpendicular to the satellite's ground track. Recordings are accumulated in rapid succession as the satellite moves along its orbit, resulting in a spectral image of the rocket-plume region. Computer processing of the spectral image provides a map of ozone depletion in the launch corridor.

IS HIROIG A DUAL USE INSTRUMENT?

HIROIG can certainly be used in more general studies of the Earth's ozone layer and other areas of environmental concern. Following its projected launch in 1997, a continuous record of global observations will be available. Perturbations to stratospheric sulfur dioxide and ozone from natural phenomena, such as volcanic eruptions in remote regions, will be recorded. HIROIG also has the potential for measuring phytoplankton growth in the Earth's oceans. In addition, anthropogenic effects on the atmosphere, such as those caused by high-altitude aircraft, will be readily observed.

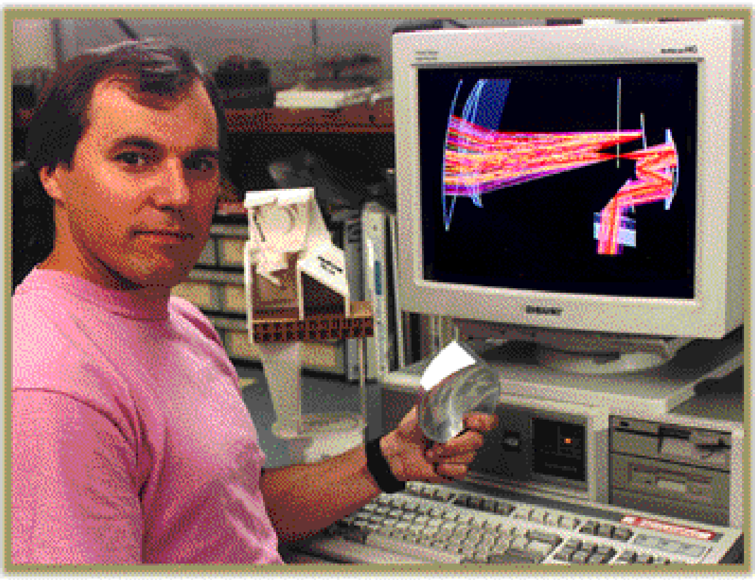
Development of detector electronics for the HIROIG prototype.

HIROIG DEVELOPMENT AND LAUNCH SCHEDULE

Scientists at The Aerospace Corporation began designing HIROIG in 1991. The mechanical and optical design and construction of a prototype prism spectrograph was completed in December, 1993. The memory logic circuits have been designed, simulated, and partially tested. These circuits will be used with RAM (random access memory) chips to provide the required 32 megabyte solid-state memory. Assuming adequate funding, HIROIG can be ready to deliver for spacecraft integration in 1996. HIROIG could then be launched on a spacecraft as early as 1997.

HIROIG SCHOOL PROGRAM

Vice President Al Gore suggested, in his book *Earth in the Balance*, that environmental data analysis from space sensors should involve schoolteachers and their students. In Gore's words, "a ... seed might be planted in the process; for example, the world's leading scientist on the problem of ozone depletion, Dr. Sherwood Rowland, first became interested in the atmospheric sciences as a youngster when he was asked to look after a backyard weather station by a neighbor who went on vacation for several weeks. [The] goals of environmental education could hardly be better served than by actually involving students in the process of collecting data. [The] program might build a commitment to rescue the global environment among the young people involved."



HIROIG optics simulation using ray-tracing software.

To meet this challenge, the Air Force and The Aerospace Corporation are establishing a program with local schools to teach students about HIROIG and elicit their participation in the development of data display formats and analyses. The program will involve students in all phases of instrument development and include exposure to computer simulations and tours of research and development laboratories.

HIROIG TEAM

The Air Force has established centers of excellence consisting of top scientists, equipped with state-of-the-art laboratories, to develop advanced military space systems. SMC has applied these resources to environmental monitoring which uses the same physics, chemistry, and space technologies as military space systems.

HIROIG development personnel; from left: David Gorney, Andrew Christensen, David Gutierrez, John Edwards, Patty Liu, Jim Hecht, Norm Katz, Joseph Stein, Kirk Crawford, George Rossano, David McKenzie, Mazaher Sivjee, Dan Mabry, and Jim Skinner. Absent from photo: Marty Ross and Capt. Bart Hedley.

The HIROIG design team is a group of experienced design professionals at The Aerospace Corporation who have participated in the development of sensors for numerous Air Force Space Test Program and NASA applications.

SMC/CEV

CEV Total Quality Goal:
Lead Space and Missile Systems Center to Environmental Excellence through Support, Technology, and Education.

SMC's Environmental Management Division (SMC/CEV) is responsible for assuring that all SMC federal actions having potential environmental impacts are evaluated in accordance with the National Environmental Policy Act of 1969 (NEPA) and Air Force Regulations 19-2 and 19-3, which implement NEPA in the United States and overseas, respectively.

In addition to managing NEPA assessments, SMC/CEV recommends mitigation measures to its System Program Offices (SPOs). Mitigation measures reduce environmental impacts of programs and often make it possible to proceed with a program that might otherwise be in jeopardy because of unacceptable environmental impacts. Environmental analysis is performed by SMC/CEV staff, environmental contractors, and consultants, with support from Air Force labs and The Aerospace Corporation.

SMC/CEV also advises and assists the SPOs in obtaining required air, water, and solid waste permits, pollution control equipment, pollution prevention technology, education, and training.

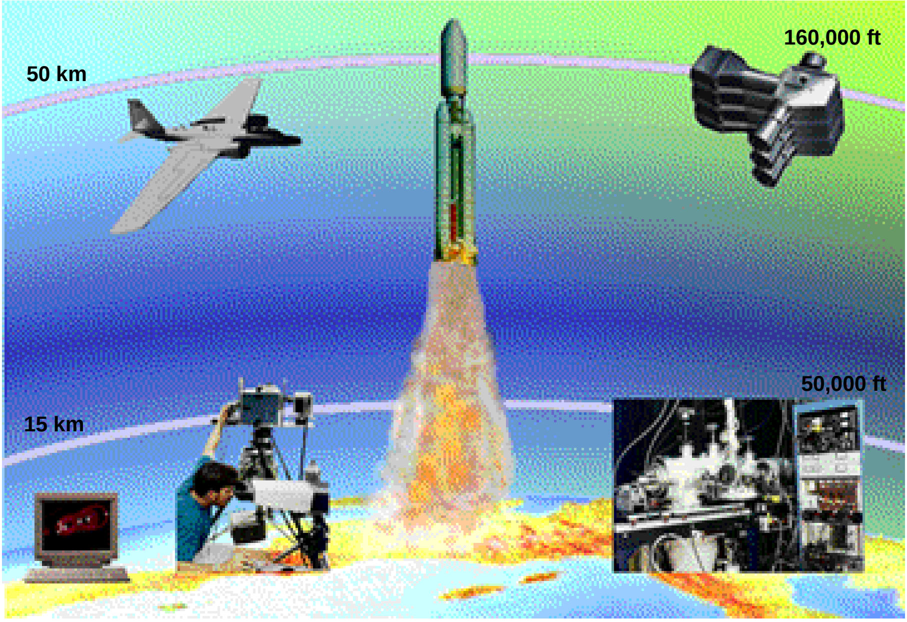
For more than 20 years, SMC programs have not been stopped or significantly delayed due to environmental concerns, even those that involved environmentally sensitive issues and controversy. This record was achieved by thorough and honest evaluation and reporting of potential environmental impacts.

HIROIG: PART OF A COMPREHENSIVE RESEARCH PROGRAM

HIROIG is part of a comprehensive Air Force Phillips Laboratory program designed to fully investigate the effects of space launch vehicles on the stratospheric ozone layer and to develop alternative propellants with reduced impacts. Current efforts of SMC/CEV are focused on understanding the environmental effects of operational solid-fueled rocket motors. Various liquid-fueled motors and alternative "clean" solid propellants will also be studied.

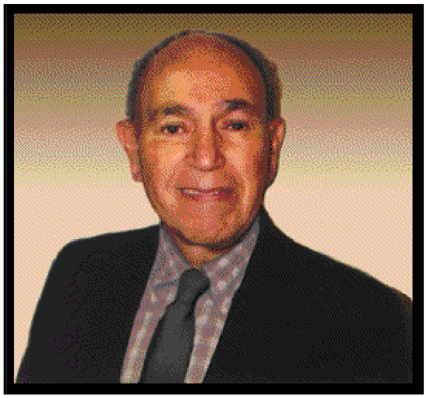
Researchers at The Aerospace Corporation, TRW, Massachusetts Institute of Technology, University of California, Irvine and the National Center for Atmospheric Research are participating in the program. Scientists at these institutions are performing laboratory experiments, running complex atmospheric computer models, and collecting stratospheric data from both ground and aircraft platforms. Under investigation are the effects of solid alumina particles on ozone; the chlorine chemistry within the plume region; and the rate of plume diffusion over the launch sites.

The information obtained from the SMC / CEV studies will help not only the U.S. Air Force, but also NASA and foreign space agencies, to accurately predict the environmental and human health consequences of their activities. Understanding the effects of current launch vehicles on the stratosphere will enable government and aerospace industry leaders to make educated decisions about future generations of launch vehicles.



Scientists perform laboratory experiments, run complex atmospheric computer models, and collect stratospheric data from both ground and aircraft platforms in order to understand the effects of current launch vehicles on the stratosphere.

DEDICATION



Mr. Raphael O. Roig
Retired from Air Force Civil Service.

The HIROIG was named in honor of Mr. Raphael O. Roig. He is considered by his colleagues to be unequaled as an environmental leader.

Mr. Roig established the SMC Environmental Management Division (SMC/CEV). Under his guidance, SMC/CEV fostered environmental awareness, improved the environmental performance of programs, and developed environmental management techniques that are now employed throughout the Air Force.

The naming of the HIROIG, therefore, was a tribute in recognition of Mr. Roig's many contributions as a pioneering environmentalist, an extraordinary supervisor, and an admirable man.

FURTHER INFORMATION

If you would like further information about the HIROIG, please contact the Space and Missile Systems Center at:

HQ SMC/PA
Office of Public Affairs
2430 E. El Segundo Blvd., Suite 4049
El Segundo, CA 90245-4687
(310) 363-0030

Printed on recycled paper.