REVIEW OF THE SPACE PROGRAM

MONDAY, FEBRUARY 15, 1960

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C.

The committee met at 2:30 p.m., Hon. Overton Brooks (chairman) presiding.

The CHAIRMAN. The committee will come to order. I have a note here from Mr. Wilcove, our consultant, that Mr. George M. Low, who was due to testify as to the Mercury project, is sick. He will not be present to testify. So we have now Mr. Richard V. Rhode, assistant director of research, and Maj. Victor W. Hammond, Air Force tracking and data acquisition program of NASA. I think that is it.

Mr. FULTON. May I welcome them both, too.

Mr. RHODE. Thank you.

Mr. FULTON. Glad to see you here.

The CHAIRMAN. We are happy to have you, gentlemen. Mr. Rhode has a prepared statement here. I would suggest, Mr. Rhode, that you proceed with your prepared statement.

Mr. RHODE. Thank you, Mr. Chairman.

STATEMENT OF RICHARD V. RHODE, ASSISTANT DIRECTOR OF RESEARCH, NASA

Mr. Chairman and Members of Congress, many problems in applied research and technology must be solved before we can accomplish our future, more advanced space missions. A great deal of knowledge has to be obtained through the research process in order to establish the facts required to make a sound judgment as to the feasibility of any development project. To proceed with development in the absence of such knowledge means that we must pin our hopes on assumptions born of ignorance.

I can assure you, gentlemen, that this can be an extremely costly process.

In order to illustrate our research activity, let us consider a space mission designed for manned circumnavigation of the Moon (fig. 109, p. 662).

I call your attention to the charts on the side wall. I am sorry the physical limitations of the room prevent me from getting up to the charts myself. I have asked Mr. Goranson to handle the charts for me. I am now speaking to the first chart.

This lunar mission entails launch and exit from the atmosphere, space flight, orbiting the Moon and exploration of the lunar surface, and finally, return to Earth, entry into the Earth's atmosphere and landing. The first phase of this or any other mission is launch and exit from the atmosphere (fig. 110, p. 662).

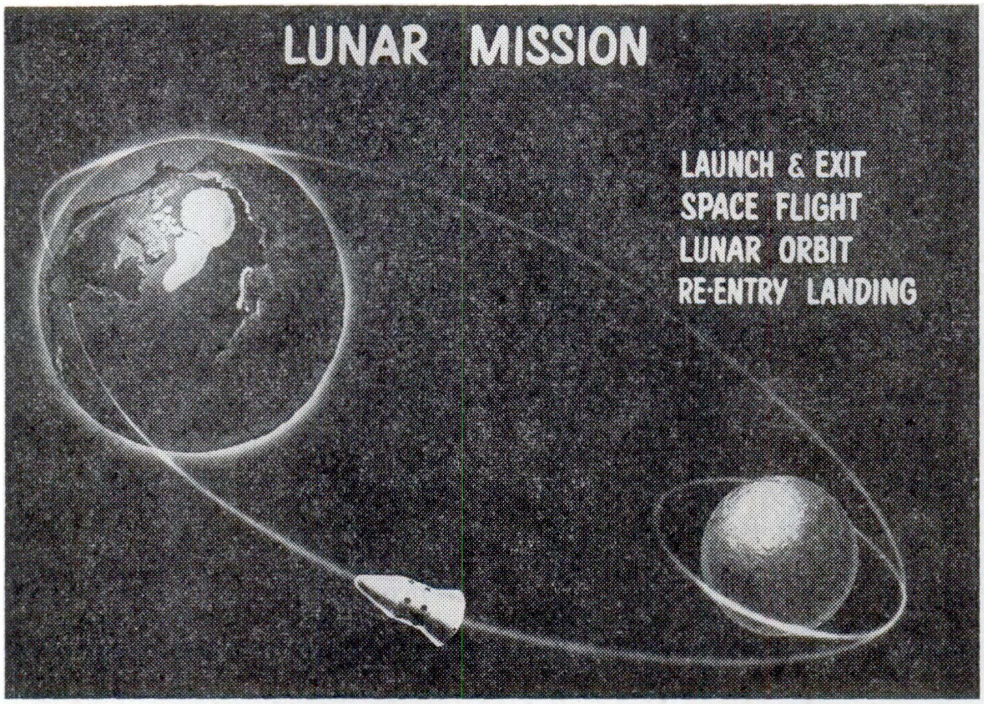

FIGURE 109

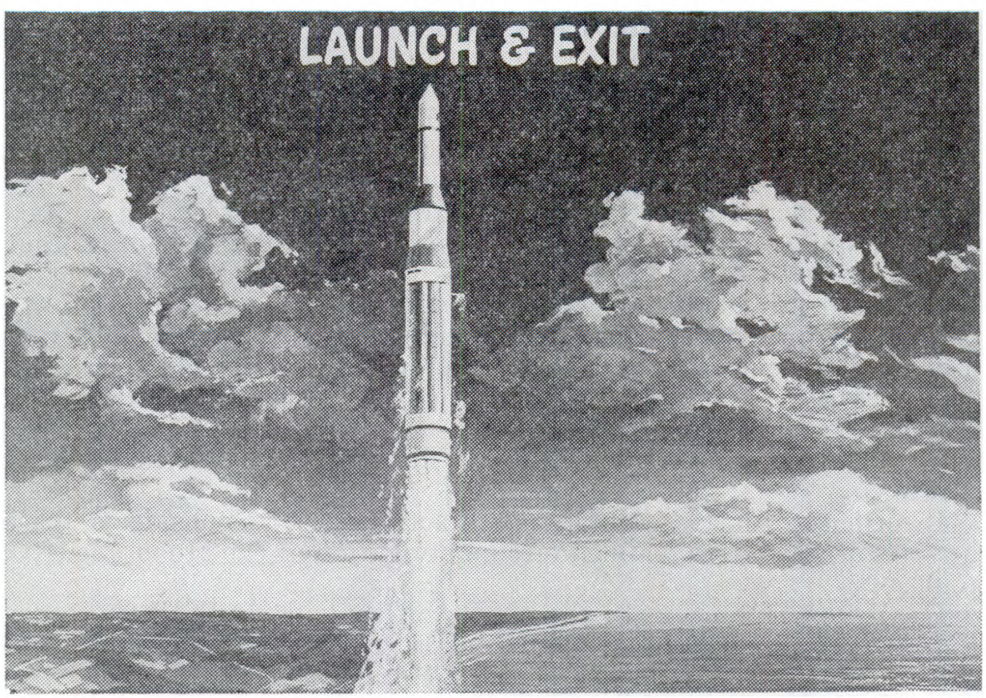

FIGURE 110

LAUNCH AND EXIT

This manned lunar mission will require a large main booster, such as Saturn, with suitable second stage and other boosters, and a payload consisting of a space craft and reentry vehicle together with their contents. Such a system is large and heavy. The length may be 300 feet and the weight a million pounds. Because of the great importance of weight, the structure will be light and flimsy by normal structural standards. On the other hand, the volume and weight of the fuel will be large. The system will be balanced on and accelerated by rocket engines having a total thrust of 1.5 million pounds, and it will be subject not only to the force of thrust along the axis, but also to side forces caused by winds and turbulence and to the corrective sidewise components of thrust from the gimbaled engines.

With such a system, having large weights and forces and a light structure, there is a very difficult problem of vibration or system dynamics.

One aspect of this problem is the interaction between the control system and the flexible structure. This aspect, which is called structural feedback, can be demonstrated by a simple model. The model, you will note, is on my left.

The control system consists of a device sensitive to motion, called a sensor, which transmits a signal to a control element. Here, the sensor is a simple accelerometer and the control element is an electro-magnetic device which causes side forces similar to those caused by the gimbaled engines. When the sensor is moved by hand, the control device also moves and causes the structure to respond.

I should like to interpolate a remark here just so you will understand that the only time that the force representing that from the gimbaled engines goes into action is when the sensor is moved. There is no external force applied. This electro-magnetic device must be regarded as a part of the system.

I call your attention to the fact that the control device is designed to shift the attitude of the machine to exert proper control, and if the machine were a rigid body, it would do so. The thing about it is that the body actually does have structural flexibility so that when the control element seeks to cause the vehicle as a whole to change its path, it does set up those structural deformations which you have just seen.

The CHAIRMAN. Show us where the gimbaled engines would be.

Mr. RHODE. They would normally be at the bottom. If you will refer to the chart you will see the engines at the bottom of the chart with the exhaust gasses coming out of them. These engines are normally mounted on swivel bearings so that the direction of thrust can be changed to cause corrective sidewise forces in the system.

Now, when the sensor is moved by hand, the control device also moves and causes the structure to respond.

In practice, the sensor must, of course, be located somewhere in the system. Suppose we mount it amid-ships and then see to it that the model is disturbed in the same way that it might be disturbed when encountering a gust in flight. Now, you see that it keeps on shaking. The response of the structure is considerable and in practice this much vibration would destroy the vehicle. It does not die out and is therefore called unstable. The shape of the axis as it bends back and forth in the demonstration is typical of a simple bending vibration. Now, let us see what happens when the sensor is placed at the nose [indicating]. You see what a more complex form of vibration is excited. That was the third mode, as we say.

One can readily see that the interaction of a control system and a flexible structure poses a problem.

As previously noted, the system contains a large mass of fuel, and the demonstration has shown that vibratory motions will cause the fuel to slosh around in the tanks, thus setting up additional large and irregular forces. This is one aspect of the problem that gives us considerable trouble, so that we have brought along with us a short movie sequence showing studies being made of fuel sloshing in the laboratory. You will first see a transparent tank with colored fuel reacting to controlled forces. This will be followed by a demonstration of the effectiveness of baffling. The gimbaled engines are simulated by an air jet at the bottom of the tank. Now—can we get that in better focus?

The operator is putting a simple baffle in the tank now. You see that the fuel does not now slosh around particularly, and the motion damps out.

These and other facets of the booster-system dynamics problem are being actively studied at our research centers by both experimental and mathematical techniques. We will have to continue to do so for some time to come, because the problems become both more serious and difficult as the systems become larger.

SPACE FLIGHT

Once the vehicle has been successfully launched into space, many new problems are encountered. Among them are the hazards of the space environment, such as meteoroids, and problems of guidance and attitude control of the spacecraft. Let us consider first the meteoroid problem (fig. 111).

Meteoroids are metallic or stony bodies that travel through space at speeds estimated to range between about 25,000 and 165,000 miles per hour. Many of these meteoroids are very large, such as the one you see in the movie, that caused the craters on the Moon or the one that fell in Arizona centuries ago to create the well known meteor crater there. Others are very small.

Fortunately the large ones are extremely rare. For example, the surface of the Moon has not been visibly changed by these large-scale meteoroid impacts since the invention of the telescope. We don't worry about these large meteoroids any more than you do when you walk down the street.

The small ones, however, are quite frequent in occurrence in space and the probability of an impact by one of them on a space craft becomes quite large. In fact if there were no atmosphere surrounding the earth we would all be likely targets for them.

These small meteoroids may be only a few thousandths of an inch in diameter.

Although very small, they can, because of their tremendous speeds, be very destructive. It has been estimated, for example, that a ball in space made of aluminum about one yard in diameter and having a thickness of .005 inch might be punctured as often as once every ten

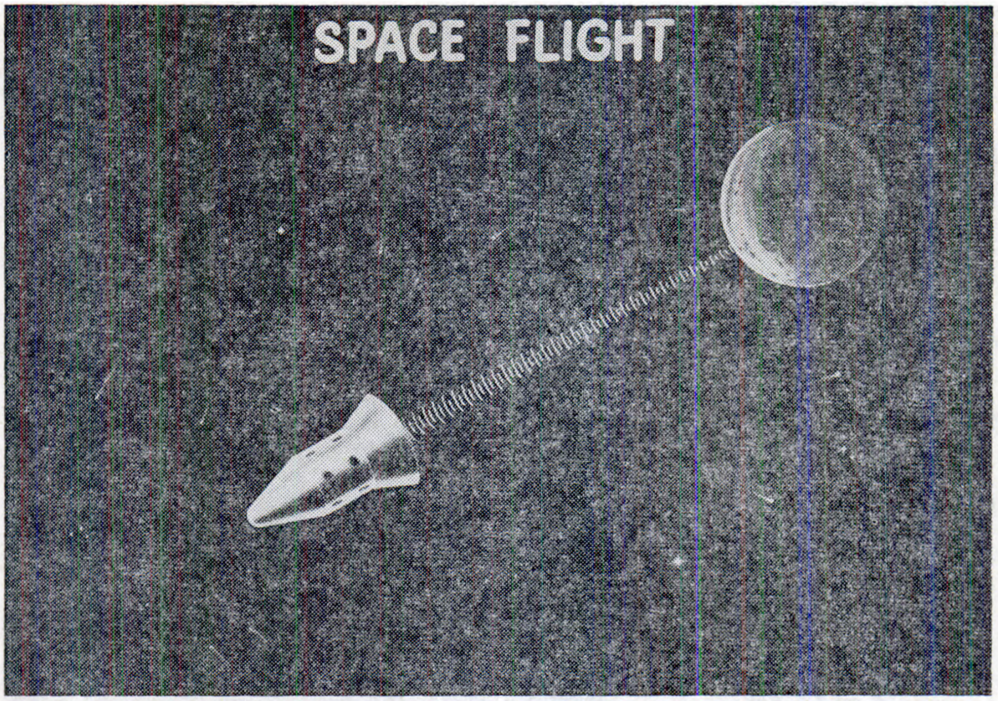

FIGURE 111

hours or twice a day. With ten times this thickness, the ball might be punctured once every 200 days. Obviously, light structures, including tanks and radiators, will not give satisfactory service over a long period of time without some protection against meteoroid strikes.

One way to study this problem is to shoot small particles at high speeds at test specimens and see what happens. We have been doing this for some time.

The photograph shows two high speed helium or light-gas guns developed at our Ames Research Center. Some of you, I understand, have seen them (fig. 112, p. 666).

They can shoot small balls about one-sixteenth of an inch in diameter as fast as 14,000 miles per hour. This speed is much faster than a rifle bullet—a typical military rifle, for example, shoots at about 2,000 miles per hour. We can obtain much useful information from such equipment, because by using relatively large pellets we can obtain the same impact energy as the smaller meteoroids have. Meanwhile, we are studying means for shooting smaller particles at speeds within the meteoroid speed range.

This next chart shows, on the left, the crater made by an actual meteoroid impact on a sounding rocket. It occurred at about 90,000 feet altitude within the atmosphere; consequently, the meteoroid must have been greatly slowed down from its original speed by the atmosphere above this level. The rocket itself was traveling at only about 3,000 miles per hour. The impact was therefore much slower than those we expect to encounter in space. Nevertheless, the incident is of great interest in demonstrating that impacts actually do occur, and in providing a rough comparison with laboratory impacts.

This is a photograph made in an NASA laboratory of an impact crater made by shooting a small steel sphere at a copper target. You

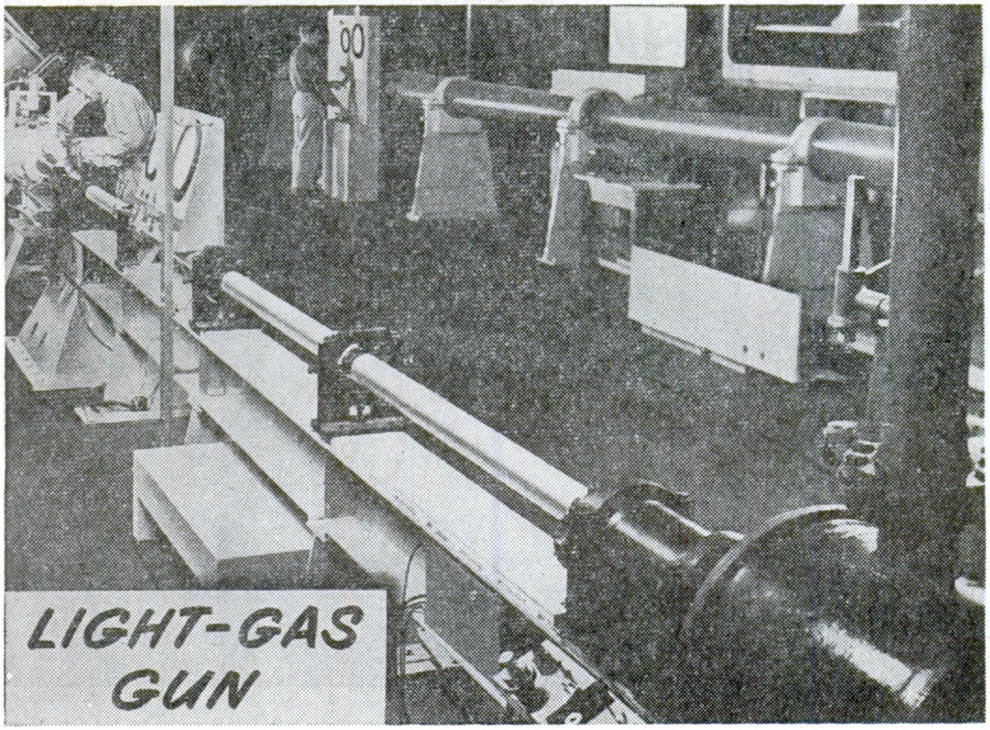

FIGURE 112

have probably seen such pictures before. This comparison simply shows the similarity of the two craters—one made by a micrometeoroid in space—the other by a particle shot from a gun in the laboratory (fig. 113).

I wish to call your attention here that the comparison is between the pockmark on the right and the central crater in the picture on the left. The marks surrounding the central crater were presumably caused by material which had melted or peeled off of the meteoroid proper, as it was coming through the atmosphere. The main body of the meteor hit in the center of that photograph and these peeled-off or melted parts hit around the crater proper.

One of the possible ways of handling the meteoroid threat is to build a light shell or "bumper" around the spacecraft. The thought here is that the particles are going so fast that when they strike the bumper they will disintegrate before striking the underlying structure. An idea of the possible effectiveness of such a bumper is shown in the next chart.

These are results of some studies made with one of the guns shown in the photograph you saw a moment ago.

The figure (fig. 83) shows the speed in miles per hour required to just penetrate the target with $\frac{3}{16}$-inch-diameter Pyrex spheres. We see that a pellet going at 2,000 miles per hour or nearly so will go through a single thick sheet. But if the sheet is split and separated a bit, it takes a speed of 4,000 miles per hour to go through. With four layers, again of the same total weight, we can withstand somewhat greater speed. Now, if we fill the space between the bumper and the second sheet with low-density glass wool, we see that particles going as fast as 7,000 miles per hour will be stopped. These tests simulate

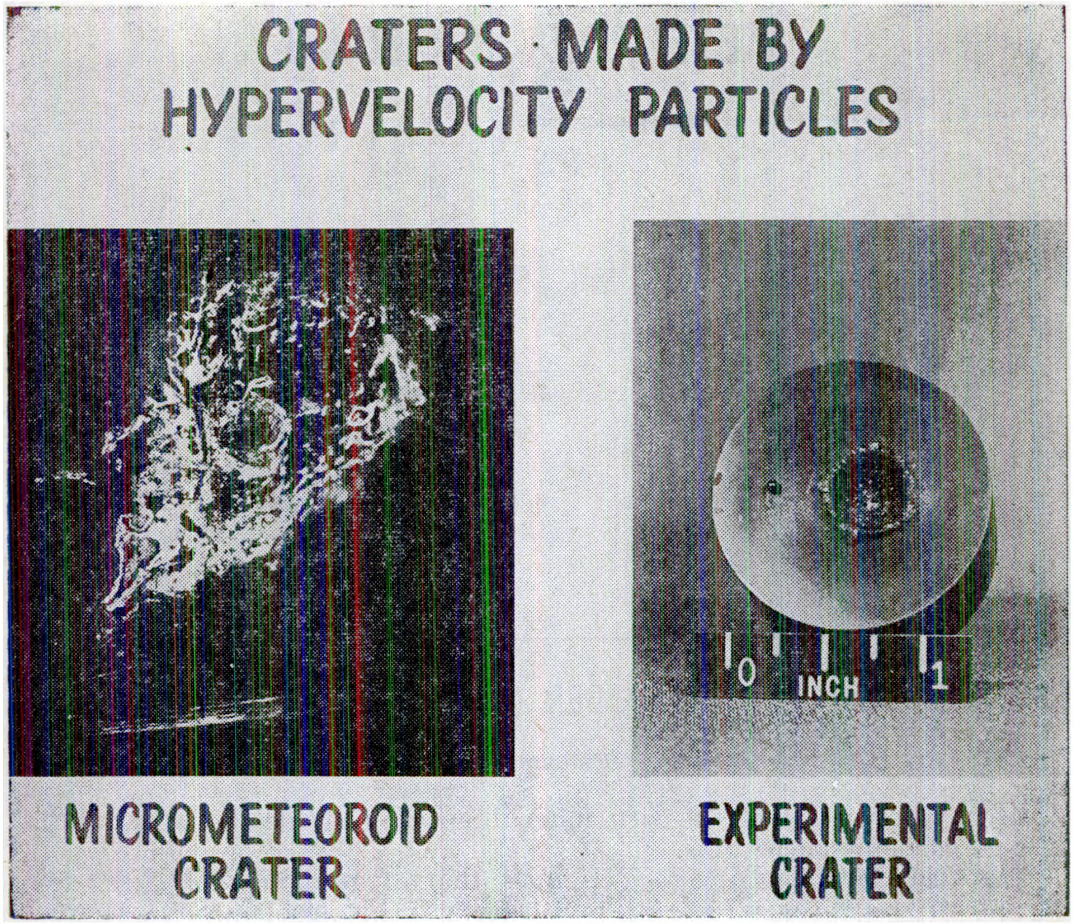

FIGURE 113

what would happen with meteoroids $1/16$ of an inch in diameter at speeds of about 40,000 miles per hour—well within the meteoroid speed range (fig. 114, p. 668).

Now, these results and conclusions I have just shown you are based on laboratory tests, and of necessity contain some assumptions and approximations. For this reason we would like to get some direct and actual data from real meteoroids. To do this, we plan to send up a test satellite this year on one of our first Scouts to test out the theories and laboratory results.

This model before me is a one-fifth scale model of the puncture experiment satellite. These segments of tube that you see here running lengthwise will be made of metal of various thicknesses and will contain gas under pressure. This, incidentally, is a full-sized tube of the kind I am now discussing.

When a tube is punctured by a meteoroid, the gas will leak out and this occurrence will be radioed back to Earth.

There is a pressure sensitive instrument in here that is hooked up with the radio system and the message is transmitted through these antennas. In this way, we will get direct information on how long a structure made of material of different thickness can be expected to last out in space. In the future, we will get more and more

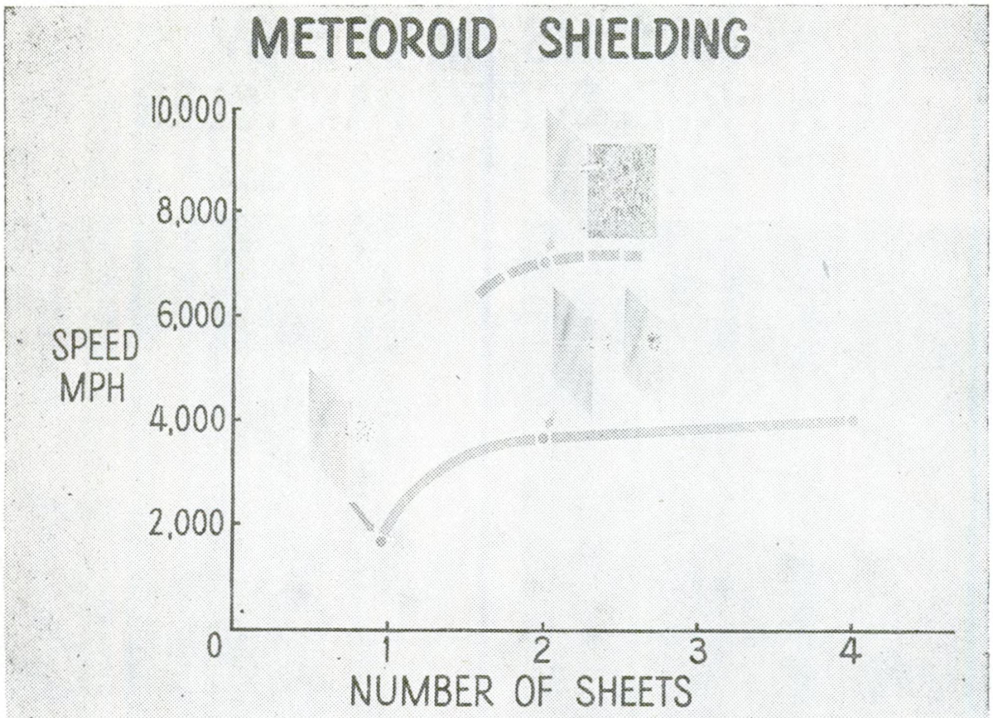

FIGURE 114

direct information of the sort that will enable us to design better and more efficient spacecraft.

Another problem of space flight is that of guidance and attitude control. I shall now review a few aspects of this problem.

Many satellite and other space missions, such as our lunar mission, require that the attitude of the spacecraft be maintained or stabilized (fig. 84). On this next chart are shown some typical requirements of attitude control. Earth satellites might be required either to continue to point toward the center of the Earth or to continue to point toward a fixed object in space (fig. 115).

Note, for example, that the Nimbus satellite, which is the meteorological satellite, always has to point toward the center of the Earth. On the other hand the satellite bearing the astronomical telescope will always have to point toward a fixed object in space. Space probes or spaceships taking navigation fixes must, in general point toward some fixed object in space.

Different missions require different degrees of precision. Earth-oriented communications and meteorological satellites require very little precision—the attitude need be maintained only within about 8° for the former, and within about 1° for the latter. Space-oriented spacecraft however demand a very high degree of precision. Interplanetary navigation, for example, requires that the attitude be stabilized within about 0.005°, and the astronomical satellite must be stabilized to the very fine point of 0.0003°. In order to give you some idea of what this means, 0.0003° is the angle contained between two straight lines starting at a point in this room and spreading only 70 feet apart in San Francisco.

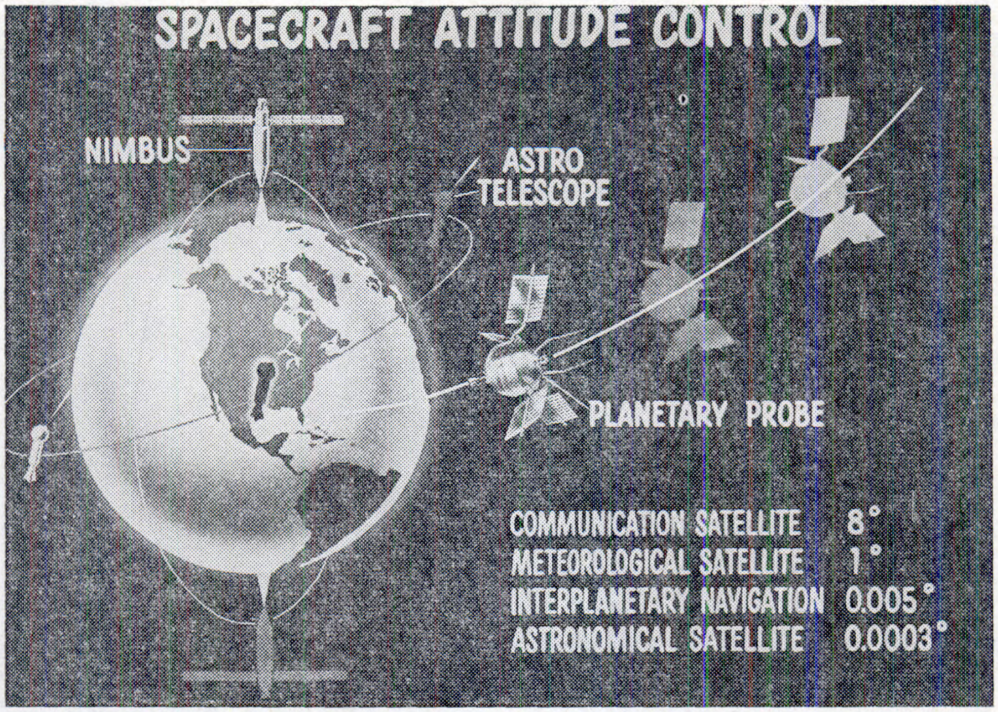

FIGURE 115

Spacecraft stabilization systems may differ in the specific means employed to do the job. All of them, however, must employ mechanisms of one kind or another to perform the required functions. These functions are to sight on some reference point, such as the lunar horizon or a star; to analyze the information from this sighting system or sensor, and finally to activate a suitable control device in order to maintain the proper attitude of the spacecraft.

I have here a simple demonstration model of an attitude control system. The spacecraft is represented by the turntable, which is quite free to rotate just as the spacecraft is free to rotate about any of its three axes in space. The sensor is a simple photoelectric cell. Its signals actuate the control device, which, in this case, is an inertia wheel that operates on the principle of conservation of angular momentum, if I may use a technical term.

Now, you will see that as the turntable is spun slowly the light beam will capture the system and stop its motion and it will continue to follow the light beam no matter where the light beam might be (fig. 116, p. 670).

All of the mechanism for doing this is contained on the turntable. There is no external force applied to cause it to do what you just saw. Now, in order to obtain the required precision, each one of the functional requirements must be subjected to the research process such as indicated by the work going on in the laboratory setup shown on the next chart.

For example, if as is likely, the sensor is a light-sensitive mechanism, its sensitivity and accuracy must be investigated in relation to the wavelengths available in the light source; some of the wavelengths may have to be filtered out. Again, control mechanisms of various

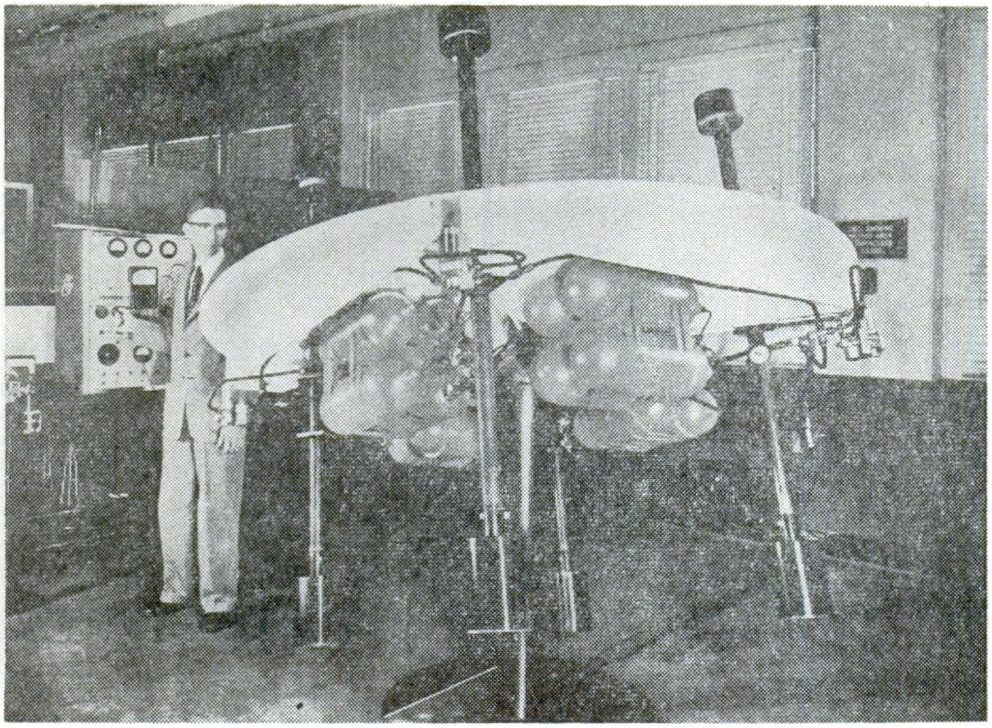

FIGURE 116

types must be investigated to determine the principles best suited to the development of controls having low power requirements and at the same time high positioning accuracy. These and many other problems are being investigated with laboratory equipment such as shown on this chart.

Progress to date indicates that we can achieve an accuracy of three-hundredths of a degree with present laboratory equipment, and that 1½ hundredths of a degree can be achieved before long. Further research is obviously required in order to develop the high accuracies required for space-stabilized systems, such as the five-thousandths of a degree and three-ten thousandths of a degree figures I mentioned earlier.

The third phase of our assumed mission is to circumnavigate the Moon and conduct the necessary exploratory activities. We would expect the men aboard the spacecraft to be taking moving pictures, television pictures, and performing other observations. This gets us into the question of weightlessness and whether men can perform the required duties in a gravity-free environment. As this question of zero g. has been touched on by others and will later be gone into by Mr. Low, I shall not go into it.

Another aspect of lunar exploration (fig. 117) is the matter of sending instruments to the lunar surface and to have them remain intact so that they can transmit information either back to the spacecraft or to Earth. To do so requires ejection of a lunar-landing system (fig. 118) and instrument package from the spacecraft, arresting its forward motion and placing it on the Moon intact, such as is indicated schematically on the chart. In principle, there are several ways

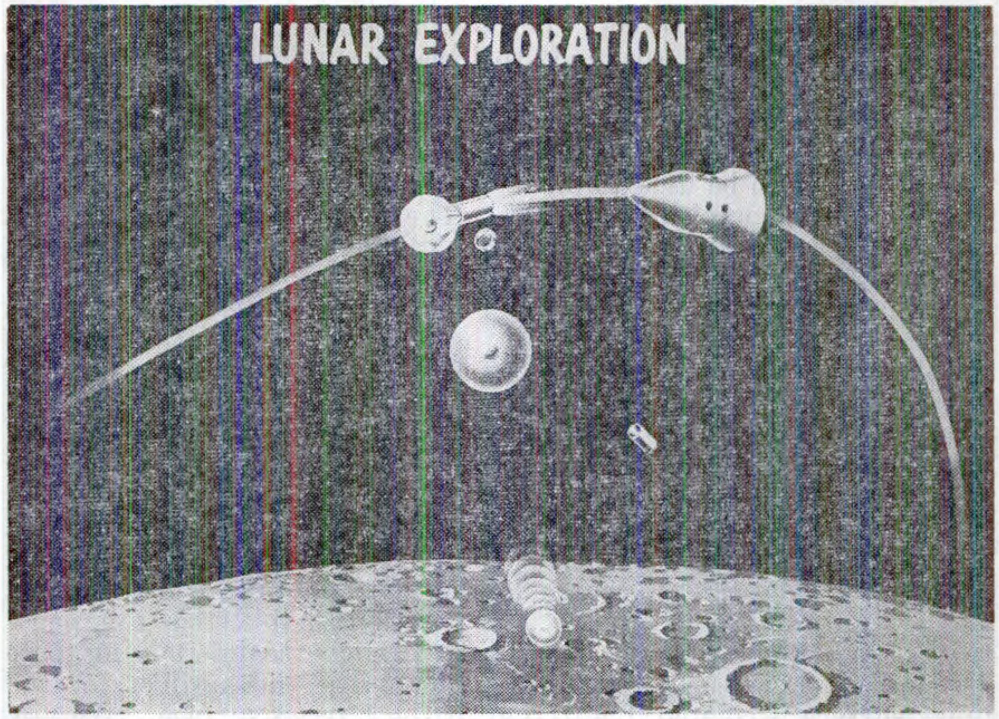

FIGURE 117

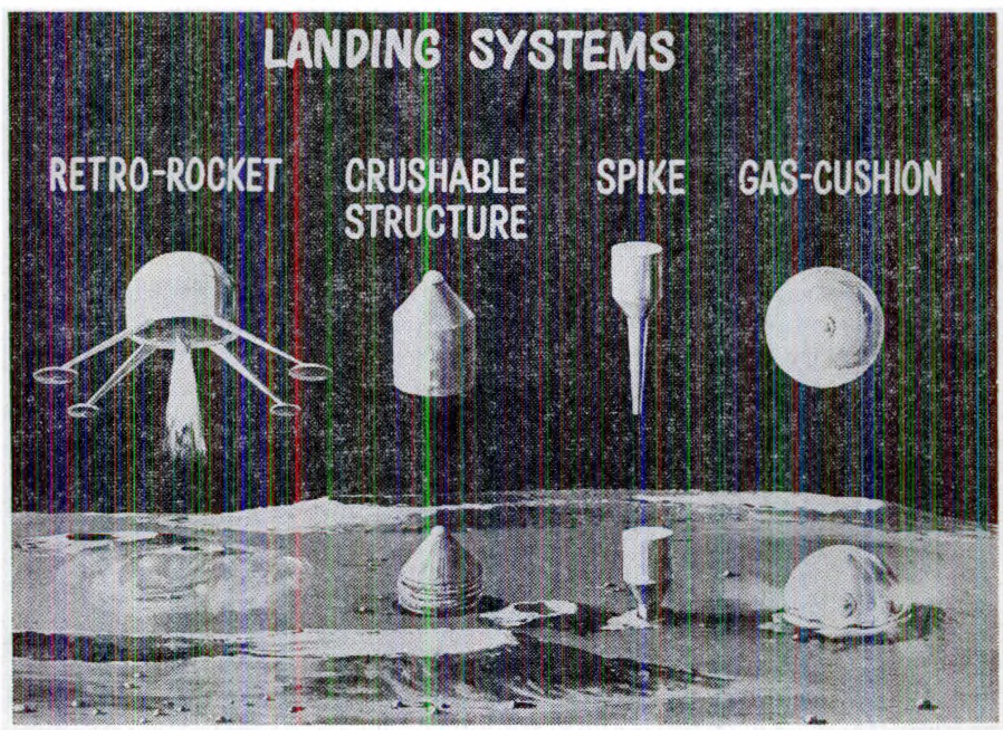

FIGURE 118

in which this can be done. You are all familiar, I am sure, with proposals that have been made to lower a suitable container to the lunar surface by means of retrorockets, such as indicated at the left on this chart. This kind of system permits a soft or easy landing, even in the absence of a lunar atmosphere, and is the kind of system that will have to be used to place a man or men safely on the Moon. However, it is complex and heavy. The research problems involved are common to other aspects of space flight—viz: lightweight structures, stabilization and control, guidance, throttleable rockets, et cetera.

Because of the complexity of the soft-landing system, we seek simple ways to land instrument packages on the Moon. Instruments can be made rugged enough to withstand impact accelerations higher than those suitable for man. Consequently, we can consider systems that land at rather high speeds, and therefore, do not require all of the guidance, control, and fuel required of a soft-landing system. These simpler systems do, however, require means for absorbing the shock of impact.

Some of the means to which I allude are now being investigated and are indicated on the chart. They are crushable structure, penetration spikes, and pneumatic cushions. Of course, in studying these systems, we must at the moment assume that the hardness of the lunar surface is comparable to that of the Earth's surface. We are, however, developing techniques for measuring the hardness of the lunar surface, so that when we send a rocket to the Moon we will be able to obtain this essential information. Meanwhile, studies of the energy-absorbing schemes are proceeding.

The crushable-structure concept employs lightweight metal structure, such as this honeycomb sample that I have here. This piece of material weighs about 2 ounces and it has a capability of absorbing about 600 foot-pounds of energy, which would be somewhere in the neighborhood of a 50-pound mass striking at a speed of 30 feet per second. After it does its job it looks like this, and in the interim it has absorbed energy by deformation of the material.

The penetration spike is a very simple device, but it works only when the surface of the ground is neither too hard nor too soft. It absorbs energy by displacing and compressing the material into which it penetrates, just as a nail absorbs the energy of a hammer blow. Both the crushable structure and spike concepts require proper orientation with respect to the impacted surface. The gas cushion, however, does not have this limitation. It is therefore, the simplest of all systems although requiring more research to understand how to design it. In the case of the gas cushion, the instrument package is suspended in the center by numerous radial cords, which, unfortunately, are very difficult to see in that sketch.

The system falls freely in the lunar gravity field because there is no atmosphere. Upon impact the cushion compresses until the instrument package is brought to rest on the impacted surface. At this instant, the bag is split to avoid rebound. Energy is absorbed by compression of the gas, by shock waves generated in the gas, and by distortion of the bag skin. Gas cushions suitable for landing instrument packages on the moon might range between 5 and 25 feet or more in diameter, depending on the orbital height and the size and weight of the instrument package.

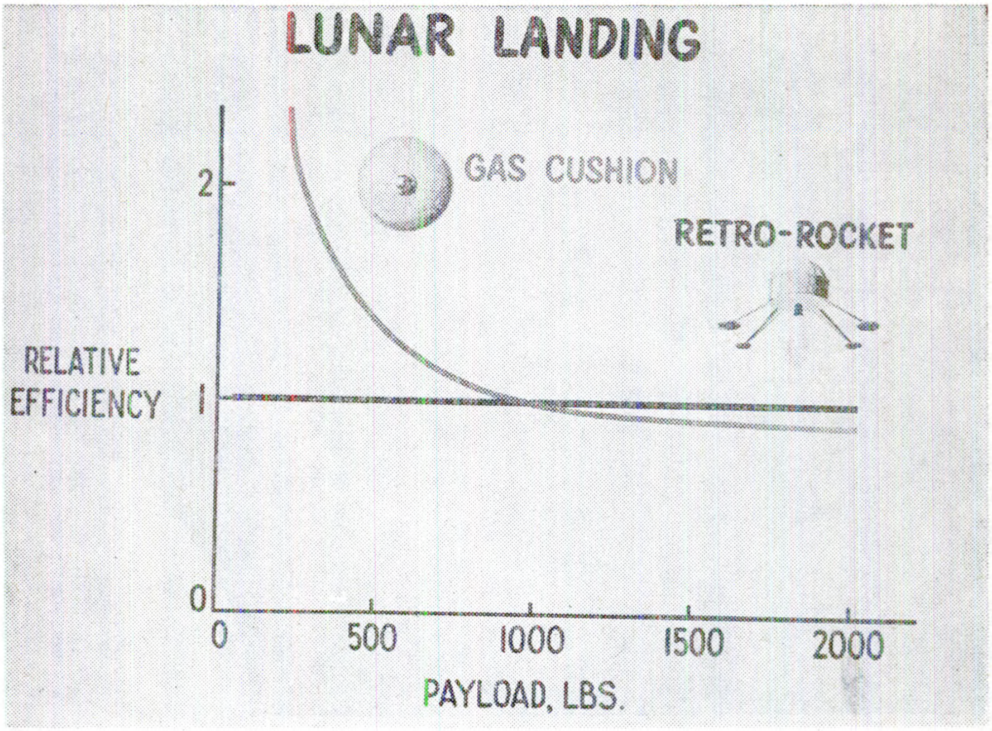

FIGURE 119

Because of the attractive simplicity of the gas cushion, it is undergoing extensive investigation in our research centers. The next chart shows how its efficiency compares with that of the soft-landing retrorocket system (fig. 119). Here, the efficiency of the gas cushion relative to the retrorocket system is shown plotted against payload weight. By payload here we now mean only the instrument package carried by either landing system. In both cases the necessary auxiliary control and guidance systems have been taken into account. As you can see, the gas cushion is superior to the soft-landing retrorocket system at the smaller payload weights especially in the very small sizes. At the higher payload weights, the choice between the two systems becomes small and the retrorocket becomes superior. Even so, the gas cushion might still be used because of its greater simplicity and reliability.

Now, before we are ready for a manned mission to the Moon we shall, of course, be sending unmanned spacecraft there. I have here a model of a spacecraft intended for lunar exploratory purposes. It is currently under development by the Jet Propulsion Laboratory. This spacecraft will weigh about 700 pounds and is intended to be launched in 1961, I think, for the first time by the Atlas Agena-B. The two folding vanes are solar energy collectors. The dish-type antenna, here, is intended to transmit and receive signals to and from the earth. The main body of this spacecraft contains attitude control and navigation equipment, instruments, radio, et cetera. At the top is a capsule which in due course of time will become detached from the vehicle and make a semisoft landing on the Moon. This is the retrorocket and these are penetration spikes. The main space craft

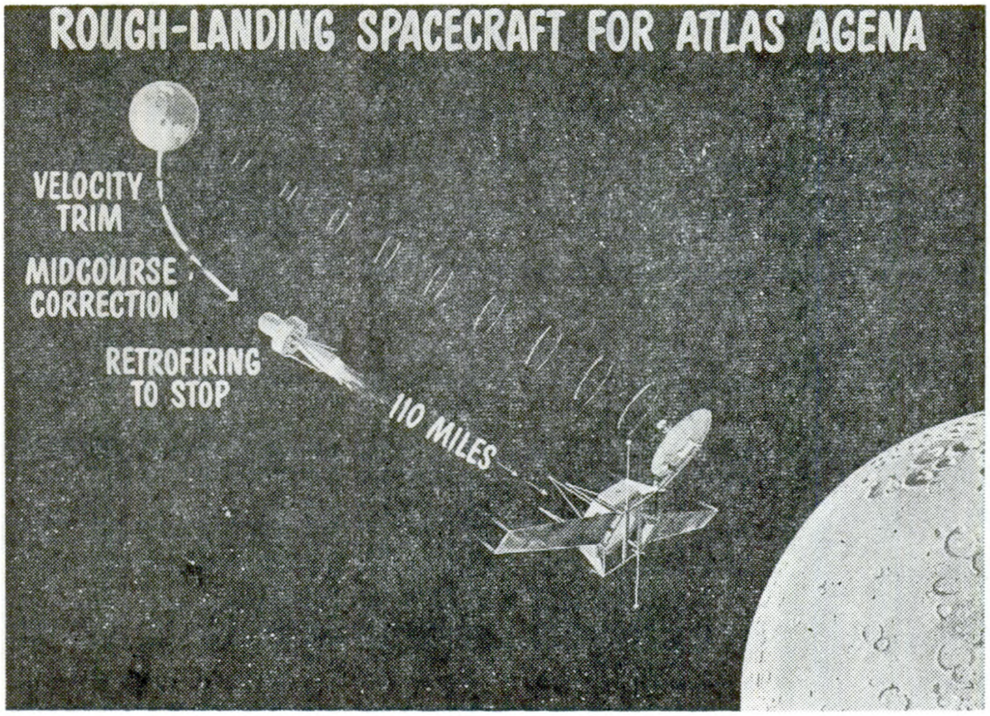

FIGURE 120

will crash. Now, we have a chart (fig. 120) on this, too, which shows the sequence of events. During the early phases of the flight, as you will see from the chart, there has to be injection guidance and midcourse guidance exerted to put the thing on its way, and when it gets to about 110 miles from the lunar surface the retrorockets fire in order to stop the motion of the capsule. The main spacecraft, as I said, goes on its way and just crashes and is destroyed on the lunar surface. The small capsule, of course, finally lands on the Moon, its impact energy is absorbed by the penetration spikes and it goes into operation obtaining data and transmitting them by radio back to the Earth.

For truly soft landings on the Moon we must wait for the larger rockets such as Saturn. Soft landing systems for both of these vehicles are under study. I have some models of those that are under study. In case any of you might be interested in them later I will describe them, but as they are just in the study or imagination stage at the present time, I shall not describe them as I have the Agena spacecraft which is currently under development and actually funded.

The final phase of a manned lunar circumnavigation mission is return to Earth, reentry (fig. 121) into the Earth's atmosphere and landing. The space-flight problems on the return trip are no different from those on the outbound trip, with the possible exception that navigational accuracy is more critical. The problem of reentry is, however, peculiar to this phase and is a very serious one. As you know by now, there are two basic schemes for accomplishing reentry: (1) The ballistic method with a nonlifting capsule, and (2) the winged or lifting method.

Both of these methods have advantages and disadvantages. The ballistic capsule is much simpler than the lifting system and is there-

FIGURE 121

fore suitable for a first step such as Project Mercury. It has the disadvantage, however, of imposing very high g. loads when reentering at higher-than-earth orbiting speeds; it also lacks operational flexibility and requires a large landing area such as the Atlantic Ocean and an extensive retrieval operation. For these reasons, lifting capsule and winged reentry vehicles are under study.

The lifting vehicle, which overcomes the disadvantages of the ballistic capsule, is more complex and is subject to higher heat loads and temperatures. Here is a photograph (fig. 122, p. 676) of a lifting vehicle structure under test at our Langley Research Center. The structure is the triangular object in the middle. The beams at the lower part of the photograph are loading devices for imposing the structural loads on the structure and the heating device is the battery of very hot lamps shown at the top, lifted out of position. Normally, during the test that battery of lamps comes down in close proximity to the skin of the model.

The next chart gives an idea of where we stand today with respect to our ability to develop and build winged reentry vehicles. This current ability has been made possible by our past research investigations, such as that indicated by the photograph shown a moment ago.

The chart (fig. 123, p. 677) shows temperature in °F. plotted against a time scale of calendar years. The upper curve labeled "Reentry temperature" shows, by its downward trend, as it moves toward the right, how the state of the art in aerodynamics, as related to the heating problem, has improved over the past few years. It represents the structural temperatures that would have been obtained during reentry at satellite speed with the best aerodynamic configurations we knew how to build at the different periods of time. With the X-15 configuration in

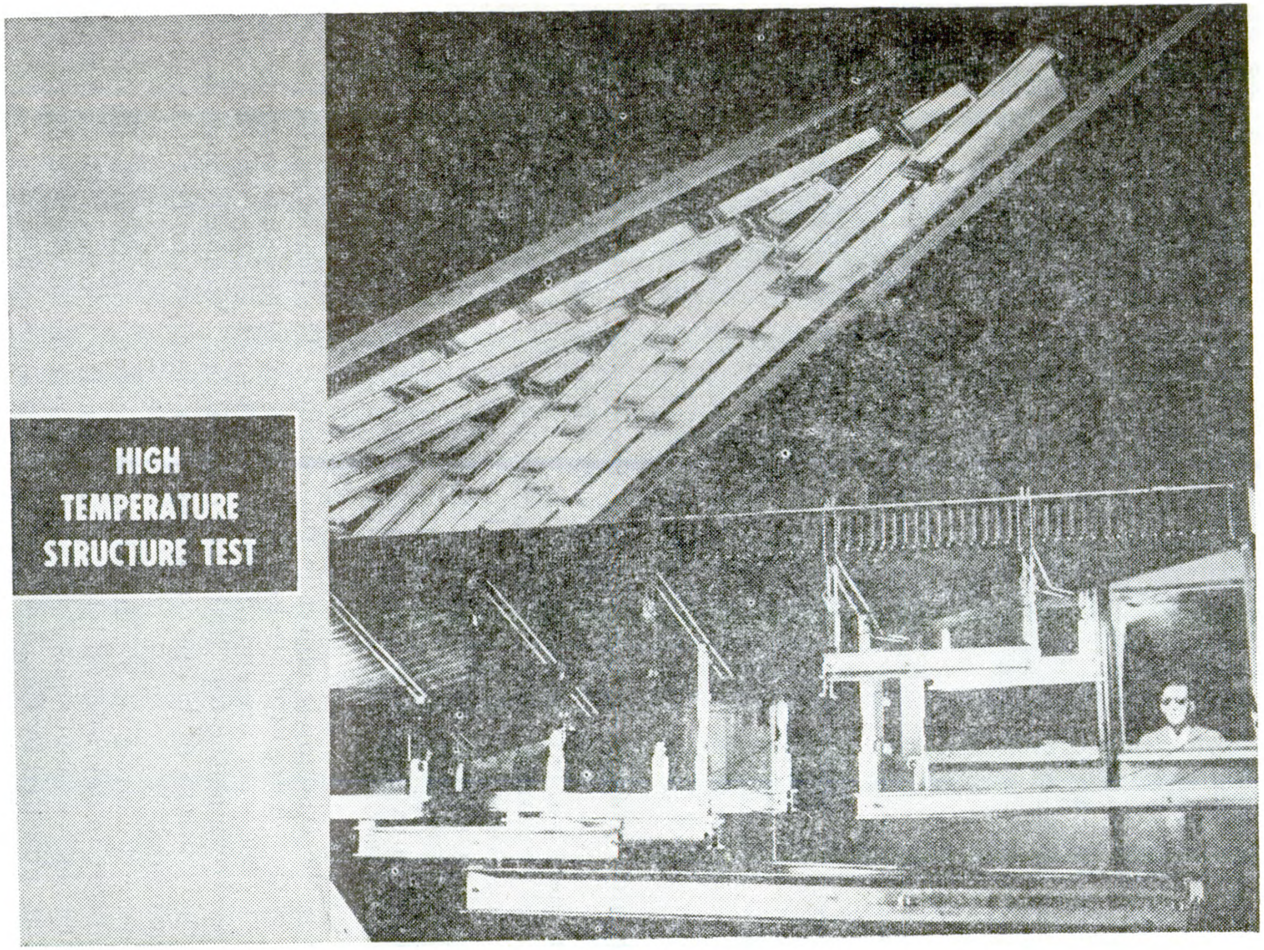

FIGURE 122

1955, for example, the temperature of the structure during reentry at satellite speed would have been something over 5,000° F. As time and research progressed, we learned how to reduce the heat load, and therefore, the structural temperatures, by changes in the aerodynamic configuration. Sharply swept-back arrow-shaped wings, blunt leading edges and operation at high angles of attack were the key aerodynamic features resulting in the reduced temperatures indicated on this chart.

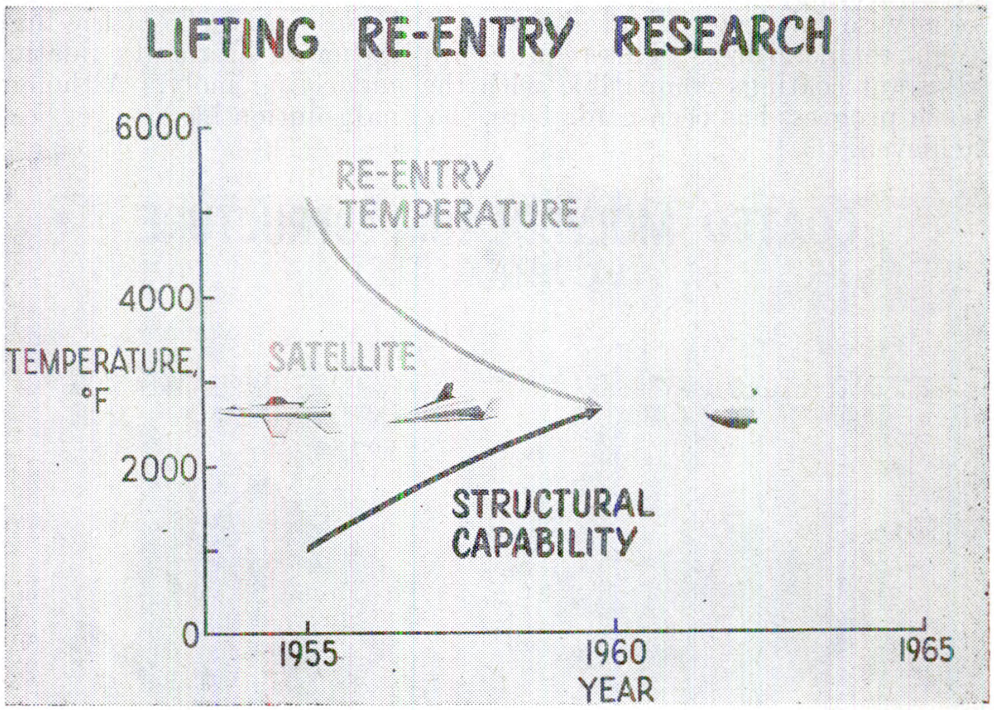

FIGURE 123

In a similar way, the lower curve shows by its rising trend how the state of the art in structures and materials has improved. This curve represents the temperatures that could have been withstood by structures that we could have built at each period of time shown on the chart. The X–15 structure, which we knew how to build in 1955, can withstand a temperature somewhat greater than 1,000° F. as shown at the left end of the lower curve. Obviously, the wide gap between the two curves in 1955 indicates that we were not ready then to build winged vehicles for reentry at satellite speed. The X–15 is not that fast.

A short time ago the two curves came together, so that now the development of a winged or lifting vehicle for reentry from satellite speeds is just barely possible. We have in essence a crude solution to this problem which makes possible the construction of a flight research type of vehicle such as Dyna-Soar or the lifting capsule, such as you will hear later about from Mr. Low.

Our lunar mission will require considerably more research, as the curves on this next chart indicate. Reentry from a lunar mission is made at substantially greater than satellite speed and the heat loads are, therefore, much higher. Unfortunately, it does not appear at present that the reduction in heat input resulting from improvements in aerodynamic shape will continue at the same rate as in the past. We must, therefore, look primarily to improvements in structure and materials to solve this problem at some indefinite time in the future.

Some progress is being made in this area, for example, with molybdenum. Molybdenum, or moly, as we say, because it is much easier to say, has a high melting point and is attractive for high-temperature structural applications, provided that we can learn how to weld it or otherwise fabricate it and also keep it from burning up at the high flight temperatures. This requires application of heat and oxidation resistant coatings compatible with the underlying moly. Although some progress has been made here, the final solution has not yet been achieved.

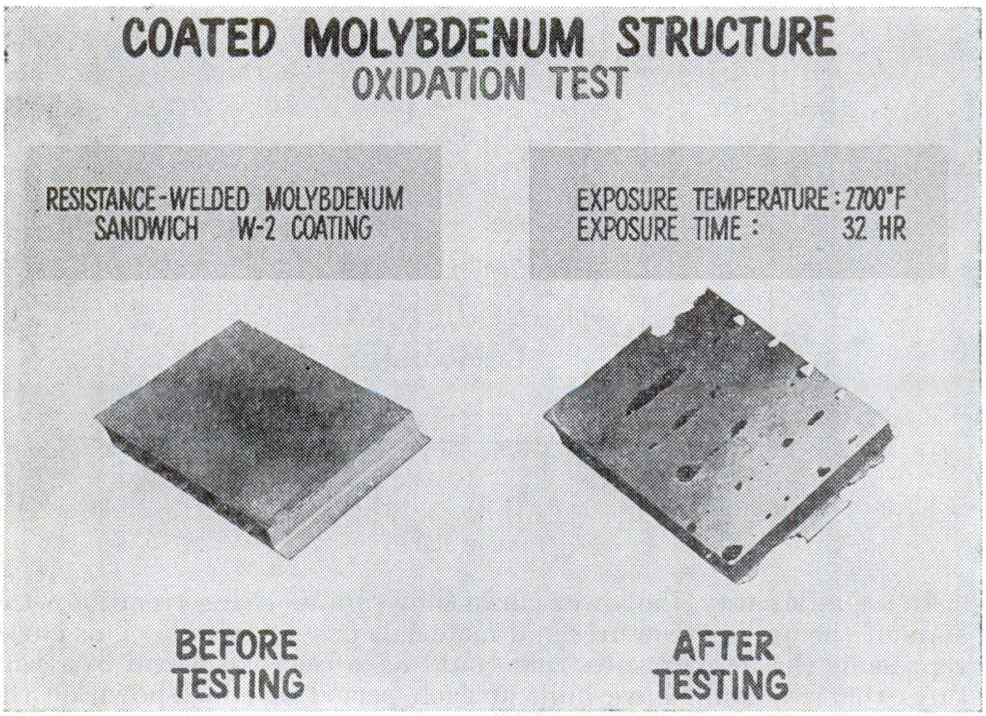

FIGURE 124

This next chart (fig. 124) shows two structural "sandwich" specimens made of molybdenum sheet and coated with a commercially available product. The fact that these specimens were made at all indicates that progress has been made in learning how to fabricate the material. Our laboratory people are quite proud of that specimen that you see at the left for this reason—incidentally, I have that specimen here in my hand if you would care to examine it.

The specimen on the left has not been tested. The one on the right has been subjected to a temperature of 2,700° F. in air. Note that on this heated sample the coating has remained intact except near the welds, so it is fairly obvious, I think, that we have something more to learn about how to keep these things from burning up, before we would wish to put men in a winged reentry vehicle from a lunar mission.

To conclude, gentlemen, I have tried to show you something of our advanced spacecraft research and technology and its meaning. This activity covers a wide variety of problems relating to launch and exit, space flight, lunar and planetary exploration and reentry into the earth's atmosphere. Current developments are pushing the present state of the art, but we are confident that our research activity will point the way toward safe, reliable and reasonably economical space flight.

Thank you.

The CHAIRMAN. Thank you very much, Mr. Rhode. Now, we have Maj. Victor W. Hammond, Air Force, tracking and data acquisition program, from NASA.

STATEMENT OF MAJ. VICTOR HAMMOND, TECHNICAL ASSISTANT TO ASSISTANT DIRECTOR OF SPACE FLIGHT OPERATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. HORNER. Mr. Chairman, Major Hammond does not have a prepared statement. He is going to talk with the assistance of some charts here at the right.

The CHAIRMAN. All right. He can proceed as he wishes to before the committee.

Mr. HECHLER. Was the witness sworn?

The CHAIRMAN. This is not a part of the other hearing.

Major HAMMOND. Mr. Chairman and members of the committee, you have heard a good deal during the NASA testimony relating to space vehicles, trips to the planets, various satellite missions, application satellites and tomorrow you will hear Mr. Low on the manned space flight program, Mercury.

However, without ground support instrumentation, in other words, the instruments that track and derive data from these various endeavors into the exploration of space, these missions that you heard so much about simply could not be accomplished.

My subject then is ground support instrumentation. I plan to give you a bit of background, to begin with, so that we will all be talking in the same language.

Secondly, I will give you a short operational example of one of our tracking systems, namely the minitrack system in actual operation, and thirdly, a progress and planning report on our various tracking and data acquisition networks.

First of all, those of us in the instrumentation business are confronted with four basic missions: The vertical probe, the satellite, and by this I mean the Earth satellite class of vehicle, the manned satellite, namely the Mercury, and the deep space probes (fig. 125, p. 680).

Now, these missions manifest themselves as problems in the way that we have to set up instruments to collect data from the various different types of missions.

First the vertical probe. The majority of these type of NASA missions are launched from Wallops Island, on the coast of Virginia. This is essentially an up and down type of trajectory, and therefore, we group our instruments around the base of the launcher and simply derive the information as the vehicle flies, recording it for later analysis. There is no hurry about analyzing the data since this is

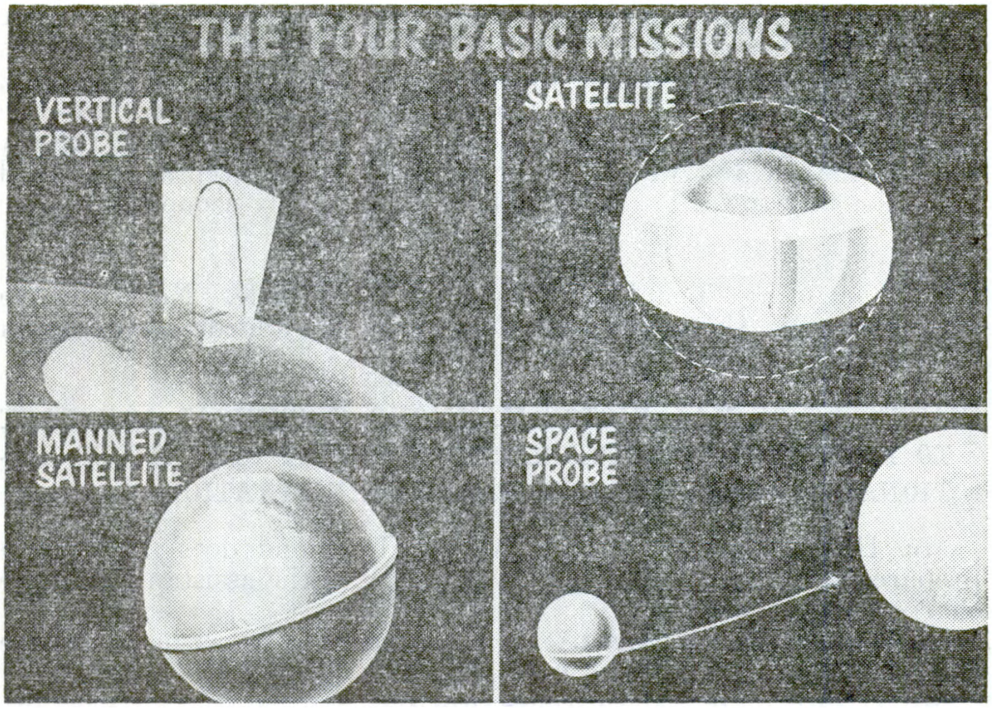

FIGURE 125

essentially a one-shot mission, it goes up and comes back. This is not so with the satellite.

The satellite, as it flies in its orbit around the Earth, its movements, plus the Earth's movements, create the effect that the satellite over a period of time and by time, I mean weeks, months and years, creates the effect that that satellite is flying and actually configuring a large band around the Earth.

Now, if we follow the same philosophy as with the vertical probe, one would think that we must keep the satellite under surveillance at all times. This is not so. We only take routine observations as it passes a single segment.

You will find, when I get to the minitrack network (fig. 126) on a map, that the instruments, themselves, are essentially deployed in a line. This allows us to have adequate contacts with the satellite, yet have only what we could call, an economical number of stations to actually do the job.

This type of data is classed as nonperishable, since there is no hurry to collect it and process it.

Now, this is quite different in the case of the manned satellite. The manned satellite, of course, will only be up its entire mission—the entire mission of Mercury must be successfully completed in about 4½ to 5 hours. Therefore, that data is quite perishable. The data must be taken, sent back to computers, and processed in real time. Now the term "real time" simply means as it is occurring.

Now the space probe, of course, is characterized by extremely long distance data links, hundreds of thousands of miles. This is why you will then see the space probe instrumentation consisting of such huge antennas as you see here in the model.

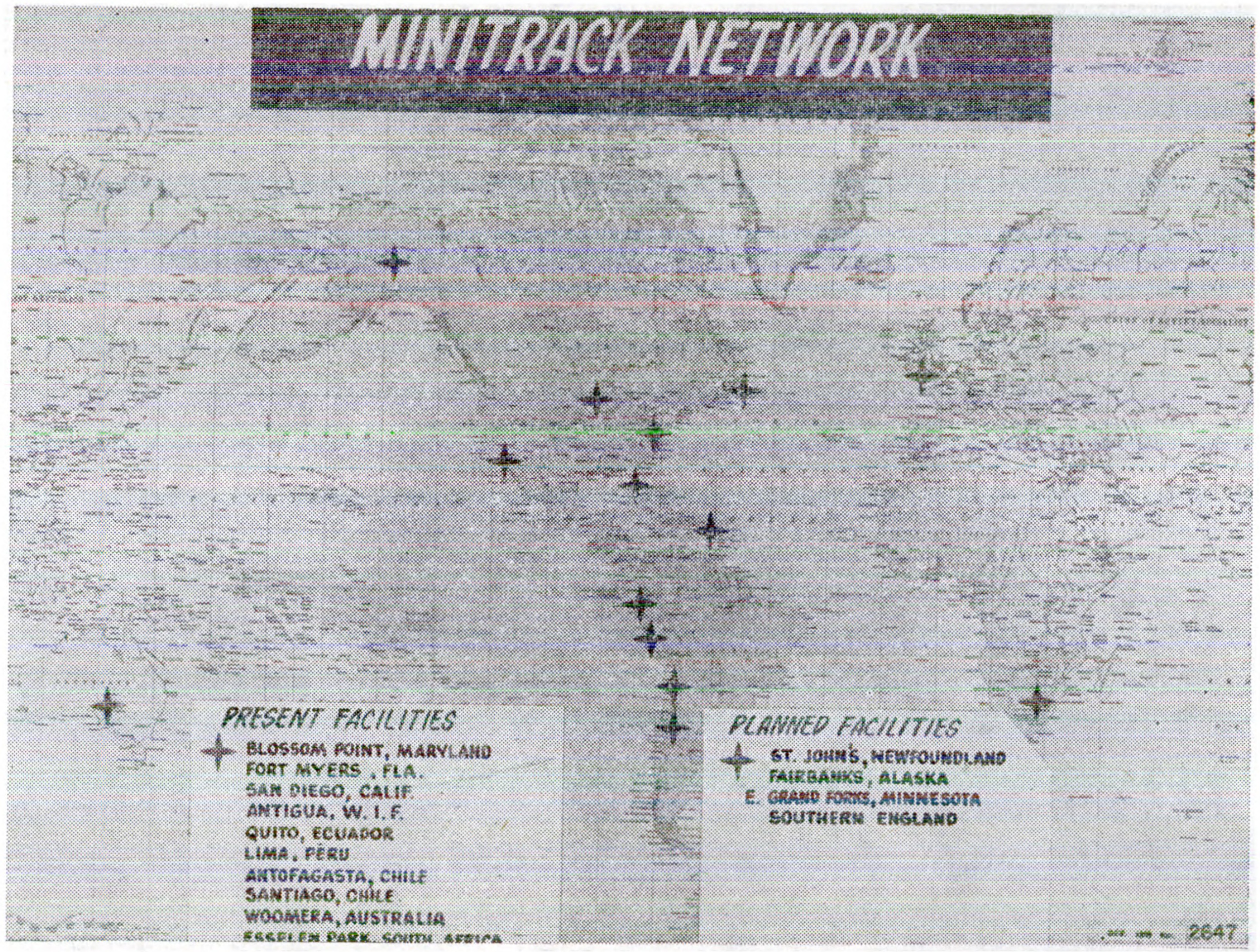
MINITRACK NETWORK
PRESENT FACILITIES
BLOSSOM POINT, MARYLAND
FORT MYERS , FLA.
SAN DIEGO, CALIF.
ANTIGUA, W. I. F.
QUITO, ECUADOR
LIMA, PERU
ANTOFAGASTA, CHILE
SANTIAGO, CHILE
WOOMERA, AUSTRALIA
PLANNED FACILITIES
ST. JOHN'S, NEWFOUNDLAND
FAIRBANKS, ALASKA
E. GRAND FORKS, MINNESOTA
SOUTHERN ENGLAND
2647

FIGURE 126

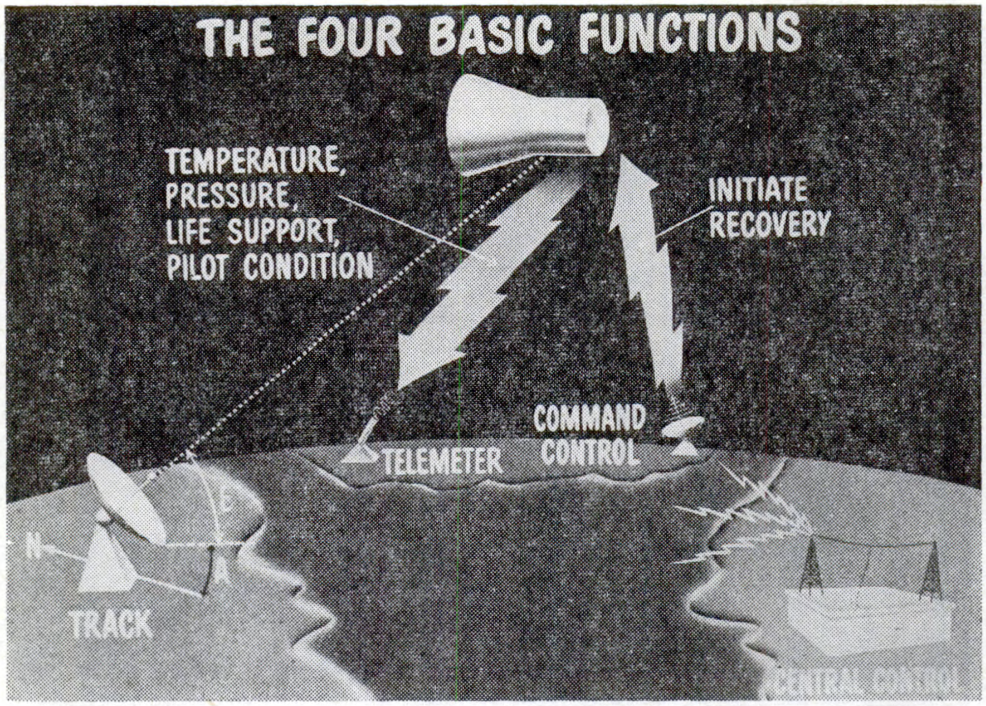

FIGURE 127

Now, on each one of these missions there are four things to be done (fig. 127). They are done differently in each case. First of all we must know where the vehicle is in space. This is the function of tracking.

Secondly, we must know what is going on inside of the vehicle. This is the function of telemetering. This is the device that reads the various physical perameters. The soundings that the scientific instruments are taking while they are actually in orbit or during a probe trajectory.

Third, it becomes necessary to give instructions to the vehicle. This is known as command control. And in the case shown in the chart here, for example, to initiate recovery we would command this to be done from the ground command control transmitters.

Now then, these three functions are tied together in the integrating element of central control. This is where now the data as it is taken, is sent to the central control, processed in computers and the entire net, the administrative tie-together, the entire integration of this into an operable network, is then—this function takes place in the central control.

Now, I would like to give you a very short example here of the times that were involved in Vanguard III that was launched last September. To do that, I will use a map showing the minitrack network. There is one technicality here. You will see I refer to a station at Grand Turk Island, which is down in the Atlantic Missile Range. That you will not—you will not see a mark on the map for that station since it has been deactivated at the completion of the Vanguard program.

The vehicle was launched at an arbitrary time "T", and the Grand Turk location received certain readings at plus 3 minutes. This infor-

OPERATIONAL EXAMPLE

(MINITRACK TRACKING OF VANGUARD III, 1959 ETA)

TIME "T" (0520Z)	LIFT-OFF	T+1HR 27MIN	ANTIGUA MEASURED DATA
T+3MIN	GRAND TURK, QUICK LOOK	T+2HR 15MIN	SAN DIEGO, QUICK LOOK
T+5MIN	ANTIGUA, QUICK LOOK	T+2HR 25MIN	QUITO, QUICK LOOK
T+47MIN	JOHANNESBURG, QUICK LOOK	T+3HR 5MIN	JOHANNESBURG, (2nd PASS)
T+1HR 18MIN	GRAND TURK, MEASURED DATA	T+4HR 40MIN	QUITO & LIMA, (2nd PASS)
T+1HR 22MIN	WOOMERA, QUICK LOOK	T+8HR 50MIN (1410Z)	CONTROL CENTER ISSUES FIRST ELEMENTS

FIGURE 128

mation was sent back to central control here in Washington. Now the same information takes place at Antigua Island, 2 minutes later. Antigua is this location right here [indicating fig. 128].

This quick-look information—I want to differentiate between quick-look and measured data that you will see coming up later. The station personnel are only confirming that the satellite did, in fact, come into their sphere of tracking. This information coupled with precomputed information prior to launch, gives some early feel for whether the satellite is going into orbit. The personnel at these two stations now proceed to take their recorded information and derive the actual measured data from it. They will be transmitting it back in about 1 hour, 18 minutes from Grand Turk and 1 hour, 27 minutes, in other words, 1 hour and a quarter to read the data and get it back. This shows the lack of hurry in this type of operation. The satellite proceeds on by Johannesburg, +47 minutes, over Woomera, an hour and 22 minutes, San Diego, 2 hours and 15 minutes. By this time the central control station here in Washington has sufficient information for it to know: Yes, we did achieve an orbit. However, as far as being able to accurately describe this orbit, mathematically, this is as yet impossible. The satellite proceeds on its way and the information continues to be taken as it passes over the subsequent stations.

Let's now jump to T plus 8 hours, 50 minutes. This is the first time with Vanguard III that the control center is able accurately to describe the orbit. This is quite satisfactory for the routine satellite mission as I defined it earlier.

However, note how completely unacceptable this would be for the manned space flight which must be completed in $4\frac{1}{2}$ to 5 hours.

This now shows you a very important difference in the engineering approaches to the satellite instrumentation as opposed to that of the manned space flight. This is one of the reasons why you will see the vast difference in instrumentation of these two types of missions.

Now, with regard to the progress and planning, first the satellite tracking (fig. 129): We track satellites, the Earth satellite vehicle, with essentially three methods.

First, the minitrack system which must have an active transmitter in the satellite.

Secondly, we use the Baker-Nunn cameras, which I will cover again in just a moment. This, of course, can track any type of satellite as long as the camera is told where to look.

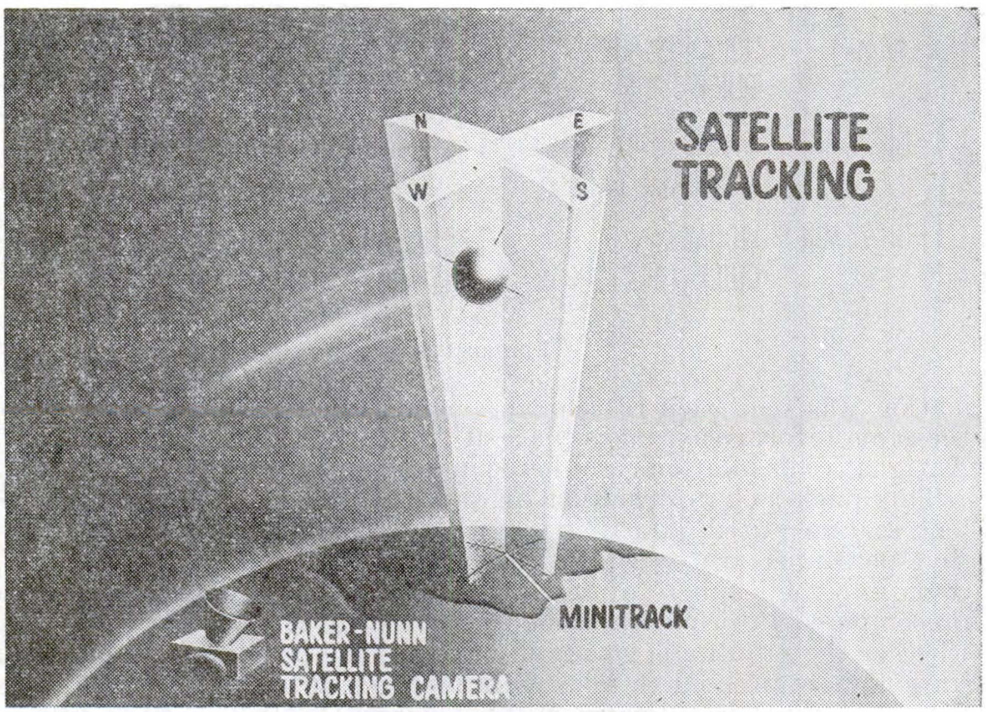

FIGURE 129

Thirdly, we use the Moon-watch teams. Again, they can track any satellite as long as they are told where to look. These again are very basic differences.

Now, as of next October we will have some 14 minitrack stations capable of tracking and receiving telemetering on not only the currently used frequency of 108 megacycles, but also on a new internationally assigned frequency of 136 megacycles.

Now, the reason I mention this frequency change is because we were—not only for technical reasons, but also because of radio frequency interference problems—were forced to go to the 136-megacycle frequency.

Now, changing frequency at a minitrack station is not quite as easy as tuning a radio receiver as one would do in their home. This is a one-fortieth scale model of a minitrack antenna [indicating]. There are some eight of these at each one of these stations. These form the interferometer baseline that is used. These antenna elements are precisely cut units, they must be cut to the proper size to receive on the optimum frequency that they are designed for.

Obviously changing frequency means changing antennas, plus the electronics that derives the tracking data from the antenna.

Now, in the original IGY, International Geophysical Year, minitrack equipment, the antennas were oriented so their antenna pattern was oriented north and south. This means that on the low inclination orbits they cut through this pattern quite nicely.

However, on a high inclination orbit, such as the polar orbit, you will note that the orbit could come essentially parallel with the beam; and the tracking, of course, would not be accomplished.

Therefore, in October, as I mentioned, our stations will also be equipped with an east-west beam that will allow this network to be able to track any satellite, providing, as I pointed out, it carries the proper type of transmitter.

Our station operators, as I pointed out in the operational example—currently have to actually read the measured data from the records. This gives rise to human errors at times. We are installing automatic translation equipment so that this will not be necessary.

Now, the Baker-Nunn locations. The Baker-Nunn camera, incidentally, is an especially designed ballistic type camera that uses a film. We have 12 of these located, as you see on the map (fig. 130, p. 686). They are limited, in that the camera must be in the dark of the Earth, while the satellite is illuminated by the Sun. This gives what is known as a good optical signal-to-noise ratio. In other words, the ambient light is not causing any fogging of the tracking camera film.

We continue to take routine observations with the Baker-Nunn network and the Moon watch teams which are, incidentally—this work is done for NASA by the Smithsonian Astrophysical Observatory on a grant.

We will augment our optical capabilities somewhat in the future for the geodetic satellite program, but currently our activities in optics are essentially to look at this limitation that I pointed out here, hopefully to give us a greater range of use of these cameras.

The data taken from these cameras, incidentally, is about 40 times more accurate than the information taken from minitrack equipment. And this is basically why it is used. This gives the finest tracking information that we have available to us.

Now, the Mercury program. You will hear the details of the Mercury program, itself, tomorrow from Mr. Low. However, from the instrumentation point of view, I would like to give you a few comments with regard to the problems that it means to the instrumentation engineer.

First of all, since there is human life involved, reliability is, of course, a very prime thing. The data, as I pointed out, is perishable, it must be handled in real time. We do not have the time, as we do with the minitrack, to essentially bootstrap ourselves into a position of accuracy. The accuracy has to be inherent in the early tracking. You will note here on the chart (fig. 131, p. 687) now that the Cape Canaveral radars have tracked the vehicle into its orbit and after about 3 minutes the Bermuda station is able to track for some 5 minutes. This tracking information is sent back to the central control where it is

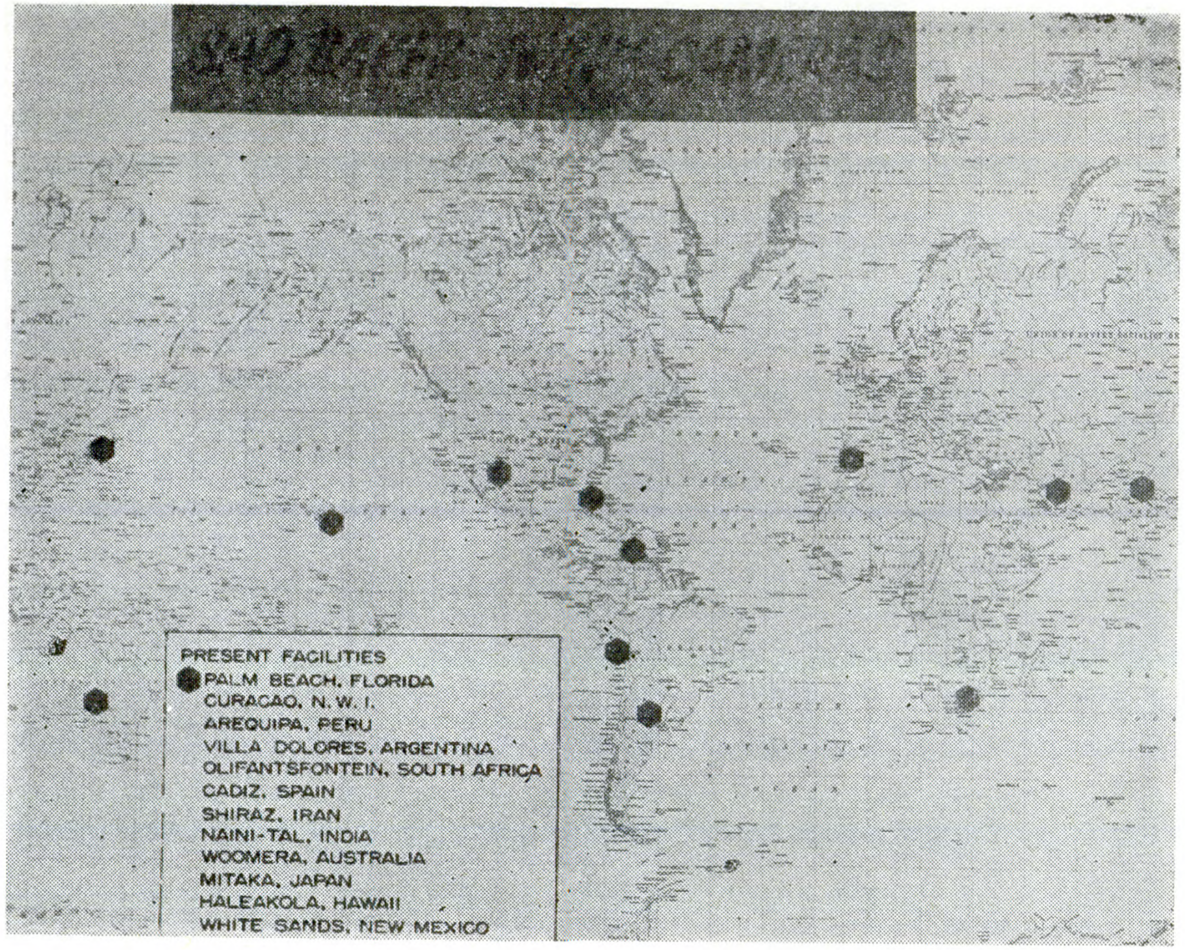
PRESENT FACILITIES
PALM BEACH, FLORIDA
CURACAO, N. W. I.
AREQUIPA, PERU
VILLA DOLORES, ARGENTINA
OLIFANTSFONTEIN, SOUTH AFRICA
CADIZ, SPAIN
SHIRAZ, IRAN
NAINI-TAL, INDIA
WOOMERA, AUSTRALIA
MITAKA, JAPAN
HALEAKOLA, HAWAII
WHITE SANDS, NEW MEXICO

FIGURE 130

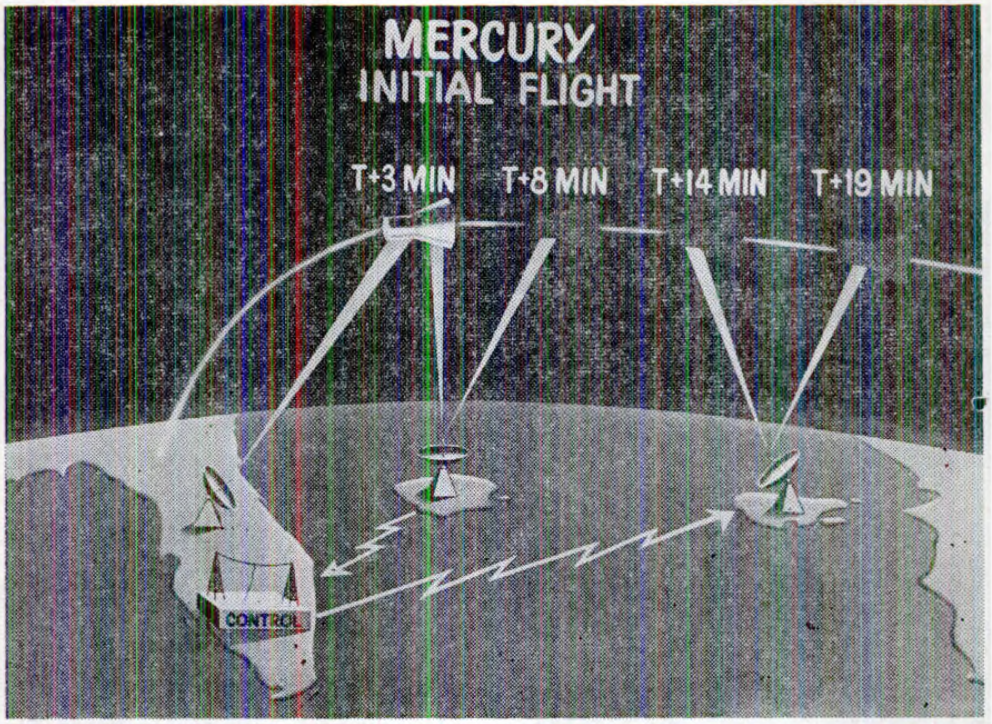

FIGURE 131

processed, the orbit is constructed and look angles, or, in other words, from the information that the computers derive from this tracking data they are now able to tell the Canary Island station, the next station along the trajectory where it must look to pick up the satellite as it comes within its view.

You will note there is a period of time over the Atlantic Ocean and where that capsule will not be under track, a period of some 6 minutes here.

This, however, although it is not tracked, there is a station in the mid-Atlantic, a ship that communicates with the capsule and receives telemetering information.

The total Mercury network is as you see it on the chart (fig. 132, p. 688) here, some 18 stations.

The Mercury network consists of various available military equipment that was already available on the national ranges, and also some Australian capability, plus several stations that have been put in by NASA specifically for this purpose.

Now, we have the Mercury launched. Let us recover it. We have the same problem exactly in reverse. That is, timely handling of the data. The station in Texas has performed its last tracking function, the station at Eglin Air Force Base, Cape Canaveral, and Bermuda, are all tracking and sending their information to the central control that is now predicting where the impact will be, and leading the recovery forces into the actual impact area.

The Department of Defense, in conjunction with the NASA, is putting together this network. It will be operational early next year. I would like to show you a model of two of the stations. I want to

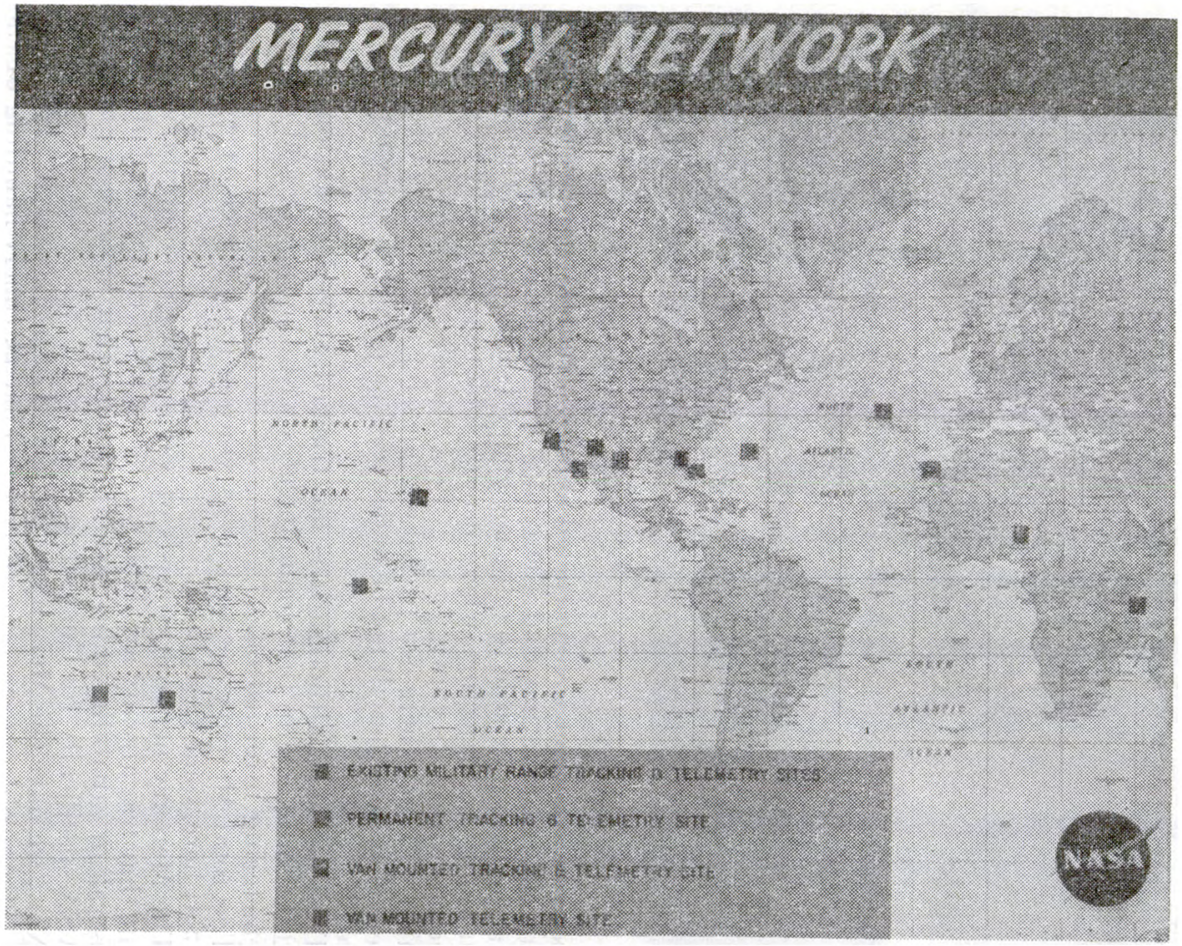
MERCURY NETWORK
NORTH PACIFIC
OCEAN
SOUTH PACIFIC
OCEAN
NORTH
ATLANTIC
OCEAN
SOUTH
ATLANTIC
OCEAN
PERMANENT TRACKING & TELEMETRY SITE
VAN MOUNTED TELEMETRY SITE
NASA

FIGURE 132

show you Kano, Nigeria, which is one of the simplest stations, and Bermuda, which is one of the, perhaps, most complex.

Perhaps if you lifted it up, gentlemen.

Now, this is Bermuda on this side [indicating]. You will note that the receiving equipment and the transmitting equipment are separated. You look at the general map of Bermuda, they are separated by several miles.

The C-band radar (an FPS–16), the S-band radar here (fig. 133), the transmitters to talk to the pilot, the command transmitters to control the activities of the capsule, itself. The equipment to, again, communicate with the pilot and to receive telemetering information [indicating].

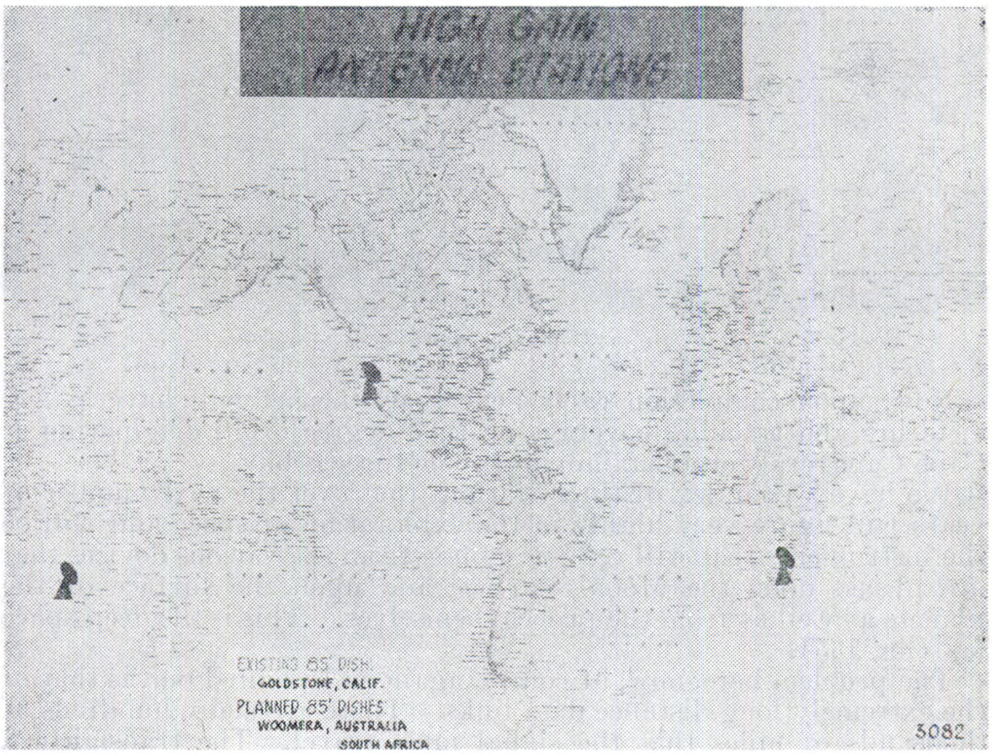

FIGURE 133

Now, on Kano, there is no tracking function taking place, only that of transmitting and receiving voice communications with the pilot and receiving telemetering information. This station, incidentally, is one of the anchor points of the ground communication links of the entire network that I will mention in a moment when I get to communications.

Now, in the design of the Mercury network, two things were held paramount. First of all, we attempted to use all existing instrumentation that was applicable.

Second, we have used a temporary-movable concept wherever possible with the idea being that the stations can be relocated at the completion of the Mercury program (fig. 134, p. 690).

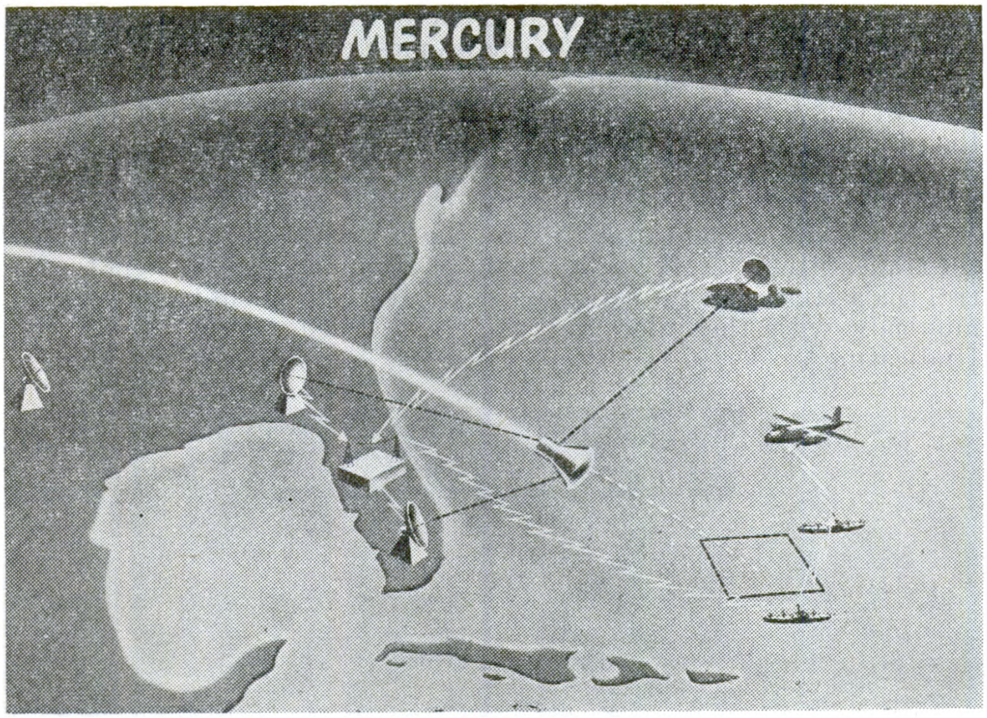

FIGURE 134

Now, upon completion early next year, the net will have a telemetering and tracking coverage on a 33 degree orbit, originating at Cape Canaveral for a maximum of some three orbits.

We have a complex of three stations that over the next number of years will figure very highly in the exploration of space and will be the instruments that will receive signals from the various devices that are placed upon the Moon's surface and upon the surface of the planets as well as from the probes themselves. This is the deep space net (fig. 135).

The problem here, now, of course, again as I pointed out, is that of the extremely long distance data links. There are many hundreds of thousands of miles that the signal must travel. The transmitters, particularly at this time period, must be kept small because the propulsion available is small. The transmitters available, that is the power available in the vehicle, is necessarily small because of the weight. And, of course, that is not at all in keeping with the distances that the signals must travel. We also have a problem of linking these three stations together. Where we had to link the stations together rapidly in the case of Mercury, and then with not such a rapid time phasing, with the routine satellite, it turns out that with the deep space probe you have to go from fast to slow to fast. I will explain what I mean by that.

This is perhaps best explained by the operation of the network (fig. 136). This is a view of the earth from the South Pole.

Now, at launch—I had better explain this chart a bit further. This is a view of the earth from the South Pole, this is South America here, Africa and Australia. This will be the station at Goldstone, Calif., and the station here at Australia, and this one in South Africa.

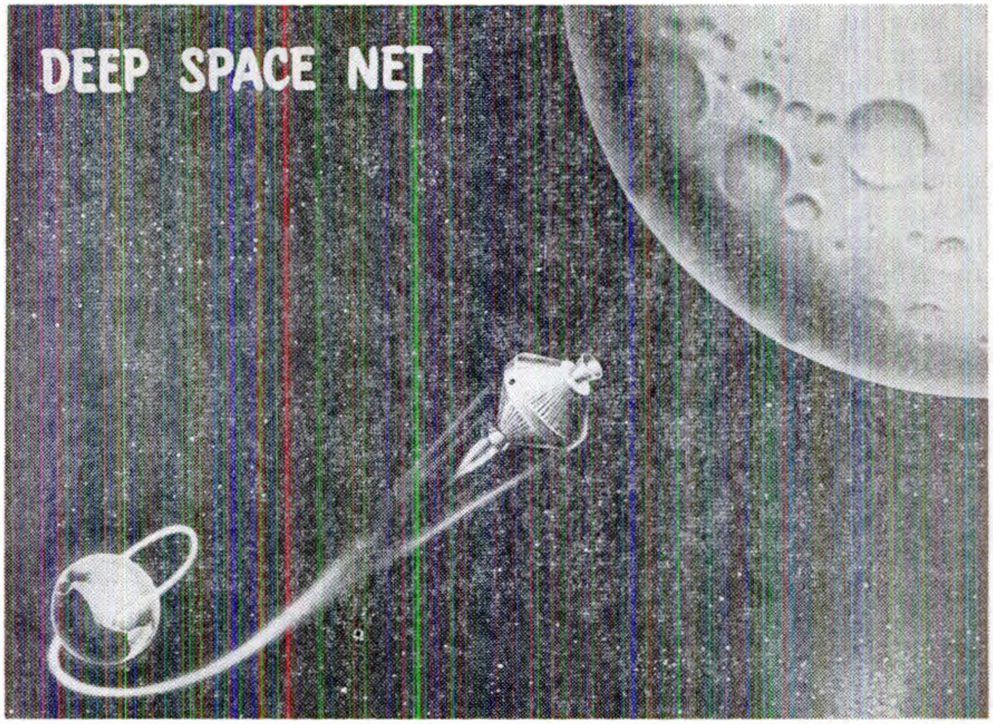

FIGURE 135

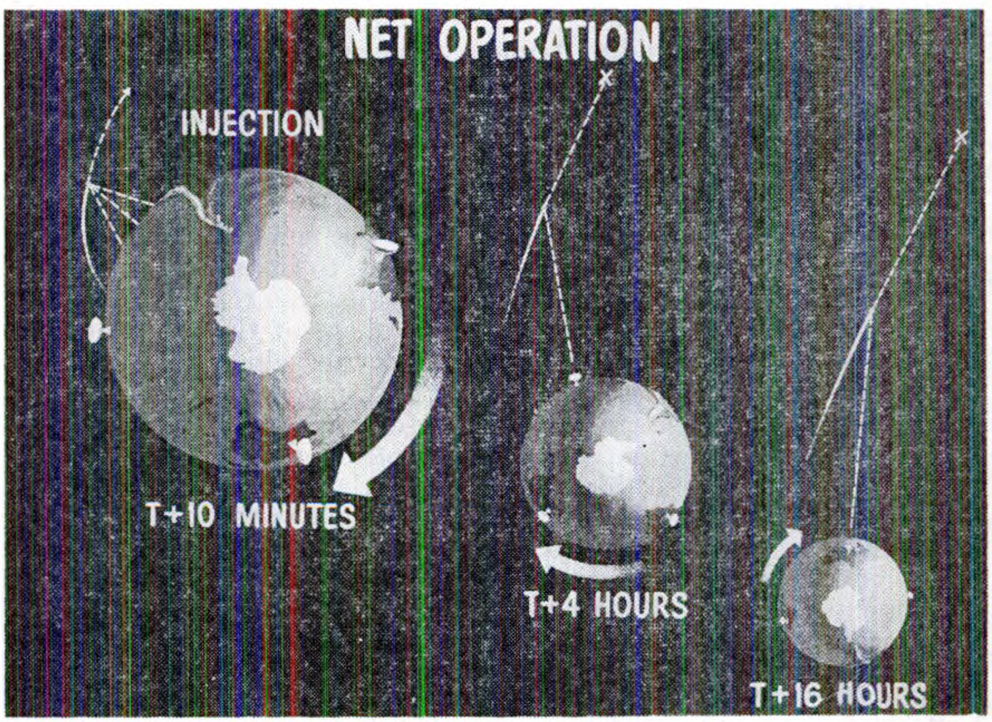

FIGURE 136

Now, at launch from, say, the Atlantic Missile Range, the AMR instrumentation derives the position and velocity data or the injection data from the vehicle and sends this to the control point that then computes and predicts in advance where the vehicle will be in some 4 hours when the earth has rotated and the Goldstone, Calif., station is now in a position to track the vehicle.

Again, as Goldstone completes its track, it must now send its information to the control point so that the predictions again can be made for Australia to find the target, lock on it, and effect its track.

Now, this is very imporant during these first few hours of flight because this is the time period when the early corrections to the trajectory are made.

However, as you proceed into the midcourse phase, or the many-day phase of flight, the predictions can literally be made days in advance. This is why I said that timeliness of transferring the data then loses its importance.

Now then, as the vehicle approaches its target, the Moon, for example, it now comes under the influences of these other gravitational forces and now we must, again, be able to track rapidly and to make corrections and send command information back to the vehicle to control a landing for example.

I would like to point out the antenna, itself [indicating]. This is a model of the antenna that is located at Goldstone, Calif., and is similar to the one that will be in Australia, and South Africa. It is 85 feet in diameter and you will recall the problem I pointed out about the extremely small power and the long distance. This is partially corrected by the fact that this large collecting surface collects the minute quantities of radio frequency energy, focuses them at this feed point and sends them on down to be amplified and acted upon.

This antenna dish, itself, not only tracks, but it receives telemetering information. However, it cannot effect the command control function that I have mentioned before. To do that, you require a second dish.

We currently have a second dish for the command function at Goldstone. We plan, as requirements exist, to install a second dish in Australia and one in South Africa.

You will recall the explanation I gave here of the net operation. The explanation I gave was one in which the vehicle was launched and injected into its trajectory over an instrumented area. If, however, the type of coast trajectory is used that is available with the Agena vehicle or the Centaur, a more optimum point is usually selected to effect this injection. This means that the vehicle will coast in what is known as a parking orbit until it arrives at its optimum point where a second thrust is given to it.

If this occurs over, say, the Indian Ocean, we do not have a highly instrumented area down there as we do in the Atlantic Missile Range. This means that this injection instrumentation now must be placed in a mobile fashion in these remote locations. This also, we are preparing.

Now, on the subject of central control (fig. 137), the minitrack network will come under immediate operational control of the Goddard Space Flight Center when it is completed this summer. The Moon watch and the Baker-Nunn networks are controlled from the

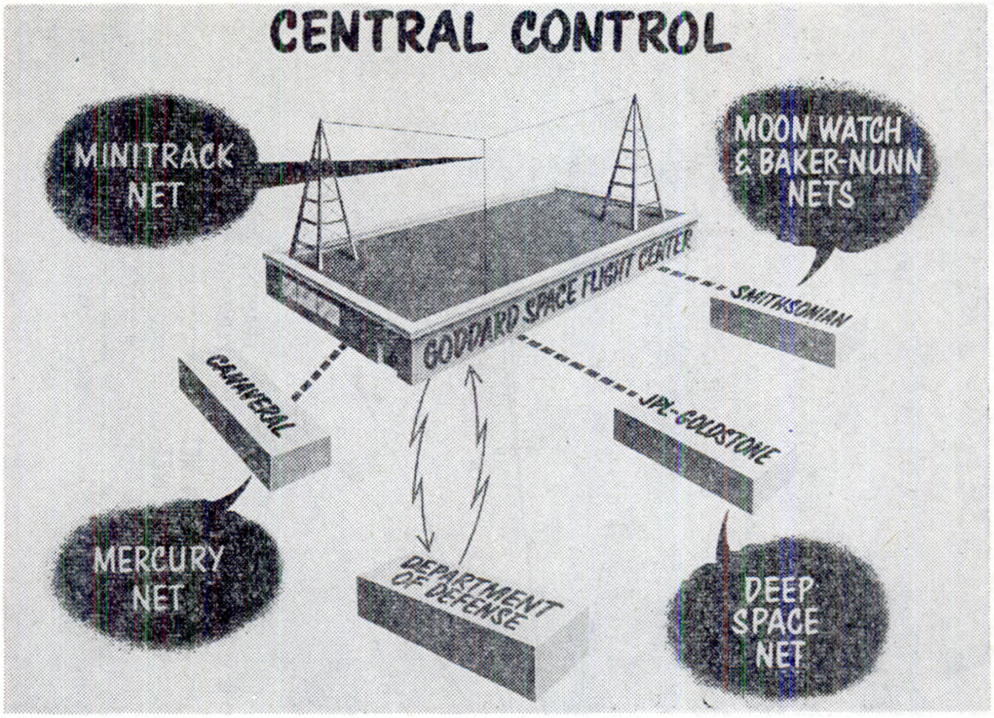

FIGURE 137

Smithsonian, the deep space net at JPL, Pasadena, and the Mercury net through the control point at Canaveral.

Goddard Space Flight Center will be assimilating these control functions as soon as technically and operationally feasible.

Our point of coordination with the Department of Defense will be out of Goddard Space Flight Center to give a single point of contact for our co-use of equipment with the Department of Defense.

Our communication picture is as shown on this chart (fig. 138, p. 694). You can appreciate the value of communications in a far-flung network. This is meant only to be a graphical presentation to indicate the farflung nature of these types of instruments that we have out. This looks complex and it is. This is our highest single line item in our instrumentation budget. In 1961, that of communications. We attempt in every case to use either Department of Defense lines that are available or use leased lines, as the case may be. They will all tie into Goddard control center in our final operational networks.

In summary, our major plans for the next fiscal year, that of the vertical probe type of missions is general improvement of the Wallops Island instrumentation, with the satellite missions, the automatic data read out equipment that I mentioned, the new tracking frequency, broad-band special type of equipment and optical equipment for the meteorological and geodetic satellites.

A completion of the manned satellite networks, the Mercury net, and a completion of an initial net receiving capability on the deep space probe.

Now, to complete the picture, our summary for funding is as you see on the chart (fig. 139, p. 695). Construction money, some $31 million, research and development, including the operation of the

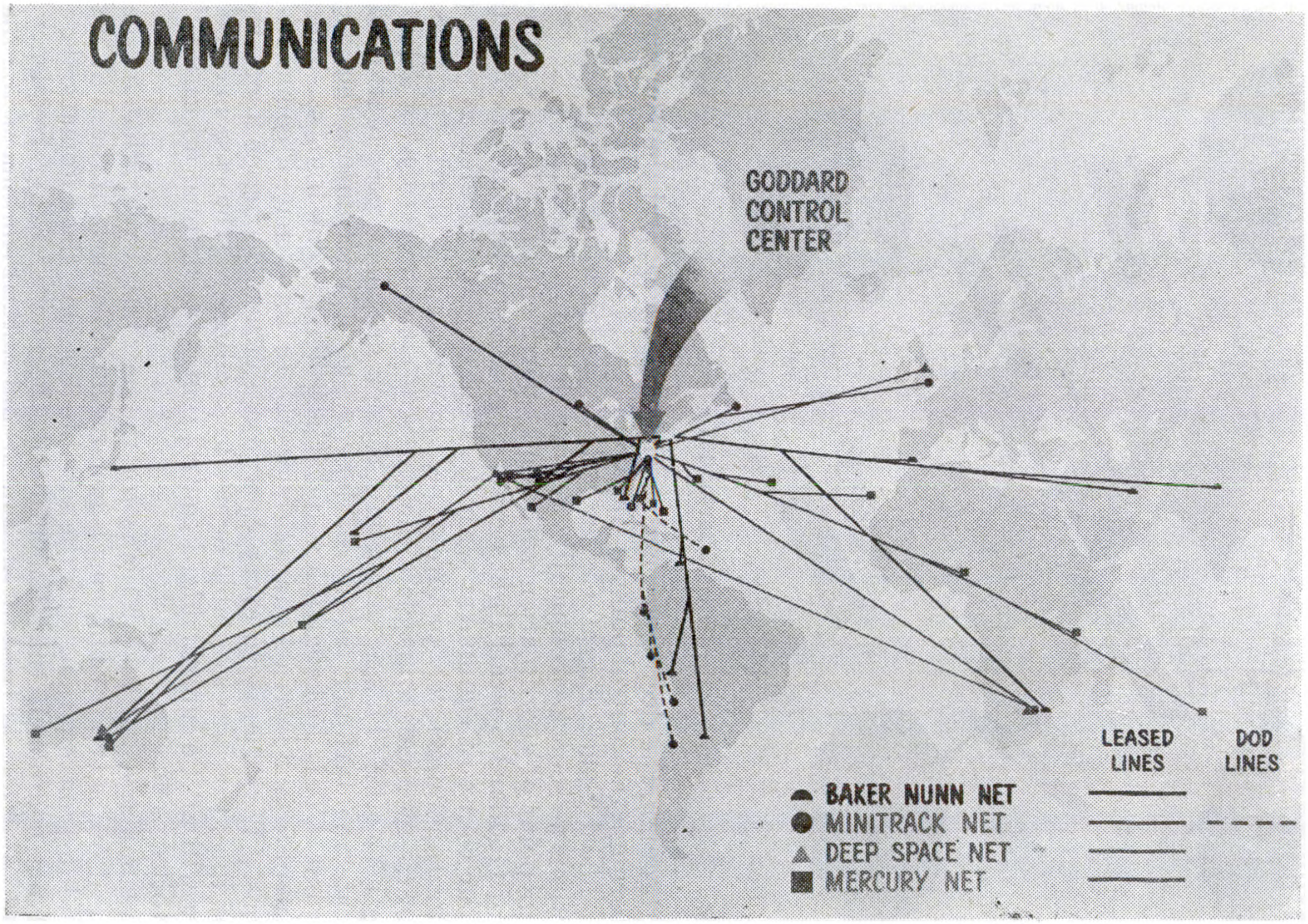
COMMUNICATIONS
GODDARD CONTROL CENTER
LEASED LINES
DOD LINES
BAKER NUNN NET
MINITRACK NET
DEEP SPACE NET
MERCURY NET

FIGURE 138

SUMMARY OF FUNDING FOR FY 61

C & E	(IN MILLIONS)
VERTICAL PROBE	4.00
SATELLITE	4.75
MANNED SATELLITE	15.00
DEEP SPACE PROBE	8.00
TOTAL	$ 31.75
R & D	
OPERATIONS, COMMUNICATIONS & UTILITIES	25.33
ADVANCED TECHNICAL DEVELOPMENT	7.22
TOTAL	$ 32.55
TOTAL	**$ 64.30**

FIGURE 139

networks and the communications, some 32, for a total of 64.3 million in this area of instrumentation.

Thank you.

The CHAIRMAN. Thank you very much, Major Hammond. That completes your statement, sir, and we have already had the statement of Mr. Richard Rhode. Are there any questions now?

Mr. HECHLER. I am pretty low down on the committee. I don't want to jump the gun.

Mr. FULTON. May I just compliment them both on an excellent presentation and thank Mr. Rhode for his longtime interest ever since he was on the National Advisory Committee for Aeronautics.

I spent one conversation with him that was some thousand miles long coming across the Atlantic.

Mr. RHODE. Thank you.

The CHAIRMAN. Mr. Hechler?

Mr. HECHLER. Major Hammond, you have been around this tracking business for quite some time, haven't you?

Major HAMMOND. Yes, sir; I have.

Mr. HECHLER. I didn't quite get clearly whether you have some experience in the Air Force in connection with this?

Major HAMMOND. My experience started out, sir, when I served as executive officer to the Chief of the Flight Determination Laboratory at White Sands Missile Range. This laboratory had the instrumentation at White Sands and the data reduction. After that, I served in the Air Research and Development Command Headquarters in instrumentation research and development. During that time I was Headquarters Project Officer for Project Space-Track.

Mr. HECHLER. You really have been pretty much in the middle of this space tracking business, then?

Major HAMMOND. Yes, sir.

Mr. HECHLER. Did you have anything to do with following this unknown satellite?

Major HAMMOND. This recent one, sir?

Mr. HECHLER. Yes. This so-called mystery satellite.

Major HAMMOND. This is not really a NASA function. We do not have in any of the instruments that I discussed a capability of detecting a satellite if we do not know where it is.

Mr. HECHLER. But you followed some of the progress of various agencies in trying to track this satellite?

Major HAMMOND. Yes, sir. I personally did, out of pure interest, right.

Mr. HECHLER. I was rather amazed and I might say somewhat shocked by published reports that the space surveillance system of the Navy, which initially picked this up, had not turned its data over, with due speed, and I just wondered whether this is really true?

Major HAMMOND. I don't know, sir.

This Spasur system, as I understand it now, and I have been away from it for some time, is really a research and development device. Is it reported as an operational device?

Mr. HECHLER. You are not aware then that there was any delay?

Major HAMMOND. No, sir.

Mr. HECHLER. You don't believe there was any such delay?

Major HAMMOND. I don't know.

The CHAIRMAN. Any further questions?

If not, gentlemen, we want to thank you very much for your very fine statements. They were very illuminating.

Now, if there is nothing further, I would like for the committee to go into executive session for a few minutes. I want to present the program for the rest of the week to the committee.

Mr. FULTON. I ask the Navy to submit a short statement so we don't have any inference of delay without some statement in the record from the agency involved.

The CHAIRMAN. If the Navy wants to submit a statement, of course, it will be all right.

Mr. FULTON. I am asking for it.

The CHAIRMAN. The Navy hasn't requested it.

Mr. FULTON. I am asking for it, if you would be so kind.

The CHAIRMAN. Commander, would you undertake that responsibility?

Commander VAN NESS. Yes.

The CHAIRMAN. If you see Admiral Raborn, it would be all right to talk to Admiral Raborn.

(The information requested was submitted but is classified.)

The committee will go into executive session.

(Whereupon, at 3:55 p.m., the committee proceeded in executive session.)

(The executive session is classified and will not appear here.)