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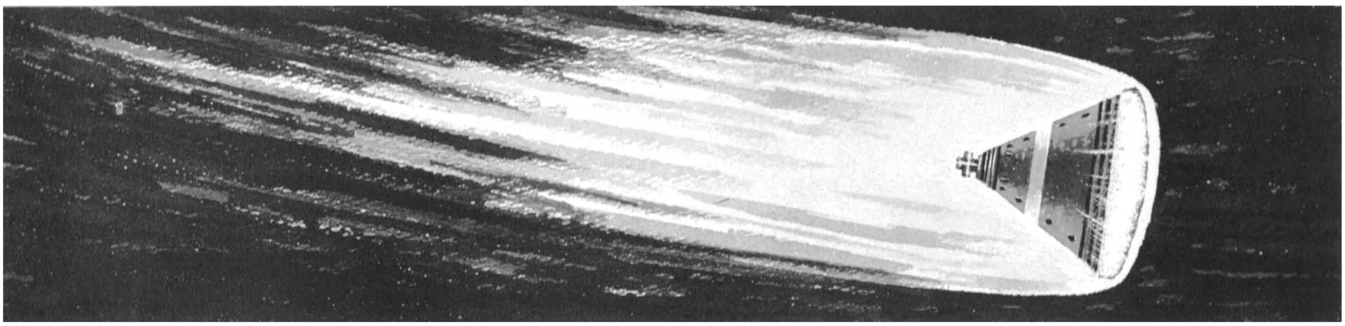
FIRE I

THE REENTRY HEATING SPACECRAFT



NASA's FIRE I Spacecraft successfully reentered the earth's atmosphere on April 14, 1964, and transmitted much valuable data about the extremely hot gas cap of environmental air with which future spacecraft will have to contend upon returning to earth from space missions. A second launching is planned.

A spacecraft returning to earth at super-orbital speed encounters the same phenomenon as natural meteors. Appearing as a fireball, the phenomenon is the result of the impact of the reentry body on the atmosphere and the reaction of the atmosphere on the reentry body.

At the fringe of the earth's atmosphere the air molecules are very far apart, but when they are disturbed by the passage of a high speed re-entry body the molecules pile up and form a dense cloud of excited atoms that envelop the body and leave a brilliant visible trail behind. Thus, the spacecraft has created a very unusual environment, which is often referred to as a hot gas cap, where temperatures are many times higher than can be contained in almost any of earth's furnaces. The environment moves with the spacecraft at high speed and envelops the spacecraft as a furnace would envelop a laboratory model spacecraft.

FIRE SPACECRAFT DESIGN PROBLEMS

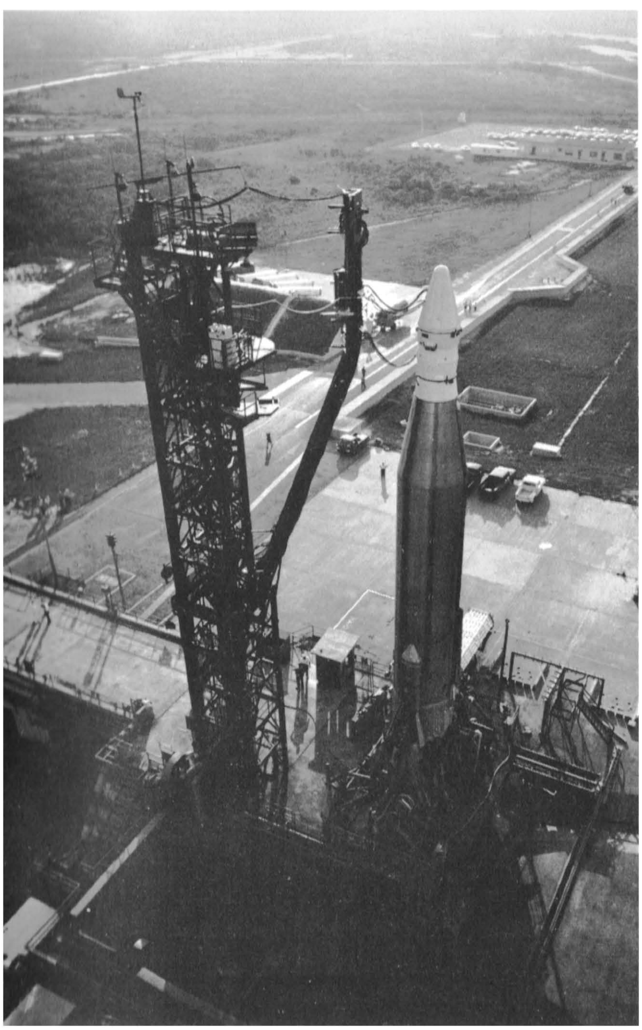
The first problem in design of the FIRE spacecraft was to find a way to reproduce the typical reentry environment of spacecraft returning from the moon. The reentry speed would be about 37,000 feet per second, which means penetrating 7 miles of atmosphere each second. The angle of approach would be a shallow 15 degrees slope below horizontal. The altitude where the environment reaction would start to become noticeable would be around 400,000 feet which is about 75 miles high.

The second problem was to design sensors and measurement systems for the spacecraft and protect them from the severe reentry environment. Temperatures would be measured both on-board the spacecraft and in the surrounding hot gas cap. Spectrographic measurements to determine the species of excited atoms of air in the gas cap would be attempted. Environmental air pressure would be measured. Antenna power losses due to the surrounding hot gas sheath would be measured. Other performance sensors such as timer sequences, orientation gyros and internal pressures and temperatures would have to be incorporated. And, the entire spacecraft would have to be designed around the sensors and measurement systems in a way to insure proper performance and provide ample protection.

The third problem was to find a way to get the measured data away from the spacecraft and back to the earth stations along the test range. The severe reentry environment would prevent direct radio transmission of the real time data because of the black-out effects of the hot gas cap. Recovery of the spacecraft and stored data after splash impact in the Atlantic Ocean would not be feasible because of excessive additional costs.

Final design of the FIRE I spacecraft grew out of these requirements and from the solution of these problems.

Looking down at the Project Fire booster and payload at Cape Kennedy. The heat shield protects, and here conceals from view, the payload (velocity package and reentry body). The shroud will be jettisoned in flight, after the payload has risen safely above the bulk of the atmosphere.



LAUNCH VEHICLE

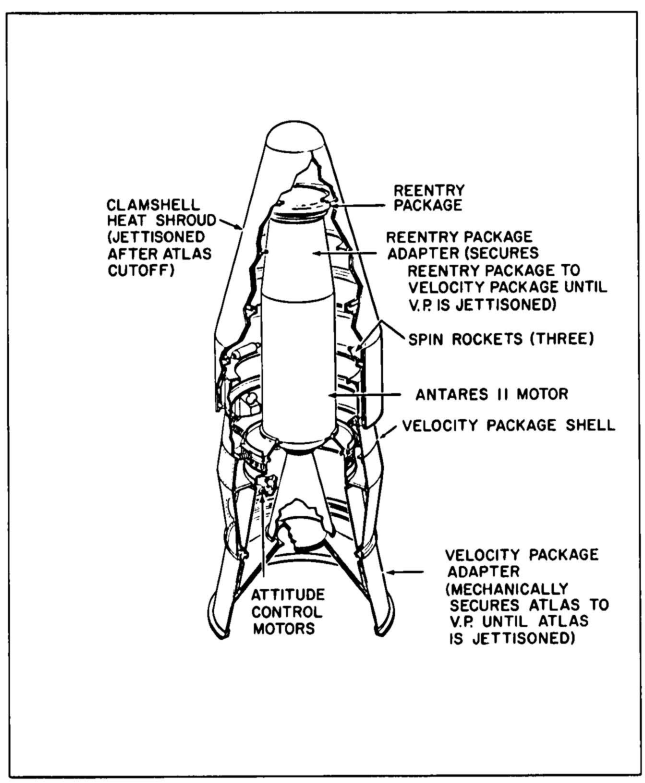
The function of the Fire launch vehicle is to boost the spacecraft into a high ballistic coasting trajectory allowing plenty of room above the earth for the final thrust back into the atmosphere, reaching the high velocity before reentry. The payload does not go into orbit. The distance from launch point at Cape Kennedy to "splash point" in the South Atlantic ocean is over 5,200 miles. The highest altitude is 520 miles which it reaches in a little less than 16 minutes after launch. The flight sequence is shown in the illustration "Trajectory and Flight Sequence."

The launch vehicle is the liquid fueled Atlas D, 66 feet tall, with a thrust equivalent to the power of more than 200 of the most powerful diesel locomotives.

SPACECRAFT (VELOCITY PACKAGE)

The spacecraft starts out as a two-ton payload which consists of two major parts—a velocity package (illustrated as it appears inside the two-piece heat shroud), and a reentry package.

The payload includes the velocity package and the reentry package, shown here as enclosed in the heat shroud.



The velocity package contains a large solid-fuel rocket, the Antares, and a highly sophisticated guidance and control system used for stabilizing and aiming the spacecraft for the final thrust back into the atmosphere.

The reentry package contains a complex arrangement of experimental instruments, batteries, and telemetry transmitters.

FLIGHT SEQUENCE

The function of the Atlas launch vehicle is to boost the spacecraft and guide it into the correct coasting ballistic trajectory where the Antares rocket can accelerate the reentry package to maximum velocity before starting the reentry experiment. The reentry package must reach a velocity of 37,000 feet per second (about 25,000 MPH) by the time it descends to 400,000 feet altitude where it must be headed 15° below horizontal.

The "flight sequence" is portrayed in the accompanying diagram starting with lift-off (1) and booster engine separation (2).

About six minutes after lift-off, the Atlas sustainer engine shuts off (3), and the two-piece shroud that protects the reentry package from atmospheric friction drops away (4), followed by vernier cut-off (5) and spacecraft separation (6). For the next 20 minutes the spacecraft coasts, while the inertial guidance system of the velocity package and a set of gas jets keep it aimed (7) in the proper position for reentry.

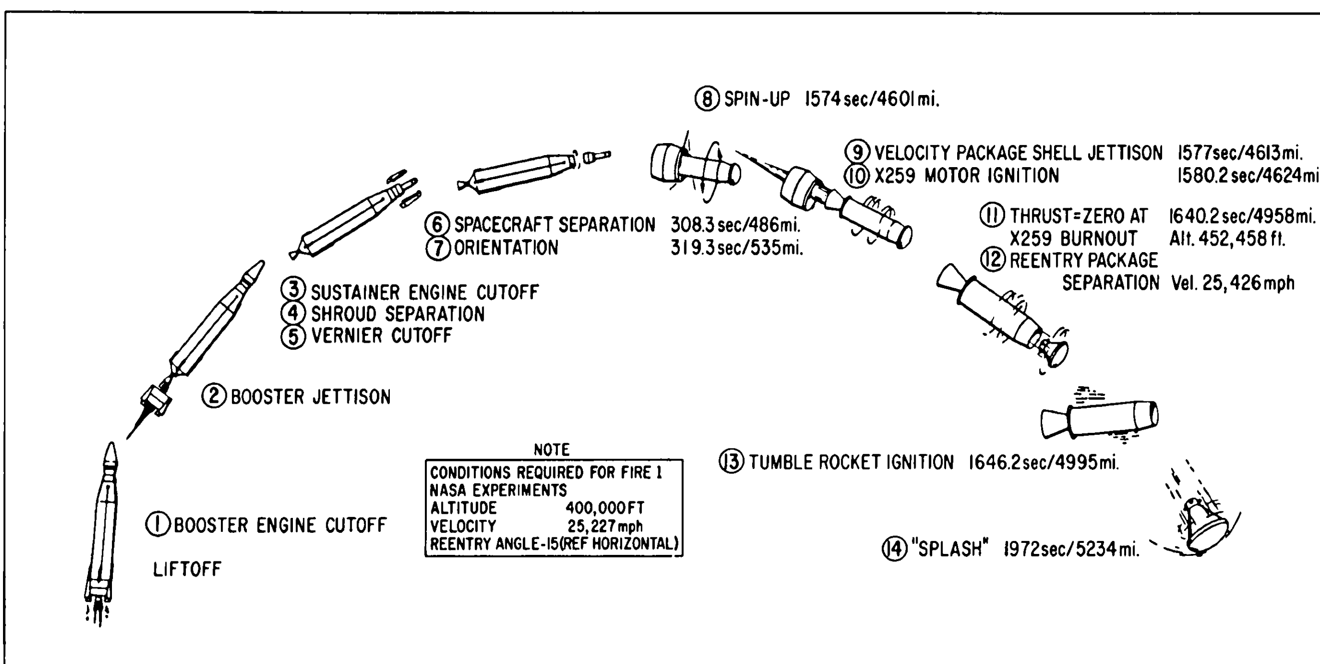
About 26 minutes after launch, the spacecraft, still holding the proper attitude, goes through its final maneuvers. The entire spacecraft is spun-up (8) to stabilize the reentry package at 180 RPM.

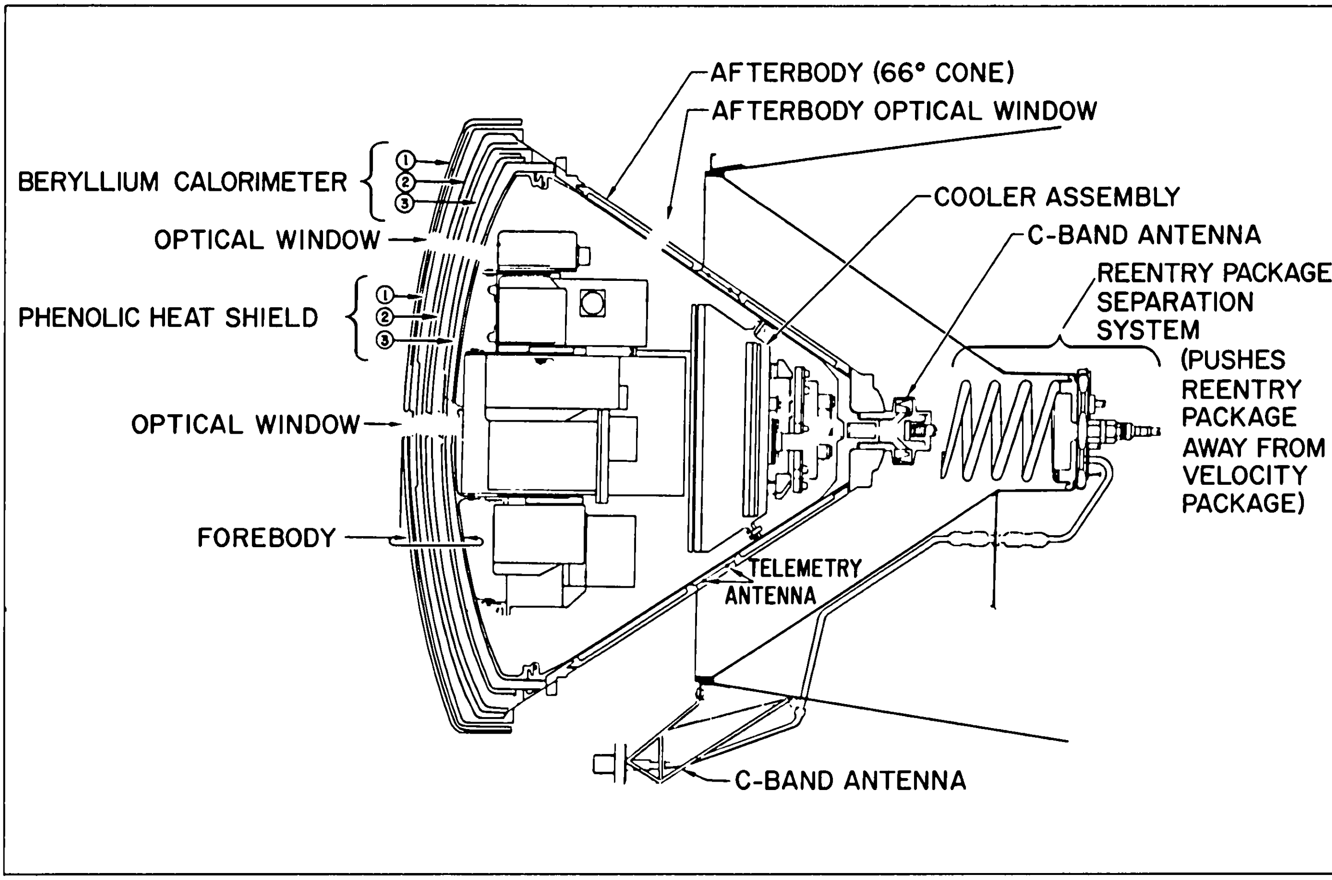
Next, the velocity package separates (9) and the Antares rocket ignites (10) and carries the reentry package through burnout (11) and separation (12). To do this, the Antares rocket consumes its 2,550 pounds of solid fuel in about 33 seconds, increasing the velocity of the spacecraft by 17,000 feet per second.

Finally, the reentry package separates itself from the Antares rocket which is slowed down by tumble rockets (13) so as not to collide with the reentry package during the experimental period.

The reentry package quickly encounters enough atmosphere to heat up. The heating rate is very high, reaching a peak a few seconds before maximum dynamic air pressure brakes the speed at a maximum deceleration load of about 78 g's. The "heat pulse" lasts for about one

Trajectory and flight sequence.





Reentry package (cross section).

minute. Getting exact measurements during this heat pulse is the primary objective of the experiment.

It is fitting now to examine the reentry package in some detail to see how this and the other objectives of the experiment are achieved.

REENTRY PACKAGE

The reentry package, with its spherical front surface and conical afterbody, is about 26½ inches in diameter by 21 inches long, and weighs about 220 pounds. Its shape is similar to that of the Apollo spacecraft which must pass through a similar environment when it returns from a moon trip.

The reentry package is tightly packed with instruments: thermocouples, radiometers, signal conditioners, sequence timers, tape recorder, batteries, two radio transmitters, a tracking beacon, and a refrigerator to maintain normal temperatures for the electronic components included in this equipment.

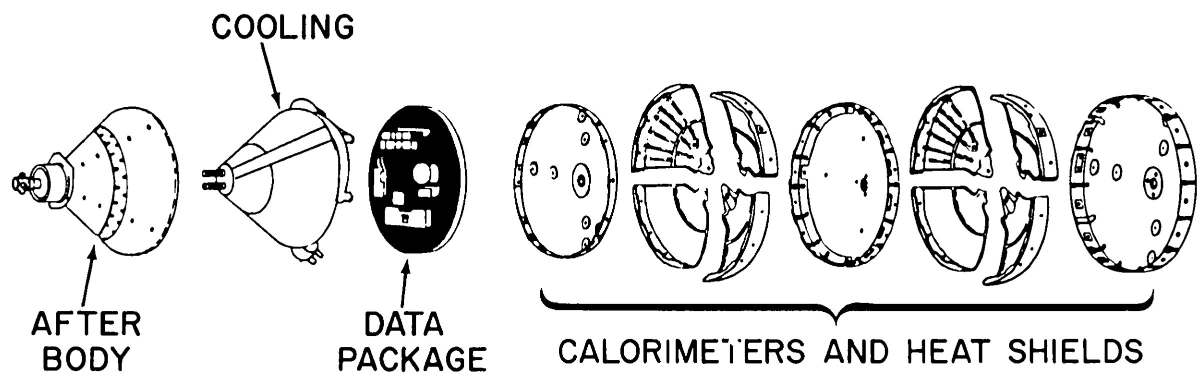
HEAT SENSORS

The front of the reentry package is of "layer cake" construction, composed of six layers.

The first, third, and fifth layers are solid beryllium, instrumented with thermocouples (electrical thermometers). Each beryllium layer with its thermocouples constitutes a calorimeter—an apparatus that measures the amount of heat absorbed from the fiery hot gas cap out in front.

The first calorimeter takes measurements at the start of the heat pulse until the temperature rises so fast that the beryllium melts away. Then a layer of phenolic asbestos protects the second calorimeter for a few seconds so that its measurements will be taken near the peak of the heat pulse. The third calorimeter is likewise protected for a few seconds and then takes measurements near the end of the pulse before the heating rate returns to normal.

These three data periods, each of a few seconds duration, help to define the heat pulse.



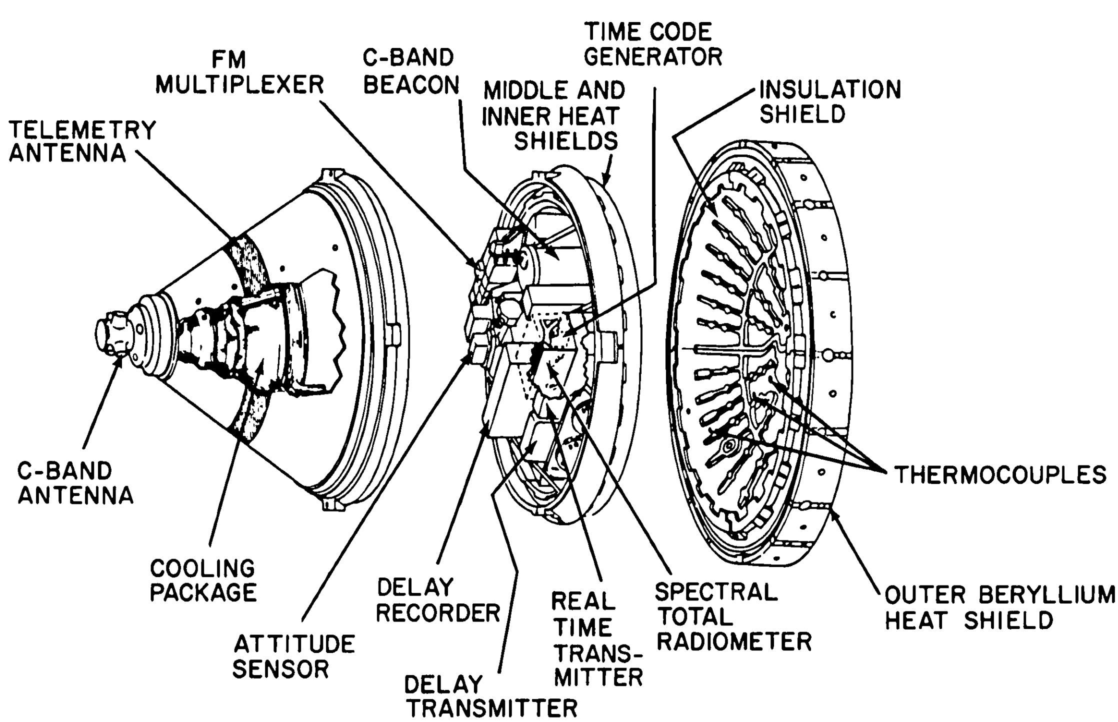
Reentry package before assembly, showing calorimeters and heat shields.

The protective layers of phenolic asbestos are also instrumented to record the temperature differences and there are other thermocouples on the afterbody and inside the reentry package. All told, the reentry package contains 258 thermocouples.

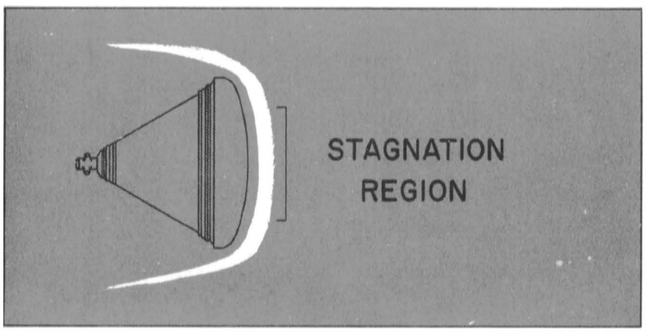
HEATING EFFECTS OF THE GAS GAP

The reentry package has a blunt face. As it speeds into the atmosphere it heats up quickly as the gaseous air directly in front is compressed. The compressed air is known as a gas cap and the center of the gas cap is known as the stag-

This exploded view of the reentry package shows the three main assemblies and instrumentation.



nation point. At the reentry speed of 38,000 fps. the gas cap becomes brilliantly incandescent, reaching a stagnation temperature of about 20,000 degrees F. Much of the heating of the front face is due to convective heat transfer from the hot gas cap to the beryllium calorimeter. Additional heat is transferred into the calorimeter by direct radiation from the incandescent gas cap. The calorimeter therefore measures the total heating it receives from both sources. Other instruments, the radiometers, determine how much of the heating it receives is due to radiation.



Stagnation region in gas cap.

MEASURING THE HOT GAS CAP

One important question that Project Fire is designed to clear up is this: What part of the total heat transferred to the spacecraft is attributable to direct radiation from the hot gas cap and what part is convective heating? To answer this question, the reentry package is equipped with special instruments called radiometers that directly measure the radiant heat. The difference between the radiant heat and the total heat will be the amount attributable to convective heating.

The radiometers are located inside the reentry package and "look" out through small glass windows of fused quartz. One looks at the gas cap stagnation area, another looks at the hot gas near the shoulder of the reentry package, and a third looks out the side where the gas forms a sheath.

All three radiometers measure the amount of radiant heat energy they see at their respective look angles. In addition, the stagnation point radiometer contains a spectrometer which breaks apart the wavelengths of light energy between 2000 and 6000 angstroms for detailed study of the molecular species to be found in the hot gas cap.

TELEMETRY

The reentry package contains two radio telemetry systems to insure reception of the measurement data by stations on the earth's surface. One telemeter broadcasts the events as they occur in "real time" and the other broadcasts in delayed time. The latter is accomplished by using a tape recorder which stores 45 seconds worth of data before playback on the broadcast channel. This means that when the reentry package is in the "black out" period caused by the hot gas cap, the measurement data is stored on tape for rebroadcast. After emergence from black out, the real time telemeter is also switched to the tape so that both channels will relay the play back of the heating data. There is time before splash for this recording to be played 5 or 6 times to make it possible for each of the receiving stations to get at least one good copy.

GROUND TRACKING AND DATA ACQUISITION

To be certain of receiving the vital recording of data from the experiment during reentry, the spacecraft is tracked all of the way from the launch pad to the peak of its trajectory and back down to the reentry point. The tracking is accomplished chiefly by use of an on board C-band radar transponder, which transmits a recognition signal to each ground based radar station involved. The tracking network extends from Cape Kennedy, along the West Indies, to Ascension Island.

Radar tracking of the spacecraft allows each of the telemetry stations in the reentry area to beam their receivers in the precise direction necessary to "hear" the spacecraft broadcast the playback data.

The radar tracking also helps a number of stations to aim optical instruments in the precise direction necessary to obtain photographic coverage of the reentry events. Ballistic cameras at Ascension get lapse-time pictures of the fireball against the known star background. The information is used to calculate exact position of the spacecraft a number of times during the reentry phase. Special movie cameras obtain events pictures which indicate the separation times of the several heat shields. Streak cameras give a composite picture of the several fiery paths made by the spacecraft, spent booster and any debris that could be present.

Most important of the optical ground based instruments is the telespectrograph located at Ascension Island. It consists of a 36-inch reflecting telescope having a spectroscope and camera attached on a servo-electric mount all weighing about 22 tons. As a back-up for the spectral radiometer on board the spacecraft, the telespectrograph photographs the spectrum of light from the hot gas cap for identification of its molecular species.

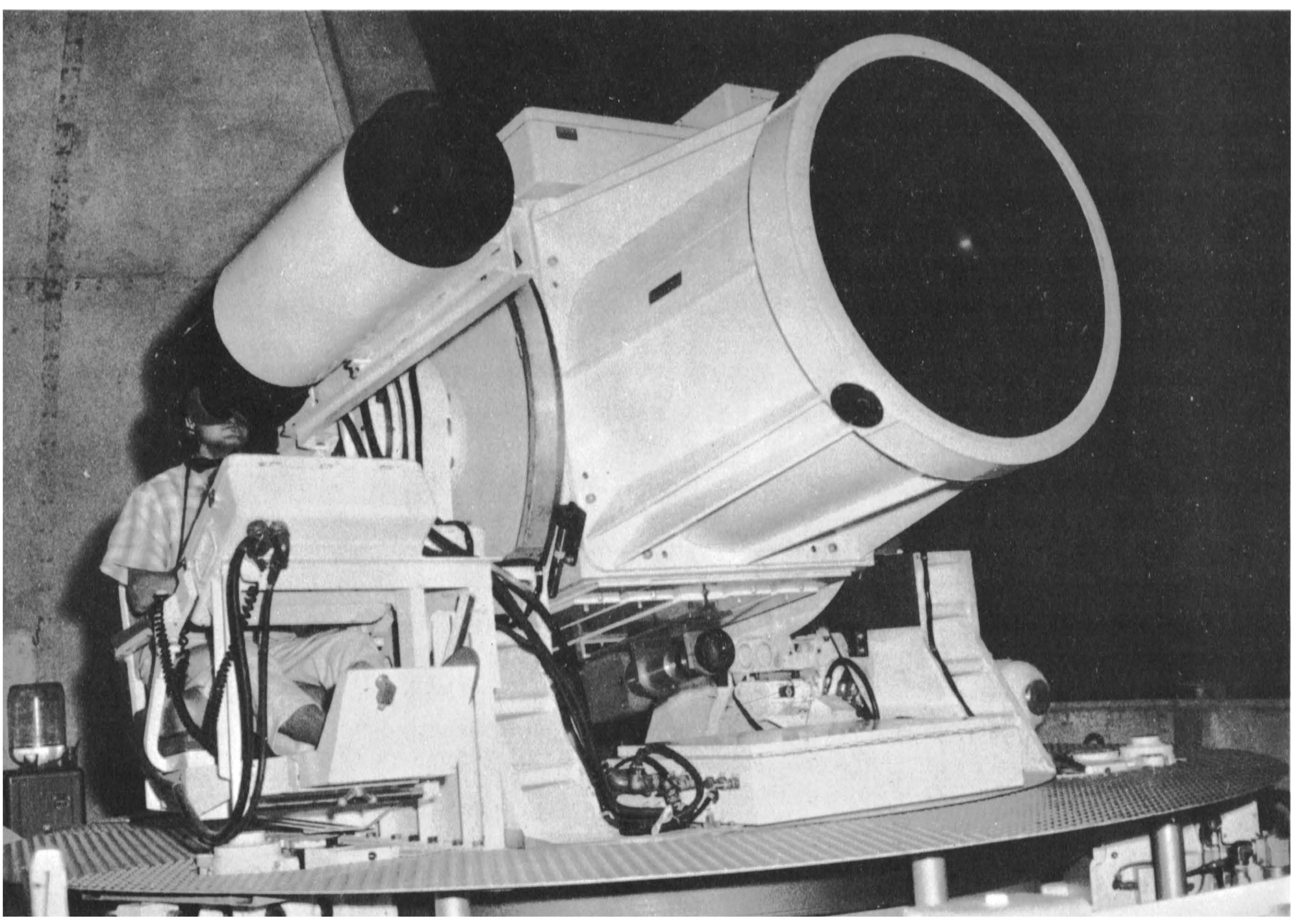
HOW THE FIRE I SPACECRAFT PERFORMED

The Fire I spacecraft was launched at 4:42 p.m. EST on April 14, 1964 from Pad 12 at Cape Kennedy, Fla. The Atlas booster performance was excellent. The spacecraft, including velocity package, separated smoothly and reoriented itself properly. The Antares motor provided additional thrust to reach a velocity of 37,890 feet per second at the start of the reentry phase. The reentry angle was 14.5° below horizontal.

The reentry package performance was very good. Timer functions and heat shield ejections worked properly.

Measurement thermocouples, quartz windows and radiometers performed as expected. All data were recorded on the delay tape recorder. Minor malfunctions that occurred were loss of some of the gyros and a periodic fade-

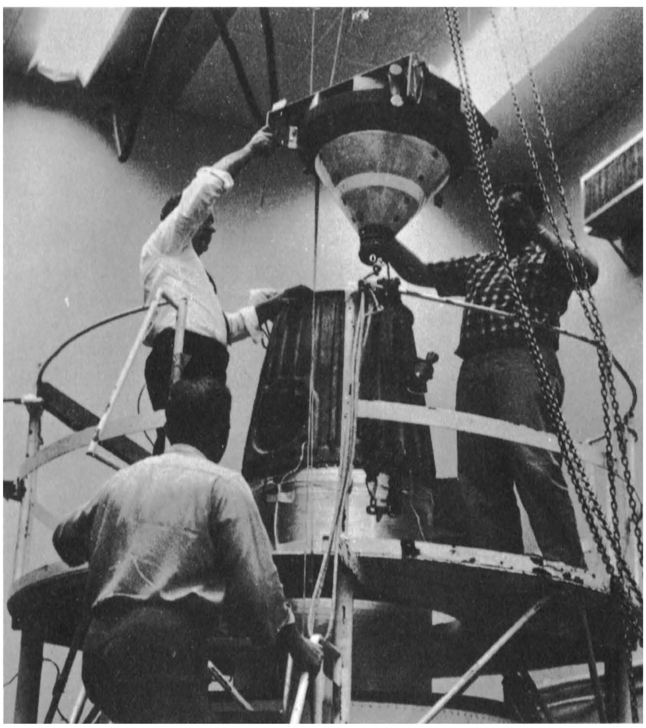
Optical spectrograph on Ascension Island. The instrument is equipped with a 36 inch optical telescope coupled to a very sensitive spectrograph to observe and analyze chemical constituents in the hot gaseous region surrounding the spacecraft during reentry. It is manually operated and is steered in correct position by radar to locate the spacecraft.



out of the delay-time transmitter which resulted in a partial loss of data at the receiving stations. Also, the burned out velocity package apparently passed the reentry package sufficiently close during peak heating to cause a severe wobble in the reentry package.

A substantial amount, 60%, of useful data was obtained. When evaluated by scientists and engineers, the new facts about the reentry heating environment will represent a significant advance in reentry technology and spacecraft design.

Cape Kennedy, Florida—Project Fire reentry spacecraft package being mated to the Antares rocket motor. An Atlas-D launch vehicle will place the payload in a ballistic path. The Antares motor adds the speed needed to drive the reentry payload back into the atmosphere at 25,000 MPH. Prime purpose for the mission is to obtain direct measurements of reentry heating, similar to a reentry after a lunar journey.



DEFINITIONS

(From NASA's Short Glossary of Space Terms)

Ablation: the removal of surface material from a body by vaporization, melting or other process.

Angstrom: a unit of length, used chiefly in expressing short wavelengths. Ten billion angstroms equal one meter.

Ballistic trajectory: the trajectory followed by a body being acted upon only by gravitational forces and resistance of the medium through which it passes.

Infrared: by "infrared radiation" scientists refer to electromagnetic radiation in the wavelength interval from the red end of the visible spectrum on the lower limit to microwaves used in radar on the upper limit.

Ion: an atom or molecularly bound group of atoms having an electric charge, a free electron, or other charged subatomic particle.

Plasma: an electrically conductive gas composed of neutral particles, ionized particles, and free electrons but which taken as a whole is electronically neutral.

Reentry: the event occuring when a spacecraft or other object comes back into the sensible atmosphere after being rocketed to altitudes above the sensible atmosphere; the action involved in this event.

Spectrum: 1. In physics, any series of energies arranged according to wavelength (or frequency); specifically, the series of images produced when a beam of radiant energy, such as sunlight, is dispersed by a prism or a reflecting grating. 2. Short for "electromagnetic spectrum" or for any part of it used for a specific purpose as the "radio spectrum" (10 kilocycles to 300,000 megacycles).

Stage-and-a-half: a liquid-rocket propulsion unit of which only part falls away from the rocket vehicle during flight, as in the case of booster rockets falling away to leave the sustainer engine to consume remaining fuel.

Telemetry: the science of measuring a quantity or quantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured.

Ultraviolet radiation: electromagnetic radiation shorter in wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4000 angstroms.

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