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PROJECT ANNA—GEODETIC SATELLITE SYSTEM

HEARINGS

BEFORE THE

SUBCOMMITTEE ON SPACE SCIENCES

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS U.S. HOUSE OF REPRESENTATIVES

EIGHTY-SEVENTH CONGRESS

SECOND SESSION

MAY 14, 15, AND 16, 1962

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NOTE.—The chairman of the full committee and the ranking minority member, Hon. Joseph W. Martin, Jr., are ex officio members of all subcommittees.

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PROJECT ANNA

MONDAY, MAY 14, 1962

House of Representatives,
Committee on Science and Astronautics,
Subcommittee No. 3,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10:12 a.m., in room 214–B, New House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. Karth. The committee will come to order. This morning we begin hearings on the geodetic satellite program.

Commander Macomber, I notice that you received your mechanical engineering degree from California Institute of Technology, and your masters degree in geodesy from Ohio State University.

Commander Macomber. Yes, sir.

Mr. Karth. I wonder if you could inform the subcommittee for the record at this point when you first became associated with Project ANNA and in terms of time when was this in relationship to the beginning of the project?

STATEMENT OF LT. COMDR. MARK M. MACOMBER, BUREAU OF NAVAL WEAPONS, DEPARTMENT OF THE NAVY

Commander Macomber. I first became associated with Project ANNA in early March of 1961. The project was started in January of 1961. It had been approved in December but actual coordination groups between the services did not meet until January. So I got in about 2 months after the start of the project.

Mr. Karth. All right. If you want to proceed, then, with your prepared statement, you "fire" at will.

Commander Macomber. All right.

I would like to mention right now, though, that I was supposed to follow Dr. Harold Brown and he was supposed to lay the groundwork for me. It might seem as though I am jumping off into an abrupt start here since I am going to talk about the technical things on the satellite.

The satellite contains three basic types of instrumentation which will be used for obtaining positioning information. For range determination, a transponder in the satellite is coupled with ground instrumentation which makes a phase comparison between a modulating frequency as transmitted to and as returned from the satellite.

Three frequencies in the very high frequency-ultra high frequency bands are used—one for transmission to the satellite, and two coherent frequencies for transmission from satellite to ground. Analysis of the difference in phase shift on the two returning frequencies permits a correction to be made for refraction effects.

To resolve any ambiguities in distance measurements, four different modulating frequencies are employed. In an attempt to keep the satellite instrumentation as simple as possible, the ground stations are tied together by a very low frequency timing net, and ground transmissions are so timed that signals from the various ground stations are received at the satellite sequentially. The ranging instrumentation, both satellite borne and ground complex, and observations on the satellite using range measurements are the responsibility of the Army, with specific responsibility being vested in the office of the Chief of Engineers.

For optical determination of direction from ground station to satellite, a high intensity optical beacon is used which, when activated, produces a series of five light flashes, spaced 5.6 seconds apart. By photographing these light flashes against a background of stars, it is possible to measure the apparent declination and right ascension of the satellite for each flash.

By projecting rays of light from several positions of the satellite, one obtains an intersection of rays which defines the location of the observing camera. The satellite instrumentation for the light beacon and the optical observation program are the responsibility of the Air Force, with coordination responsibility being exercised by the Office of the Chief of Staff.

Range rate information is obtained by observing the Doppler shift of ultrastable transmissions of the satellite. Four frequencies will be broadcast continuously for this purpose. The pair of frequencies designed for geodetic measurements will be 162 and 324 megacycles, with 54 and 216 megacycles being reserved for refraction studies and for a possible backup in case of failure of the prime tracking frequencies.

All four of the frequencies are generated by the same oscillator, so tracking can be accomplished using any two of the frequencies. The Doppler satellite instrumentation and the range rate tracking program are the responsibility of the Navy, with specific responsibility assigned to the Bureau of Naval Weapons.

The temperature controlled crystals which drive the ultrastable transmitters are also used to run a satellite-borne clock. An internal timing pulse is generated every 5.6 seconds. For correlation of ground station clocks with the satellite, every 16th pulse is broadcast from the satellite as phase modulation on two of the Doppler signals.

By keeping track of the frequency drift of the crystals, from observations by the Doppler tracking stations, it is possible to correct the time of transmission of each of the time signals to better than ½-millisecond. This time accuracy is equivalent to about 10–15 feet of satellite travel. The same clock which provides these timing signals also initiates the flash sequences for the optical beacon so that the Doppler and optical observations are tied together in time.

A small satellite memory, consisting of 22 16-bit words, has injected into it, while over the Washington area, an indication of that 5.6-second timing pulse which should initiate each light flash sequence. When the satellite clock agrees with the timing word in the memory, a light flash sequence is initiated.

The satellite is oriented with the earth's magnetic field so that the pole of the satellite which is visible from earth is a function of the geomagnetic latitude of the satellite. There are two beacons which face the north pole of the satellite, and two which face the south pole. Only 15 bits of the 16 in each word in the memory are used for light flash timing.

The 16th bit has injected into it an indication of whether the north or south lights should be flashed. The 22d word of the memory will not initiate flash sequences, but is used for telemetry purposes to indicate whether or not the lights did flash as planned.

In addition to the geodetic systems instrumentation, the satellite contains various minor experiments which test the environment and the attitude of the satellite.

The NASA has no special instrumentation in the satellite, but does plan to observe both optically and electronically. Initially it is proposed to use the tracking network of the Smithsonian Astrophysical Laboratory and the Minitrack Optical Tracking System, with voluntary participation of observatories being phased into the observational program after a calibration phase of about 3 months' duration. NASA electronic tracking will be accomplished by the minitrack network, using the telemetry transmitter in the satellite as a tracking device.

During the first 3 months after launch, an intensive calibration program will be undertaken, wherein the three types of measurements (direction, range and range rate) will be compared among themselves, and with terrestrial survey results. This calibration program is considered of prime importance to prove that no biases exist in any of the instrumentation used, nor in the methods of data handling utilized.

If any biases do exist, they must be eliminated or corrected prior to undertaking a worldwide observation program. Upon successful completion of the calibration phase, a worldwide geodetic observation program will be initiated with the intent of refining our knowledge of the earth's gravitational field, and of providing the location of tracking stations relative to the earth's center of mass.

Two primary observing techniques are available for use, the first one, called the "intervisible" or "simultaneous" technique, being independent of forces acting on the satellite, while the second, the "orbital" technique, requires a knowledge of all forces working on the satellite.

Considering, for simplicity, only the optical measurements, let us take a case where we have two stations which are located with respect to each other, such as two stations at triangulation stations in the Eastern United States. If the satellite were to flash while over the Atlantic, just to the east of the United States, directions from these two stations would determine, by their intersection, the position of the satellite for each flash.

If, at the same time, a camera on Bermuda observed the same flash sequences, then the direction from ground station to satellite, turned through 180 degrees, would go from the satellite position as determined from the U.S. stations, through the unlocated camera station on Bermuda.

A series of these lines of direction would establish the location of the Bermuda site with respect to the U.S. stations. In this case each flash of light is treated as an unoccupied triangulation station, and there is no attempt to tie the flashes of light together.

The orbital method permits greater steps to be taken in locating positions. Let us start out the same, establishing the points where the light flashed over the Atlantic, just east of the United States, but rather than having a camera on Bermuda, let's move it to Australia.

In this case, it would be impossible to see the same flashes from both locations. Instead, the observations from the United States serve to establish the satellite orbit. By knowing the forces which act on the satellite, we can tell where it will be at any time in the future, so that when light flashes are observed from Australia, they are related, through the orbit, to the United States.

At present our knowledge of the gravitational forces acting on the satellite is incomplete, so our orbit predictions will be somewhat in error. In addition, the stations in the United States, although known with respect to the North American datum, are not known with respect to the center of the earth, and, since the satellite orbits about the center of mass of the earth, the lack of knowledge of the absolute location of the U.S. stations gives an erroneous orbit.

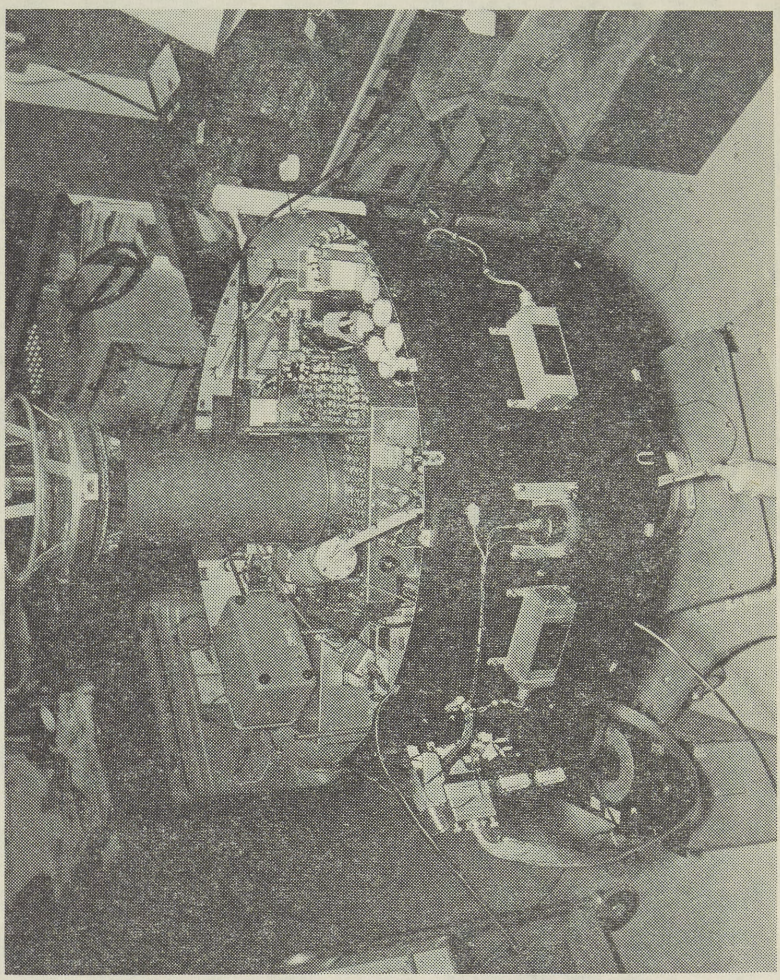
In practice, the best possible theory will be used to compute what observations should be obtained at each station. These will be compared with observations actually made, and, through a least squares adjustment, our knowledge of the earth's gravitational field and all station locations will be improved simultaneously to give a minimum residual of fit.

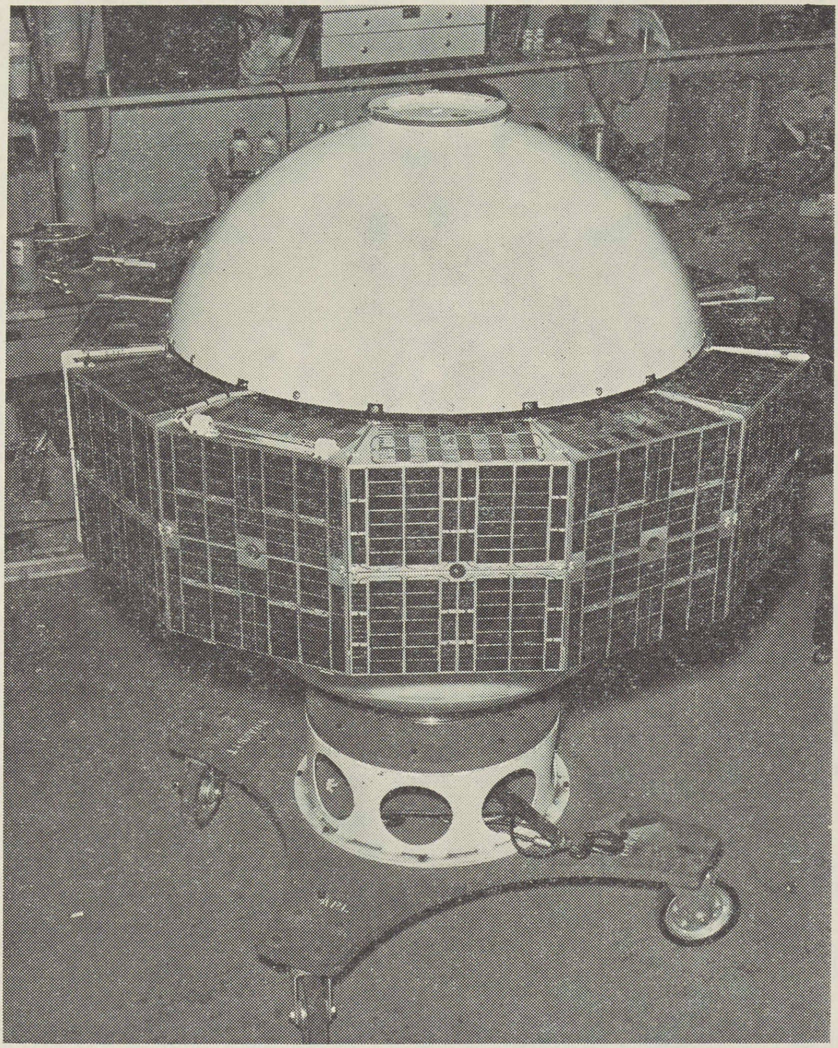
The orbital mode of observation permits the the greatest possible exploitation of a satellite for geodetic purposes, but it must not be considered that perfect answers will be obtained with only one satellite orbit. A strong correlation exists between the perturbing effects of various factors of the gravity field for any given satellite orbit.

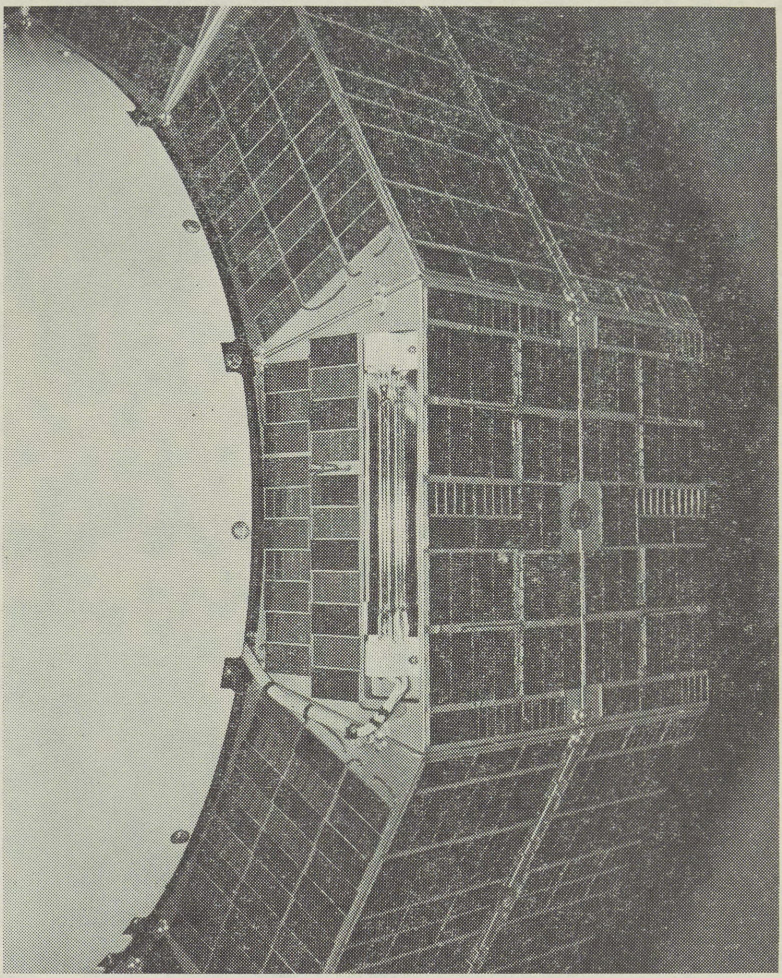
A solution for the gravity field can be obtained which would be perfect for one inclination, but which would give completely erroneous results for a satellite in some other orbit.

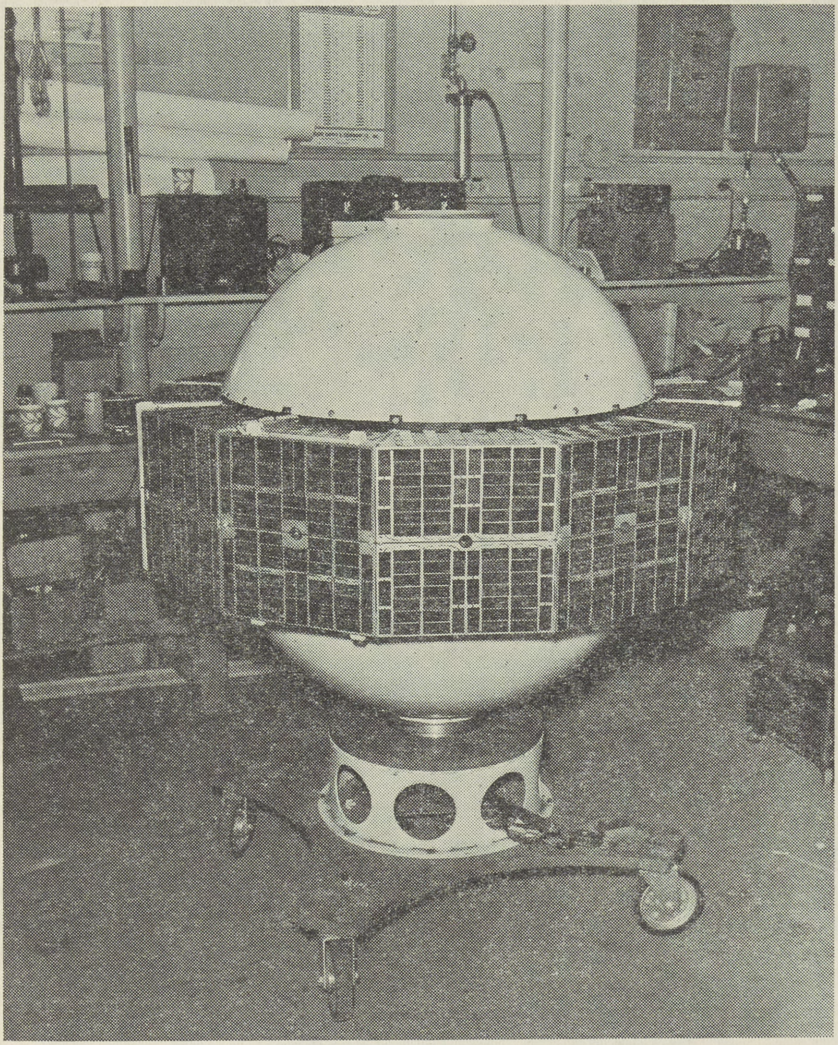
In order to reduce the correlation between terms of the gravitational field, and to define this field as it actually is, there must be a variety of orbits, both in inclination and in altitude, and the observations from all orbits must be analyzed together.

A second attempt to orbit an Anna satellite is now scheduled for late summer. This operation is a backup for the unsuccessful attempt of May 10, and will require the same orbital parameters (i.e., 50 degrees inclination, 600 nautical miles altitude) as the original. I am submitting photographs of the Anna satellite for the record.









Mr. KARTH. Commander, I think, if there is no objection, it might be well to have your biographical sketch copied into the record at this point.

(The biographical sketch of Commander Macomber is as follows:)

Lt. Comdr. Mark Morris Macomber, U.S. Navy, is currently head of the Geodetic Satellite section of the Bureau of Naval Weapons. He was born in Lomita, Calif., December 3, 1924, received his B.S. in mechanical engineering from the California Institute of Technology in 1945 and his M.S. in geodesy from the Ohio State University in 1958.

Lt. Comdr. Macomber, who has been in the Navy since 1943, was commissioned in 1945, and designated for special duty only (hydrography) in 1949. Since his designation as a specialist, his duty assignments have been either at the Hydrographic Office or in ships under the technical control of the hydrographer except for his postgraduate studies at the Ohio State University and his present tour at the Bureau of Naval Weapons.

Lt. Comdr. Macomber has made contributions to computational procedures followed in using precise electronic navigation systems for control of hydrographic surveys, and to the simplification of computational techniques used in geodetic surveys. He is married and has three children.

Mr. KARTH. Commander, what happened on May 10?

Commander MACOMBER. We had a propulsion failure between the first and second stages. The signal did not get to the second stage to light off.

Mr. KARTH. What booster system did you use?

Commander MACOMBER. This was the Thor-Able Star booster system.

Mr. KARTH. This has not been a very dependable booster system, has it?

Commander MACOMBER. We have had several sad results with it, but the booster problem is really outside of my field.

Mr. KARTH. Well, it is very important to this subcommittee because if, in fact, we have had poor experience with that booster system, and Project ANNA is for any importance, then it seems to us maybe we should have picked a more reliable booster system. I would assume that we have several vehicles in our stable, any one of which would be capable of doing this job and which have demonstrated greater reliability than has the Thor-Able Star. Would you say this is an accurate statement?

Commander MACOMBER. Yes, sir, but we get into a problem of how much capacity we need. The Thor-Able Star is in the right weight range for the orbit we want. Thor-Delta would probably do almost the same job. We have investigated moving to it, but we had the Thor-Able Star available at the time and we had been assured that we had a very high probability of success on this mission.

Mr. KARTH. The Thor-Delta is almost identical with the Thor-Able Star, with the exception of a restart capability, isn't that right, Commander?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Who makes the decision on what booster you should use? You are in charge of this project. Who makes a decision on the booster?

Commander MACOMBER. This is decided upon between the management people in the Navy. I am in on it, Chief of Naval Operations' personnel are in on it. The Thor-Able Star had been giving us good results in the Transit program and we assumed that it would continue to give us good results on this shot.

Mr. KARTH. I understand there have been only two successful shots from the Thor-Able Star in eight attempts. This is a rather low ratio of success to failure; isn't it?

Commander MACOMBER. Yes, sir. There was a period of time when the vehicle was going through a developmental stage in which we had very poor success. But the Transit-4–A and 4–B shots following each other sequentially were outstanding shots, I might say. And we thought that all our problems had been solved in the booster field.

Mr. KARTH. And what problem appeared not to be solved after the shot was made and the Thor-Able Star did not perform?

Commander MACOMBER. It was apparently a failure in one relay, an item which is supposedly of outstanding reliability. The complete analysis of the failure has not been made. This is a preliminary decision.

Mr. KARTH. Who specifically is in charge of Project ANNA now, Commander?

Commander MACOMBER. The Bureau of Naval Weapons.

Mr. KARTH. Who is the man in charge in the Bureau of Naval Weapons?

Commander MACOMBER. I am the project officer.

Mr. KARTH. So you are the man who is in charge of Project ANNA at this point; is that correct?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Who was before you, or have you always been since March 1961, at least?

Commander MACOMBER. Since March 1961, I have been in charge continuously. Before that it was probably Mr. Nicolaides who was in charge of the program. He was with the Bureau of Naval Weapons at that time. He is now with NASA.

Mr. KARTH. You say that this became a program as such in January of 1961?

Commander MACOMBER. Yes, sir.

Mr. KARTH. This thing was conceived considerably sooner than that; was it not?

Commander MACOMBER. The original program plan was made in August of 1960, but it took some time to work out funding arrangements, get approval of the various participants and getting the go-ahead.

Mr. KARTH. But in August of 1960 was the earliest date of conception; is that correct?

Commander MACOMBER. Yes, sir.

Mr. KARTH. What is the present status of Project ANNA, Commander?

Commander MACOMBER. We have just had one unsuccessful launch attempt. We now have a backup satellite available and another booster is coming off the production line for a firing later this summer.

Mr. KARTH. What booster is that?

Commander MACOMBER. That is another Thor-Able Star.

Mr. KARTH. Can you tell the subcommittee why Project ANNA started out as an unclassified project, became classified and then was declassified?

Commander MACOMBER. No, sir. It was classified when I came into it. I believe Dr. Brown intends to take up the reasons of classification.

Mr. KARTH. And what is Dr. Brown's status with the Project ANNA?

Commander MACOMBER. He is the Director of Defense Research and Engineering and since this is a triservice project, things do funnel through the Defense Research and Engineering Office and through Dr. Brown.

Mr. KARTH. He has many other duties and assignments, I assume?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Just by virtue of his title.

Commander MACOMBER. Yes, sir. ANNA is a very small part of his occupation.

Mr. KARTH. You think Dr. Brown will be able to answer the question as to why it was classified?

Commander MACOMBER. Yes, sir.

Mr. KARTH. You said in your testimony that NASA's participation will be to observe. Now what does this mean, really? Does that mean that they will have no functional responsibilities in this program, that they will only be interested as observers, or is there something in addition to this, Commander, that will be their responsibility and their objective?

Commander MACOMBER. They will have a much greater role than just observing. With the project open to the scientfic community, all the liaison with that community is through NASA. Any promulgation of results will be through NASA.

They are, you might say, comanagers with the Navy. The Navy will handle it for the DOD and NASA will handle it for the scientific interests. This includes a lot of dissemination of alert information, as well as some analysis of results, preliminary filtering, before we have one final data analysis operation.

Mr. KARTH. Who funds Project ANNA?

Commander MACOMBER. The three services have funded it.

Mr. KARTH. Has NASA ever funded any part of it?

Commander MACOMBER. No, sir. We have gotten help——

Mr. KARTH. What are your future expectations on funding?

Commander MACOMBER. Well, I would hope NASA would participate in the funding program since they are now participants in the program itself?

Mr. KARTH. They started out as participants, did they not, and then when it became classified, they withdrew from the project? Isn't that correct?

Commander MACOMBER. They never committed themselves to be in the project, as I understand it. This was before I came to it.

Mr. KARTH. How did we develop the word "ANNA," then?

Commander MACOMBER. We were hoping to get them in at the time the program plan was written, but in view of the classification, their participation did not materialize.

Mr. KARTH. But originally when it was conceived and when it was unclassified, NASA was considered a part of the project, is this correct?

Commander MACOMBER. I would say so; yes, sir.

Mr. KARTH. Did any negotiations develop between the services and NASA with regard to their participation?

Commander MACOMBER. No, sir. We got one letter from NASA explaining what NASA's role would be in the project if it were unclassified, but that was the extent of the communications between us.

Mr. KARTH. This was after it was classified, or before?

Commander MACOMBER. It must have been after it was classified. This was in September of 1960 because the classification issue was raised in the letter from NASA.

Mr. KARTH. But no negotiations, no exchange of correspondence and no exchange of conversation took place among the three services and NASA prior to classification, is that right?

Commander MACOMBER. Yes. We had informal NASA cooperation in drafting the original program plan in August of 1960.

Mr. KARTH. I see. So before it became classified NASA was interested in the project, were they not?

Commander MACOMBER. Yes, sir. And since it has become classified, we have had the same informal participation of members of NASA in our working groups who help us in an advisory capacity. But NASA officially did not join the program as an observer.

Mr. KARTH. Because it became classified, is that correct?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Who made the decision as to whether or not it should be classified?

Commander MACOMBER. I have no idea of that. I believe Dr. Brown will speak on that point.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. I want to listen for a little bit, but I will have some questions, later. I am just catching up here.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. What do you ultimately hope to achieve with Project ANNA?

Commander MACOMBER. We hope to get the location of primarily tracking stations, shall we say, and the earth's gravitational field. The tracking stations are important because when you start out, say, for a shot to the moon, you have stations that are separated by about the diameter of the earth that are tracking the vehicle. These stations have to be tied together very closely so that you get a good indication of where the vehicle is.

Any error, in, say, a base line of some 4,000 to 7,000 miles would give you a tremendous error in range when you get out toward the vicinity of the Moon or going toward Venus.

Mr. DOWNING. In other words, you can't accurately locate these tracking stations now?

Commander MACOMBER. No, sir.

Mr. DOWNING. Do you know what your margin of error is at the present time?

Commander MACOMBER. There are figures of all orders of magnitude floating around. If you come out with the statistical analysis it is meaningless because there are so many void areas in the world. The statistical results show that you might have an error anywhere from 500 feet to a thousand feet, but the lack of information over a wide part of the earth may vary, so it could be more, it could be less.

Mr. DOWNING. If this program is successful you can pinpoint more accurately these tracking stations?

Commander MACOMBER. Yes, sir.

Mr. DOWNING. Would any other result be achieved?

Commander MACOMBER. The gravitational field is of utmost importance since that is what controls the motion of satellites and probes. And also from an investigation of the gravitational field you can get an indication of what has been going on in the earth the last few million years, the degree of isostatic compensation that has been accomplished and things of a geophysical nature.

Mr. DOWNING. Any other foreseeable results?

Commander MACOMBER. No, sir; that is the primary purpose.

Mr. DOWNING. How many shots do you plan to make?

Commander MACOMBER. There has been authorization for only two shots, one of which has been a failure.

Mr. DOWNING. And what was the amount funded for that?

Commander MACOMBER. That one shot cost about $4½ million.

Mr. DOWNING. What is the whole program funded at?

Commander MACOMBER. It is on the order of $12 million. This includes the ground complexes, data analysis, data collection, things like that.

Mr. DOWNING. I think that is all, Mr. Chairman.

Thank you very much, Commander.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. I don't know that I followed you; you used the word "location" of tracking stations.

Commander MACOMBER. Yes, sir.

Mr. RANDALL. You mean an effort to coordinate the activities of those? I don't know that I follow the meaning of it there. Tracking stations of other nations?

Commander MACOMBER. No, sir. Our own tracking stations that are located on other than the North American Continent. Each continent has its own geodetic system. Ours is based on a location out in Kansas at Meade's Ranch. Every position in the United States is relative to Meade's Ranch in Kansas.

Mr. RANDALL. They are all tied in with Meade's Ranch?

Commander MACOMBER. Yes, sir. But we don't know where Meade's Ranch is with respect to the center of the earth.

Mr. RANDALL. I follow you now.

Commander MACOMBER. So that although anything within one major datum is precisely tied with respect to that datum, the independent datums can shift with respect to one another.

Mr. RANDALL. Thank you. That satisfactorily explains the word "location," with respect to the center of the earth. That is very illuminating.

Thank you.

Commander MACOMBER. Yes, sir.

Mr. KARTH. Commander, you talked about the degree of error that we now have in locating certain points on the earth. What will Project ANNA reduce this to?

Commander MACOMBER. We expect to be able to obtain positions within 100 feet, based on the center of the earth, plus or minus 100 feet.

Mr. KARTH. From 1,000 to 100?

Commander MACOMBER. Yes, sir.

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Mr. KARTH. You say up to this point you have been authorized two shots?

Commander MACOMBER. Yes, sir.

Mr. KARTH. And that this involves some $12 million in funding. How many shots, Commander, will you need to reach the objective that ANNA has been designed for?

Commander MACOMBER. We have done some preliminary work on this subject.

Mr. KARTH. I mean successful shots, you understand?

Commander MACOMBER. Yes, sir. We feel that six successful shots would give us all the information we would require.

Mr. KARTH. And what would you anticipate the cost of six successful shots to be?

Commander MACOMBER. Based on present vehicle reliability where we consider 50 percent for the one we are using, a total program would run in the vicinity of some $70 million. If we can get increased vehicle reliability and go to smaller vehicles, we could reduce this to perhaps $45 or $50 million.

Mr. KARTH. Well now, don't we have increased reliability in the Thor-Delta, Commander? I don't want to be picky about this, but this is a very important part of our discussion here it seems to me.

We are talking about $45 million versus $70 million. This committee has the responsibility of authorizing funds for such programs, if NASA does participate, and you say that it is your hope that they will; this is one of the reasons why we have become interested in the project. It seems to me that we should make every effort to go to a more reliable booster that has pretty much the same capability, instead of just assuming that we should follow the course of a less reliable booster.

Commander MACOMBER. The Thor-Delta actually has a slightly smaller capability than the Thor-Able Star.

Mr. KARTH. But can it do the job?

Commander MACOMBER. It cannot for a 50° orbit. If we were going due east from Cape Canaveral it would do the job. It would be sufficiently high altitude to get above the appreciable drag region.

Mr. KARTH. How many shots do you have to make on the 50° orbit then?

Commander MACOMBER. One successful one.

Mr. KARTH. So we don't have to plan to use the Thor-Able Star, in more instances than just one, do we, Commander?

Commander MACOMBER. That is correct.

Mr. KARTH. Is that the way you are proceeding at the present time?

Commander MACOMBER. I was going on the basis of the Thor-Able Star. I have been considering going to the Thor-Delta, though.

Mr. KARTH. In five of the six instances, is that correct?

Commander MACOMBER. In four of the six.

Mr. KARTH. Four of the six?

Commander MACOMBER. There is one high altitude shot which cannot be done by a small vehicle like this. And I have also been considering going to an even smaller vehicle if it improves slightly. This would get the price down considerably beyond what it is now.

Mr. KARTH. Which vehicle is that, Commander?

Commander MACOMBER. The Scout.

Mr. KARTH. Have any of these three systems in the satellite which you have talked about been tested in space?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Which ones?

Commander MACOMBER. The doppler transmitters have been tested under the Transit program. We have gotten outstanding results with these to date. The range transponder has been sent aloft, but in every case the orbit has been, shall we say, unsatisfactory. Sometimes we have had failure of separation so that the antenna pattern was not good and to date we have not gotten a good test on the ranging system.

The optical beacon has not been tested in space. The theory behind it is sound and optical measurements have been made on pyrotechnic-type flares, shall we say, but not on a long-life beacon such as we plan to test.

Mr. KARTH. What is your problem with Secor, Commander?

Commander MACOMBER. What problem is this, sir?

Mr. KARTH. Well, what relationship does this Secor have to the Project ANNA?

Commander MACOMBER. That is the ranging transponder. It is the one that has not been——

Mr. KARTH. Is this thing operating, is this facet of the program operating with complete satisfaction?

Commander MACOMBER. There is some work to be done to tune up the ground complexes. The satellite equipment is operating perfectly, and we want to get one successful flight in order to tune up the ground complex.

Mr. KARTH. But otherwise it has been satisfactory?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Mr. Hammill?

Mr. HAMMILL. Commander, you mentioned that an ideal program would call for six satellites in orbit, is that correct?

Commander MACOMBER. That is our initial estimate. We have invited comment on this from people such as the COSPAR group who may come up with different ideas on what would be a good program, but six shots looks like a good setup right now.

Mr. HAMMILL. Where would these shots be made? By that I mean what altitude, and what inclination, and so forth?

Commander MACOMBER. The majority of them would be in the vicinity of 600 nautical miles. This will give us a little tolerance on achieving orbit and still stay out of the drag region.

The first one, the approved one, of course, is at an inclination of 50°. We would like to have one due east out of Canaveral. This, of course, could be handled very nicely by a Delta. Then we would like to go into some specialized orbits where certain phenomena occur in secular motion, shall we say. If we go at an inclination of 63.4°, there is no rotation of the orbital elipse within its plane due to the even order harmonics of the earth, the equatorial bulge, things like that.

So that we can look at the effect of the smaller terms on this motion. If we were to go at, say, 90° inclination, then all the gravity terms that are not dependent on longitude would have no effect on the precession of the orbital plane around the pole and we could get an indication of what terms there are that are longitude-dependent that would move this plane.

If we were to go equatorial, we could get an indication of the lack of rotational symetry of the earth.

Finally, if we were to get up to a much higher altitude, say 2,000 miles, which is roughly half of the earth's radius, we could use the satellite for bridging directly between the major continents. We could see it both from Europe and the United States, say, at the same time, and use the intervisible technique to tie everything together.

Mr. HAMMILL. Would this high altitude satellite be in the equatorial plane?

Commander MACOMBER. No, sir, that would be at—well, we would probably go due east out of Cape Canaveral to get the maximum effect from the earth's rotation.

Mr. HAMMILL. This 50° inclination of the first satellite is really a compromise inclination, is it not? We understand that it is not ideal from any particular standpoint. Is that so or not?

Commander MACOMBER. That is true. It was a compromise from various—for various reasons. First of all we wanted to tie the major geodetic masses together, shall we say, and we needed an orbit that would be seen from all of them and in addition to being able to be seen from all of these major land masses, we didn't want to always look south at the satellite; sometimes we wanted to look north.

So if there were any peculiarities in the refraction we could balance these out to get a better tie. This does cover all the major land masses, this 50°, and it is the maximum inclination we can get by shooting to the north, and it does exhaust the vehicle capability.

Mr. KARTH. Commander, what would have been the ideal, then, if 50 degrees isn't? What would have been? And what advantages would that have had as opposed to the 50 degree inclination?

Commander MACOMBER. When we are speaking of proving the feasibility of the system (and we have not been authorized to go on) you can't pick one that would be ideal. To fit into a program, an overall program, we could have picked something perhaps that would have been better.

Mr. KARTH. OK. Let's talk about that which would be better, then, instead of ideal. What advantages would that have had and where should it have been?

Commander MACOMBER. We would probably have gone directly into something like a 63 degree, 63.4 degree orbit, so we could get a better indication of the secular motion of the line of apsides and its orbital plane. This is for use in the gravity field only, analysis by secular motion. We can still use the 50-degree inclination for determining position and for getting the gravity field through things other than secular motion changes.

Mr. KARTH. Any other advantages to the 63-degree inclination?

Commander MACOMBER. No, sir. It covers slightly more of the earth but very little more.

Mr. HAMMILL. In a recent meeting of our panel on Science and Technology, Dr. Van Allen stated that the geodetic satellite is the only recommendation of the Porter committee which has not been carried out. And he described the slowness with which the program was pursued as almost a national dereliction.

Do you have any comment to make on that, Commander?

Commander MACOMBER. Well, I feel that the satellite we have put together is one of the most complex satellites that has been instrumented to date. Primarily because we want a long life out of it. We want 6 months to a year. We plan on a minimum of 6 months.

We would like to get extremely longer than that, but we know we can get 6 months. We had problems in matching the various pieces of equipment one to another, to prevent interference. For instance, the optical beacon, which has never been flown for a long-life time item has a discharge at the rate of about one million watts.

Mr. KARTH. Excuse me, Commander Macomber. Chairman Miller has just joined us. Mr. Chairman, thank you for coming down, sir.

Commander, this is George P. Miller of California, chairman of the full committee.

Mr. MILLER. How do you do.

Commander MACOMBER. How do you do.

Mr. KARTH. Proceed with your answer to the question, Commander, if you feel it needs further answer.

Commander MACOMBER. The optical beacon has a discharge rate of around a million watts. This is over a very small period of time, but we get a terrific field built up by this large amount of power and we had to make sure that this system was compatible with our radio frequency type systems.

We had to make sure that this discharge of power would not change the memory which controls the time of flashes of these lights. And technically speaking, it was a terrific job. I think that that is the reason that we did not implement this proposal, say, in 1958 or 1959.

Mr. HAMMILL. I think that the implication of Dr. Van Allen's remarks, and those of Dr. Whipple as well, was to the effect that the classification of the program was the primary cause of the delays.

Would you say that classification of the project had any effect on how vigorously the program was pursued within the Department of Defense?

Commander MACOMBER. No, sir. We went forward at the maximum rate on the satellite fabrication.

Mr. HAMMILL. Commander, as project officer, are you satisfied with the program?

Commander MACOMBER. Yes, sir.

Mr. HAMMILL. You don't believe it could be improved?

Commander MACOMBER. It could be continued for better results, but the instrumentation is the best we can get, I would say. I think I will be supported in this by other persons that are to appear before this committee.

Mr. KARTH. Commander, you say that you have been authorized two shots.

Commander MACOMBER. Yes, sir.

Mr. KARTH. And that to get the effect from ANNA that it was originally designed for, so that it would meet its objective, you need about six successful shots?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Now apparently DOD has not planned to continue this program to its optimum because nothing further has been authorized. Now what plans does DOD have at this time to authorize six shots or get authorization for six shots?

Commander MACOMBER. At this time we are still proving the feasibility of the system. Although we are confident it will work the way it is supposed to, we have never actually demonstrated it in space.

Until such time as we prove feasibility, we do not want to plan an expanded program and then have it collapse on us.

Mr. KARTH. If your next shot is a failure, if you haven't proved anything then, what would be the plans of DOD?

Commander MACOMBER. We would want to get funded for additional boosters so we could prove the feasibility. I have gotten permission from Dr. Brown's office to discuss with NASA the proposal for a follow-on program, I might say, so that this is in the mill, although we do not have it authorized at present.

Mr. KARTH. But you don't feel there would be any interruptions or any delays beyond what could be considered normal? Do you see any delays as a result of lack of funds, for example, in this program?

Commander MACOMBER. If the follow-on program is approved, we will have to get some boosters in a short period of time. If we are successful in our next shot, I would like to get permission to start a follow-on series with launchings at about 6-month intervals. And the initial booster procurement would be a delaying factor.

Mr. KARTH. Can you get these additional funds through a transfer of funds within DOD, Commander, or would you have to come to the Congress to get the additional funds?

Commander MACOMBER. I will defer that question to Dr. Brown, if I may.

Mr. KARTH. What about mapping as a part of this program, and what advantages do you see in it? Do you plan to use this program as a method for acquiring, shall we say, more accurate maps on a worldwide basis?

Commander MACOMBER. This program is of use to mapping pursuit, shall we say, but it is not a mapping program as such. The output from it will be used by mapping agencies.

Mr. KARTH. Do you see a considerable benefit, though, for mapping, Commander?

Commander MACOMBER. Not for a limited-area mapping.

Mr. KARTH. Broad-scale mapping, then; do you see an advantage to it in that field?

Commander MACOMBER. For tying continents together only.

Mr. KARTH. I see.

Commander MACOMBER. Within any small area you can get maps that are accurate relative one to another.

Mr. KARTH. Could it be adapted to more accurate mapping on a worldwide basis, not just tying continents together, but pinpointing locations, for example, and doing the job in many areas of the world where we need a job of mapping done?

Could you adapt the ANNA program to reach this objective?

Commander MACOMBER. I think we are going to have a definition of terms now. By "mapping" you mean establish control points at various places throughout the world?

Mr. KARTH. Whatever it takes to draft maps that are accurate to 100 feet, as you indicated the accuracy of this project to be, in any area where the satellite might overfly?

Commander MACOMBER. The present program would not do that. We can get the location of points where we set up our tracking equipment, but in order to map from these points it is necessary to go into such things as aerial photography, conventional systems of mapping.

Mr. MILLER. Mr. Chairman.

Mr. KARTH. Mr. Miller.

Mr. MILLER. You could, though, with this establish control points very accurately, couldn't you?

Commander MACOMBER. Yes, sir.

Mr. MILLER. In the different continents?

Commander MACOMBER. Yes, sir.

Mr. MILLER. And their relation one with the other?

Commander MACOMBER. Yes, sir.

Mr. MILLER. And this is something that you are not too positive about today, are you?

Commander MACOMBER. That is true. As I say, the output of this program has a tremendous impact to mapping agencies.

Mr. MILLER. It will either confirm what we now believe to be the best estimates or it will be in a position to give us these control points throughout the world?

Commander MACOMBER. Yes, sir, in any territory we can occupy.

Mr. MILLER. Occupy? All right. The mapping control point system and map are quite different. Control points give you relative positions and from the control points then you can start your mapping.

Mr. DOWNING. Mr. Chairman, that interests me, if I may. An airplane can go from one point on the globe to another point with extreme accuracy. Now I am having trouble relating it in my own mind to space.

Mr. MILLER. Well, say you are flying an airplane from here to Paris; we are supposed to know the distance between Washington and Paris fairly accurately. The assumption was that the world was round, so we would calculate it on this basis.

Now we find it is not round. There may be some differences. But when you leave here you head in the general direction of Paris, and before you get to Paris you pick up beacons coming into Paris that you fly in on. The type of aerial navigation used in known parts of the world are different today. You don't apply the same old type of navigation that you use when you are on a ship at sea or if you are out in new territory.

The thing is to get, accurately get certain points in the world with their relation to one another. Isn't that correct?

Commander MACOMBER. Yes, sir.

Mr. MILLER. It is the triangulation that was necessary in the old days for the Geological Survey; they had to go out and establish points through triangulation. After it got those points well established, then they could go out from these points and do their detailed mapping.

This is a worldwide triangulation system in a sense; is that not right?

Commander MACOMBER. Yes, sir.

Mr. KARTH. Mr. Chairman, as a result of that I felt that this Project ANNA very well adapted itself to more accurate worldwide mapping.

Mr. MILLER. It will because it will tie in the maps with reference to these points that can be definitely established as control points. In that respect it will lend itself to mapping.

But I think the commander's interpretation of the word "mapping" and ours may be a little bit different. As laymen, we look upon it as one thing, while mapping to him means the actual delineation on paper of the areas, including contours showing the elevations and depressions, and all of this on a physical setup. And this thing wouldn't be too well adapted to that.

You do this from an airplane and very successfully from an airplane, but the airplane, if it went over and mapped part of France, you wouldn't know where this part of France was with relation to, say, New York, and Houston, Tex.

Mr. KARTH. You would have your reference points.

Mr. MILLER. They are reference. So once you have these reference points, then you could do this. You notice I gave Houston a plug.

Mr. CASEY. I appreciate that.

Mr. KARTH. This is rather a long-drawn-out, tedious process, isn't it, Commander? First, you establish reference points and then you can do your mapping by aerial photography, but this is rather a tedious way of doing it, time consuming, rather difficult to do, I suppose.

My question was aimed primarily at whether or not ANNA, in itself, could be adapted at some future date to, in fact, do worldwide mapping.

Commander MACOMBER. It would be completely different instrumentation.

Mr. KARTH. I see.

Commander MACOMBER. That is a subject that I think perhaps Dr. Brown might speak on. It is completely outside the realm of work I have been doing recently.

Mr. KARTH. Are there any further questions of Commander Macomber?

Mr. RANDALL. Mr. Chairman, maybe Dr. Brown will answer it. I observed in going back over your testimony, you explain the Doppler system. Would you elaborate on what that is?

Commander MACOMBER. This comes back to the principle of the train whistle. As the train approaches you, you get an increase in frequency or apparent frequency, the frequency you hear, and as the train leaves you there is a decrease in the frequency. So that as the satellite comes around the earth and it is approaching us, we have an apparent increase in the transmitted frequency. At the closest point of approach where it is going neither away nor toward us, but perpendicular, we get the true frequency as broadcast, and then as it starts receding there is a decrease in frequency.

This change in frequency is a direct measure of the speed toward or away from the observing station and by knowing the path that a satellite must be constrained to follow by the laws of gravity, we can fit the velocity toward or away from the station to an orbit.

Mr. RANDALL. Then I note that you also have this, to put it in simpler language, a camera or a flash device or something on the satellite. But I also observe that you will have a camera on Bermuda, an observing camera, on the ground and then you say maybe one on Australia? Do you have a camera on the ground actually catching this flash from the satellite?

Commander MACOMBER. Yes, sir.

Mr. RANDALL. And the two are necessary, I mean they tie in, correlate with each other? Is that part of the technique of ANNA?

Commander MACOMBER. You mean the Doppler and the optical?

Mr. RANDALL. Yes, sir.

Commander MACOMBER. Yes, sir, all three of these systems have certain points that are very good for them and certain points where they are a little weak.

Mr. RANDALL. To recapitulate, would you enumerate the three systems?

Commander MACOMBER. The optical and the range system.

Mr. RANDALL. The range, thank you.

Commander MACOMBER. Now then, the doppler, for instance, has its maximum radial velocity from the station when it is closest to the horizon. When it is overhead, shall we say, where you have less refraction than you do at any other spot, you have no velocity toward or away from the station. So that at that point it is weak.

Now then at that point the optical is extremely strong because you are looking straight up at the satellite and there is no bending of the light rays.

Mr. RANDALL. Thank you.

Commander MACOMBER. And the systems are compatible with each other. They do reinforce each other in getting good data.

Mr. RANDALL. Only one other question, Mr. Chairman.

On page 3 I know we have always heard the expression "two-bit words." I think he has a 16-bit word. What is that, Commander?

Commander MACOMBER. I think it is a contraction of binary digit.

Mr. RANDALL. What is that?

Commander MACOMBER. Binary digit.

Mr. MILLER. You had better quit right there.

Commander MACOMBER. It is zero or one, then you carry over, you never get up to two.

Mr. RANDALL. Thank you.

Mr. KARTH. Are there any further questions?

Commander, thank you very much for appearing before us and giving us your testimony. We appreciate it greatly.

Commander MACOMBER. Yes, sir.

Mr. KARTH. Dr. Brown, would you take the witness chair, please? Dr. Harold Brown is the Director of Defense Research and Engineering. We welcome you to the subcommittee, Doctor. I understand you have a prepared statement that you would like to make. Following that I am sure the subcommittee and Chairman Miller would like to ask you some questions.

Mr. MILLER. Mr. Chairman.

Mr. KARTH. Mr. Chairman?

Mr. MILLER. I am particularly happy to welcome Dr. Brown because Dr. Brown comes from Alameda County, Calif.

Mr. KARTH. Yes, sir.

Mr. CASEY. Many good men come from there.

Mr. MILLER. I am very happy to welcome Dr. Brown here. He comes from the University of California. Whereas he does not live in my district—in this he doesn't show especially good sense—the great part of his work before coming here was done in what is now my district.

So Doctor, I have double reason for welcoming you here. If you had only moved out to Livermore, I would give you the same kind of welcome I used to give Dr. York.

Dr. BROWN. I regret not being a constituent of yours.

Mr. KARTH. If there is no objection on the part of the committee members, we will have your official biography placed in the record at this point.

(The official biography of Dr. Harold Brown is as follows:)

Dr. Harold Brown was born in New York City on September 19, 1927. He was educated in the New York City public schools and at Columbia University, where he received an AB degree in 1945, an AM in 1946, and a Ph. D. (in physics) in 1949.

From 1947 to 1950, he was a lecturer in physics and a member of the scientific staff at Columbia. He held a Lydig Fellowship in 1948–49. His research during the period was in low energy nuclear physics. During 1945–50, he was also a lecturer in physics at Stevens Institute of Technology.

In 1950, after spending a year in post-doctoral research at Columbia, he joined the University of California Radiation Laboratory at Berkeley, to work on a project aimed at using high intensity beams of particles from nuclear accelerators to produce isotopes in large quantities. In the course of this work he did research on neutron physics and expanded his activities in nuclear reactor designs.

In 1952, when the Livermore site of the Radiation Laboratory was established, he became a staff member there, being appointed a group leader in 1953, division leader in 1955, associate director in 1958, deputy director in 1959, and in July 1960, Director of the Lawrence Radiation Laboratory at Livermore. During this period his research interests included nuclear explosive design, applications of nuclear explosives to military and nonmilitary purposes, controlled release of thermonuclear energy, nuclear reactors of advanced design and weapon systems of numerous kinds.

In the past few years he has done research and analysis in the problems of detecting nuclear explosions in various environments, and has participated in a number of studies in the area of arms limitation and control.

He is a member of the American Physical Society, of Sigma Xi and Phi Beta Kappa.

Since 1956 he has been associated with the Department of Defense in a variety of advisory capacities. He was a member of the Polaris Steering Committee from 1956 to 1958. From 1956 to 1957 he was a consultant to the Air Force Scientific Advisory Board, and has been a member since 1958. From 1958 to 1961 he was a member of the Scientific Advisory Committee on Ballistic Missiles to the Secretary of Defense.

Dr. Brown was an adviser to the U.S. delegation to the Conference of Experts on the Detection of Nuclear Weapons Tests in Geneva during the summer of 1958, and a scientific adviser to the U.S. Delegation to the Conference on Discontinuance of Nuclear Weapons Tests in October 1958. (Senior Scientific Adviser from November 1958 to February 1959). He was also a consultant to the Department of State during the period 1958–60.

Dr. Brown was a consultant to several panels of the President's Science Advisory Committee from 1958 to 1960, and was appointed a member of the President's Science Advisory Committee by President Kennedy in January 1961.

He was appointed Director of Defense Research and Engineering by President Kennedy and took office on May 3, 1961.

The U.S. Junior Chamber of Commerce named Dr. Brown as one of the 10 outstanding young men for 1961.

In October 1953, he was married to the former Colene D. McDowell of San Francisco, Calif. They have two children, Deborah, 6, and Ellen, 4. The family has its home at 416 Argyle Drive, Alexandria, Va.

STATEMENT OF DR. HAROLD BROWN, DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

Dr. BROWN. Thank you very much. I believe this is my first appearance before this subcommittee. I do want to apologize for starting it off by arriving part way through a hearing. I was at a meeting in the Department of Defense which had been set up before, and I greatly regret that it prevented me from getting here at the beginning.

Mr. KARTH. Doctor, we understand.

Dr. Brown. I do have a prepared statement which I will be very happy to read or submit for the record, whichever you prefer.

Mr. Karth. Doctor, we really have no strong preference as to how you should proceed. Use your own judgment. However, the subcommittee is not as thoroughly versed on Project ANNA as we would like to be, and it may be helpful to the subcommittee if you did read it, and then extend your remarks in any shape or manner as you proceed.

Dr. Brown. Thank you. I hope I don't repeat the answers too much, the answers that Commander Macomber gave, in my prepared testimony.

Mr. Chairman and members of the committee, it is my pleasure to appear before your committee today on the subject of Project ANNA which is a U.S. geodetic satellite program. The name "ANNA" is an acronym for Army, Navy, NASA (the National Aeronautics and Space Administration), and Air Force. These are the agencies which originally collaborated on formulating the program or which were expected to participate actively in the observation program.

When the proposal for the geodetic satellite program was first presented in the Department of Defense, it was considered that the output of the program, in addition to being of a scientific nature, might be of critical military significance. For this reason, the program was temporarily classified. I still consider the program is of military significance, but I do not believe it is classified. Like much fundamental data which is also of military significance, it need not be classified.

As a result of the initial classification, NASA participation in the project did not materialize. A review of the program and its expected results has been made, however, and the classification has been removed. This opens the program to participation by NASA and, through NASA, to the worldwide scientific community.

Project ANNA is under overall direction of the Bureau of Naval Weapons, with the project director being Commander Macomber from whom you have already heard. Technical direction and responsibility for development of the satellites have been assigned to the Applied Physics Laboratory of the Johns Hopkins University.

The first ANNA satellite is scheduled to be launched into a near-circular orbit inclined at 50° to the equator, with an altitude of about 600 nautical miles. The extent of the program is limited at present, with only two launches being authorized, although we are considering further plans, of course. The second launch is scheduled as a backup to the first, both to insure a successful orbit, and to provide a sufficiently extended period of observation to produce some significant data.

It is a good thing there was a backup launch because, as you know, the first launch failed.

Mr. Karth. I wonder at this point if you would care to address yourself to the question previously raised to Commander Macomber? Let's say that the second shot is also a failure, but even considering the possibility of it being a success, how do you intend to properly fund the program so that you can have six successful shots which would then allow Project ANNA to meet its objective?

Are you going to ask Congress for further authorization or will you do it by transferring funds?

Dr. Brown. Mr. Chairman, a full project to develop all that you can from such an approach, a geodetic satellite approach using these three techniques, would take a number of years—probably 3 years more. And so we have not projected out that far.

However, I think that, should the next launch again fail, I think we would want very seriously to consider providing funds for an additional launch. In order to do that, we would not normally ask for additional funds, supplementary funds from Congress. The Defense Department prefers, because its R.D.T. & E. appropriations, total appropriations, are so large, not to come in for small amounts of money, but to reprogram for them.

Mr. Karth. Thank you, Doctor. Proceed.

Dr. Brown. The science of geodesy is concerned with the determination of the size and shape of the earth, the gravitational field of the earth, and the precise location of control points on the earth's surface. In regard to some of the questions you have asked before, you see that by itself this does not determine a map. All it does is say where the control points or points or latitude, lines of latitude and longitude, perhaps are, and whether a city is in one place or another place is not determined purely on the basis of geodesy. It needs a map, because, after all, the gravitational field of the earth and the shape of the earth, and so on, don't determine whether a river is in one place or whether a city is in one place or another.

Excellent techniques have been developed, particularly during the last two decades, which relate points on a given land mass relative to one another with impressive accuracy. These are matters of triangulation of the usual civil engineering kind. However, the recent advent of advanced space techniques has introduced new, more demanding, geodetic requirements.

In particular there is an immediate need for: (1) increased accuracy in relating the major land masses (via the major datums)—the datums are the grids essentially that cover each major continent—to each other and, of equal importance, to the earth's center of mass, (2) substantial improvement in determining the detailed structure of the earth's gravitational potential, and (3) accurate determinations of the positions of selected islands and of ocean bottom features relative to each other, to the major datums, and to the earth's center of mass.

Such results will be of civilian use, in tying together the 14 different world data in a rigid worldwide grid system. Similarly, the shape and gravitational potential of the earth are most important in geophysics, because the small departures from a perfect spheroid reflect large differences in the mantle of the earth, and knowledge of the mantle properties in turn give us information on the history of the earth.

These are the various layers as one goes from the surface of the earth down to the middle which help determine the earth's shape and gravitational potential. So by learning about the latter two things, the shape and the gravitational potential, we can learn more about the structure of the earth.

Astronomical problems will in turn be aided by determination of the fundamental reference points with respect to which astronomic measurements are made (for example, the center of gravity and axis of rotation of the earth).

Well before the first sputnik was placed in orbit, it was recognized that suitably instrumented artificial satellites could help satisfy these new requirements. Significant contributions to physical geodesy have already been made with the satellites that have been launched in the last 3 years even though none of these satellites was specifically designed for geodetic purposes.

For example, studies of the Vanguard I orbit (such as those by O'Keefe, who I believe is in NASA's theoretical division) have yielded a measure of the earth's oblateness—that is how much it is squashed—and have established the existence of a north-south asymmetry in the gravitational field; the Army's Project Betty enabled determination of the positions of remote points on the earth; the Navy has used the Transit satellites for determining positions and for extending our knowledge of the earth's gravitational field.

Most significant is that techniques for determining satellite position have been brought to a high level of sophistication, such that the necessary tools for making measurements of geodetic precision are now available. The most accurate of these techniques falls into three general groups—optical, radio ranging and radio Doppler. A continuing effort has resulted in the accumulation of considerable experience in the use of these techniques, and in the development of rather extensive systems for acquiring and analyzing satellite data which can readily be extended or modified to meet the exacting requirements of military and geodetic research.

As stated above, there are two interrelated, but distinct problems to be solved, the position problem and the gravity problem. Considering the earth's gravity field first, we note that the trajectory of a satellite is determined by the forces acting on it, and for orbits high enough to reduce atmospheric drag effects to an acceptabel level (above 400 nautical miles), the principal forces are those resulting from the earth's gravitational field.

Thus, sufficiently accurate measurements of satellite trajectories, or orbits, over an extended time period will provide information for determination of the gravity field. Orbits nearest to the earth are clearly the most sensitive to the detailed structure of the earth's gravitational field. Since gravity falls off inversely, or the potential falls off inversely with the distance from the center of the earth, and the higher harmonics, that is the perturbations in the gravity field fall off still more rapidly from the center of the earth, the closer you get to the surface, having however to remain above the atmosphere, the more accurate information you have.

Mr. KARTH. Haven't we collected considerable information on this as a result of the various orbits we have already achieved?

Dr. BROWN. Transit and Vanguard, for example, have been useful in finding out what some of the perturbations from a perfectly uniform gravitation potential are in the earth. However, those satellites, Vanguard and Transit, were not specially instrumented for this purpose and so they are not as accurate, they haven't given as accurate answers as it should be possible to get.

Mr. KARTH. I see.

Mr. MILLER. Mr. Chairman?

Mr. KARTH. Mr. Chairman.

Mr. Miller. Didn't we get some data on this field from Sputnik II?

Dr. Brown. Yes, sir, also from Sputnik. Although again I think there the measurements are probably even a little bit harder to make. However, I think you have raised a very good point, Mr. Chairman, because this shows that this is one of the arguments against classification. You can find out some of this data from somebody else's satellite.

Mr. Miller. As a matter of fact, Dr. Appleton, the head of the University of Edinburgh, or the vice chancellor, told us that we milked Sputnik dry of information that the Russians didn't know how to gather. This was part of it.

Dr. Brown. Position determinations can be accomplished in two ways, by the "orbital" method, or by the "intervisible" method. First, by the orbital method it is possible to make careful satellite position measurements in one datum—that is, in one grid which is known within itself—and to use a computed satellite trajectory to relate these to a similar set of position measurements, made in another datum.

Since the orbit is most naturally described in terms of a geocentric coordinate system—that is one whose origin is located at the center of the earth—these measurements will also locate the data relative to the center of gravity of the earth.

Second, positions can also be measured by the geometric, or "intervisible," technique; that is, through simultaneous satellite triangulations—by angle and/or range measurements. In this latter method, the satellite serves only as a reference point; its detailed orbit need not be determined.

This is very much like a situation on the surface of the earth. If two people can't see each other because there is something hiding them from each other, but can locate themselves by being able to look at another point which is visible to both of them, they can, by the use of trigonometry, tell where they are relative to each other.

Three different mensuration techniques are proposed for use in ANNA satellites: optical, radio ranging, and radio Doppler. The optical method is an extension of the classical astronomical approach. It makes use of observations of a flashing light contained in the satellite.

The flashing light is turned on at an accurately known, predetermined time, and is photographed against the star background. Using existing star charts, it is then possible to obtain the apparent right ascension and declination of the satellite as seen from the camera at a known time, that is, what angles it makes with various things, various planes. The resulting data are thus measures of angle versus time. The estimated accuracy is 2 seconds of arc, which is equivalent to an accuracy of 10 to 30 meters for ANNA satellite ranges.

The radio ranging method makes use of an apparatus designed by the acronym secor (sequential collation of range). A frequency-modulated radio signal is transmitted to the satellite and detected in a receiver; the modulation is then applied to a transmitter in the satellite which transmits to the ground stations.

The path length in wavelengths (of the modulation) from the ground station to the satellite and back to the ground station can be determined by measuring the phase difference (at the ground stations) between the transmitted and received modulation.

The outcome of all this is that—and I won't read the rest of it—is that by measuring this difference of phase you can tell how far you are from the satellite and in so doing can get the relative ground station positions to within 10 to 30 meters.

The radio Doppler technique utilizes a satellite transmitter whose frequency is controlled by a very stable quartz crystal oscillator. (This oscillator is also used to control the clock which triggers the flashing light.)

The Doppler effect produces a shift in the frequency which says how fast the satellite is moving relative to the ground stations. Here again we have some information on the basis of earlier Transit satellites which were able to measure speeds to a tenth of a meter per second. In ANNA the precision of the measurements will be one hundredth to two hundredths of a meter per second, which is roughly equivalent to position errors of 15 to 50 meters.

So we have got three different methods which produce three basically different types of data—angle, range, and range rate. The flashing light tells you what the angles are that the satellite makes—that a line between the satellite and the ground station makes with the axis of the earth and the plane of the ecliptic, say. And so doing, enables us to get one way of getting at the gravitational potential and the various distances between control points. The range is another way of triangulating, essentially, and the range rate is still a third. As Commander Macomber has described, these tend to complement each other. I think actually only two of them, the angle and the range, are equivalent to anything you do in civil engineering on the earth. But there again you can check a position measurement made by calculating angles with one—with a calculation made on the basis of ranges.

Here in the case of ANNA we have an additional one made on the basis of range rate, that is how fast the distance is changing. Since each method is subject to different sources of error, the direct comparison of the results will help to defend and perhaps correct the errors peculiar to each. Equally important the use of all three types of data in combined analysis will strengthen the control of the computing process itself, so that the resulting geodetic parameters will not only be more accurate than the results obtained by analyzing a single type of data, but will also be more accurate than a simple average of the results of three separate computations.

Well, that described the method of the plan, development of the plan, Mr. Chairman. I would be very happy to answer any other questions or any questions on this or any other aspect of the ANNA project which you or the committee members might care to ask.

Mr. Karth. Doctor, who made the original decision that Project ANNA should be nonclassified and then that it should be classified and now that it should be declassified?

Dr. Brown. I am not sure that an original decision was made that it should be unclassified, Mr. Chairman. I believe the program was started something like a year and a half or more ago so that I can't answer from my personal experience, but I do know that projects in the Defense Department are born classified and have to be unclassified by some kind of action.

Mr. Karth. It was our understanding that at its original conception Project ANNA was not designed to be a classified project and that it then became classified, and now, because of its scientific value as opposed to its military value, it has become declassified.

Dr. Brown. Let me distinguish between what I know and what I have to surmise, because it happened before I appeared on the scene. What I surmise is that the original plans were made on the basis of an unclassified program, but that the plans weren't released in an unclassified way because they weren't made final and that before the program actually became an approved program, that worries on the part of some of the military people caused it to be born as, and continue as a classified program.

Mr. Karth. Doctor, can you enumerate the facts that have changed the initial cause for classification as opposed to the now declassification?

Dr. Brown. I can discuss the factors in the latest consideration which caused the decision to be reached that the project should be unclassified, and I can perhaps make some suggestions about what may have changed in the interval.

The principal worry that people may have had, that is the principal argument against declassification, is that this gives more accurate, this could give more accurate targeting information. That is if you are shooting at something with a ballistic missile, knowing exactly where it is gives you a more accurate impact point.

Mr. Karth. Except in almost every area within the United States, for example, which might lend itself to a target so far as an aggressor is concerned, it is pretty well known and pretty well mapped and pretty well pinpointed.

Dr. Brown. I haven't talked about mapping yet. I just talked about geodesy. Actually a target point depends both on mapping and geodesy. If all you have is geodetic information, then all you have is a grid, it doesn't tell you where anything is located on that grid except those points, those control points that went into making up the grid.

If your geodesy is poor enough, then it can influence the targeting error, because even though you may have a map of the United States, for example, if you don't know where those points are—if you are shooting at the United States from some other continent and you don't know where the points in the United States are relative to the launching points, then this can contribute to error and of course it works the other way, too.

However, it has, I think, become clear, and I think it has only become completely clear recently, which is why I think there is some justification—well, which is why I think the present decision is the correct one, that there is already quite good geodetic information. There is lots of unclassified geodetic information. There is also some classified geodetic information.

But the unclassified geodetic information is at least calculated by the people who have derived it to have an accuracy that is quite good, probably good enough for almost all military purposes. And the improvement that can undoubtedly be made by a still better program like the ANNA program is not considered by the Defense Department, Secretary of Defense, to be important enough to alter the military situation particularly.

Mr. Karth. Then the program becomes scientific rather than military, does it not?

Dr. Brown. The program by itself has very great scientific implications, and is very useful scientifically. Like other scientific programs, like many other scientific programs, it also has defense implications and will be used by the Department of Defense in a number of its things, but its motivations are by no means entirely military, and so declassification is warranted on that ground, too.

The principal grounds on which a decision has to be made on declassification is: Will declassification make available to a potential enemy information which will produce an appreciable improvement of his ability to conduct military operations against the United States? And the answer in this case was "No," so it is declassified.

Mr. Karth. Yes. So in effect it does become scientific rather than military?

Dr. Brown. I find it very hard to make the distinction because there are many things that are scientific that have military applications. This is one.

Mr. Karth. I am in agreement with you that certainly almost every advance in the state-of-the-art might have, and possibly does have, some military application. When you put one against the other, however, in this instance it would probably be more scientific than it would be military, is that not correct?

Dr. Brown. It it more of a fundamental scientific program than it is a purely military application program, yes, sir.

Mr. Karth. And since that is true, Dr. Brown, who is going to manage this program? Wouldn't it then become NASA's responsibility rather than a DOD responsibility?

Dr. Brown. I agree that if we had known at the beginning and if everyone had agreed at the beginning that it was principally a scientific program, the management might have been done differently.

However, since the program has been set up as it is, I am not at all clear that the best way to do this from now on is to give it—is to transfer it to NASA. DOD has a fairly large number of scientific programs, or programs that are principally scientific in interest.

We have, for example, roughly a $200 million a year basic research budget in the Department of Defense. So that the fact that it is——

Mr. Karth. All of which, however, might lend itself to military capability, as well as scientific capability.

Dr. Brown. Yes, and I think that is true probably of the ANNA program as well, in the sense that anything that is scientific or many things that are scientific, basic science, may later turn out to have military applications.

Mr. Karth. But when you are talking about research and development, Doctor, you are talking about the unknown rather than talking about the known, so here in Project ANNA I think the situation is rather reversed. We are talking about the known now as opposed to the unknown.

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It seems that this lends itself to just a little different observation from the standpoint of who should manage a program of this type rather than basic research which the Department of Defense, of course, is interested in, does have appreciable funds to engage in, and which is understandable, and certainly this committee would have it no other way.

But now we want to talk about this ANNA project. Isn't there some kind of a DOD–NASA agreement that would affect the management of a program such as ANNA because of its scientific implications?

Dr. BROWN. I think that whoever did this, whether it was DOD or NASA, would consider it basic research and as basic research I think that——

Mr. KARTH. Just like the manned lunar landing is pretty much basic research.

Dr. BROWN. I wouldn't consider that basic research. I think that is space exploration which is a very large development project. I think that in the case of ANNA we have developed the techniques and what we don't know is the scientific information that we are going to get, namely what shape is the earth? I will leave the state of the manned lunar landing program to the NASA people who are running it, but I think that there, there is the matter of a very, very substantial development to do before you can actually explore the moon.

Otherwise we would be doing it today, instead of taking a whole decade to do it.

Mr. KARTH. Doctor, isn't there an agreement in effect, though, between DOD and NASA that a program such as this should be assigned to NASA or handled by NASA?

Dr. BROWN. NASA does have the responsibility for basic research having to do with the characteristics and exploration of space. I would consider ANNA—and I am not saying this because I think it ought to go one way or the other, I am just trying to say what category I would put the ANNA program in.

I would consider ANNA the use of space as a tool to learn more about the earth.

Mr. KARTH. A good many of NASA's satellites are designed to do the same thing.

Dr. BROWN. Oh, yes, but we are using space here as a tool and not to learn more about space. So that I think that NASA's fundamental responsibility, NASA's responsibility to conduct programs in science, space science, to learn more about space, although it is something I completely agree with, doesn't carry over. This is not, say, a perfect example of that kind of program.

Mr. KARTH. Well, despite its imperfections, Doctor, I wonder if you would be so kind as to submit for the record a copy of the agreement between NASA and DOD in this regard?

Dr. BROWN. These decisions are made on an ad hoc basis formalized and reported in the minutes of the Aeronautics and Astronautics Coordinating Board. There is no formal, general agreement.

Mr. KARTH. Has there been any specific agreement between NASA and DOD on Project ANNA, Doctor?

Dr. BROWN. Yes, there was an agreement at the beginning that the Department of Defense would do it and NASA would participate in it.

Mr. KARTH. I wonder if there is a specific written agreement that has been reached between NASA and DOD on ANNA and if there is, I would also request that that be submitted for the record.

Dr. BROWN. I think you may not find any written agreement of that, but I will try to find one and if there is, I will be happy to submit that for the record, sir.

(The information requested follows:)

The minutes of the Aeronautics and Astronautics Coordinating Board of September 26, 1960, reflect that the following was agreed to—

(1) NASA would not pursue their proposed flashing light geodetic satellite program;

(2) DOD would make available on a classified basis precision orbital data to the NASA.

(3) NASA would not be required to utilize its stations in the acquisition of this data;

(4) NASA would analyze the data to obtain unclassified scientific results pertaining to such things as the shape, size, and tides of the earth;

(5) NASA would disseminate these unclassified results in the open scientific literature.

Mr. KARTH. Fine. Thank you very much.

Mr. Chairman?

Mr. MILLER. No questions.

Mr. KARTH. Mr. Casey?

Mr. CASEY. Did I understand you correctly, Dr. Brown, to say that there is sufficient data available now for military purposes, accuracy for intercontinental missiles and so forth?

Dr. BROWN. There is sufficient geodetic data available now, Mr. Casey, for the current military needs on accuracy of ballistic missiles.

The question of the future is something else again. But there again I would anticipate that as the needs may become greater, additional programs—well, refinements of unclassified programs can probably take care of it.

Mr. CASEY. You mean for possibly the present type of missiles that we have or the potential enemy might have, and the degree of accuracy now?

Dr. BROWN. Yes, for the present kinds of missiles that we have, or are thinking about, the accuracy or the lack of accuracy is not governed by the imprecision in geodetic data.

Mr. CASEY. But if it was desired to have missiles with limited capabilities, in other words, not an all-out wipe-out operation, but limited power, but high accuracy——

Dr. BROWN. Yes.

Mr. CASEY. You would need more information than you have now.

Dr. BROWN. That is one possibility. We have considered this problem quite carefully and although I don't think I can go into it any more in open session, I think that the point that you raise has also been considered.

Mr. CASEY. Well, now, won't ANNA supply this additional information for future uses, future accuracy?

Dr. BROWN. ANNA will improve accuracy beyond what it is now, geodetic accuracy compared with what it is now.

Mr. CASEY. Well, you have to have geodetic accuracy before you can get mapping accuracy, do you not?

Dr. BROWN. It depends on the kind of map you are talking about. I think that you don't particularly need geodetic accuracy to give you a local map.

Mr. CASEY. No, but by your own terms here this is to increase the accuracy in relating the major land masses.

Dr. BROWN. That is right. If you are making a world map, if you are making a map that includes the United States and Europe, both, for example, then geodetic accuracy is important. If you are making a map that only includes the State of Virginia, then geodetic accuracy is not important.

Mr. CASEY. We are more interested as far as this is concerned in this world map proposition, are we not, than we are in how far it is from here to Richmond?

Dr. BROWN. Yes, because that is what ANNA will help you on, the first one and not on the second one, that is correct.

Mr. CASEY. That is right.

Dr. BROWN. That is correct.

Mr. CASEY. And you stated also it would be an accurate determination of the positions of selected islands. That could also be selected points on any continent, couldn't it?

Dr. BROWN. Yes. But then that would be a very limited number of points. That is to say the control points.

Mr. CASEY. Yes.

Then taking that into consideration and thinking of future developments in weapons and so forth, don't you think that there is a possibility that some of this should be considered classified?

Dr. BROWN. No, sir, I do not, and I would be glad to discuss that in closed session. I think that the arguments that go into a determination of classification or not, inevitably include some classified discussion.

Mr. CASEY. Just out of curiosity and of course I may be exposing my ignorance, of which I have lots in this particular field, I notice in your statement that you state the flashing light—this is on page 5—using the optical system, the flashing light is turned on at an accurately known, predetermined time and is photographed against a star background.

Dr. BROWN. Yes, sir.

Mr. CASEY. Using existing star charts, it is then possible to obtain the apparent rate ascension, declination and so forth.

Are existing star charts—are we relying completely on them now or are we going to find out they are out of kilter like we thought the earth was round, we have now found out that it isn't?

Are we relying too heavily on these existing star charts?

Dr. BROWN. I think we can rely on the star charts to a much greater extent than we can on the supposition of a spherical or spheroidal earth, because we can see the stars and we can map the way the stars look quite well. There is nothing in the way. And the stars are very far away, so that there is no gravitational perturbation on them.

What they are essentially is a fixed reference far, far off that enables you to say that there is a sphere at a very great distance from the earth, an imaginary sphere on which the stars are hung and looking at them gives you a fixed background, so that you can say what the angles are that the lines between the flashing light and the observation point make with that fixed background. And so it orients that line in space quite well.

We talk about a two-second of arc uncertainty in the direction and the fixed stars should be—well are accurately enough located to give you that accuracy.

Mr. CASEY. Thank you, Mr. Chairman.

Mr. KARTH. Mr. Randall.

Mr. RANDALL. Doctor, I think somewhere in the testimony it is suggested that May 10 was the date of a test, is that right?

Dr. Brown. Yes, sir, it was the date.

Mr. Randall. And the commander made some reference to the cause of the failure. Is it all right if you discuss and tell us what you believe the cause to have been?

Dr. Brown. So far as I can tell, the cause was the failure of a relay in the first stage of the booster to close and thereby institute the program which would separate the second stage and then start it. So the second stage didn't start, didn't detach, and didn't fire, and the payload didn't go into orbit.

This is a distressingly frequent occurrence, but it has nothing to do with the particular payload that we are talking about.

Mr. Randall. And to recap again, what were you using now, the different stages?

Dr. Brown. Let's see, it was a Thor-Able Star, I guess.

Mr. Randall. And in simpler language, a relay is simply a switch; is that right?

Dr. Brown. That is right, the switch failed to close and make a contact that would have caused the second stage to disengage.

Mr. Randall. Page 3 of your testimony, near the top, you referred to a mantle, a lack of knowledge of mantle properties. What are you including in the expression "mantle"?

Dr. Brown. Well, that is the crust of the earth.

Mr. Randall. You are not referring to the navigational electromagnetic fields, you are talking of the earth?

Dr. Brown. That is right. This is a part of space, this is a use of space to tell you something about the characteristics of the earth from the surface down.

Mr. Randall. Then that correlates very closely with the comment you made about the question of classification a moment ago. That the purpose or real objective is not so much a study of space as it is a study of the earth?

Dr. Brown. Yes, but we are using space to study the earth.

Mr. Randall. Using space to study the earth?

Dr. Brown. That is right.

Mr. Miller. We know very little more about inner space than we do about outer space; is that right?

Dr. Brown. That is right, sir.

Mr. Randall. Going a little further on Chairman Miller's comment about Sputnik, there are some in the Congress who feel that the Russians in many particulars have been less than fully revealing, and it was certainly my impression after Major Titov was here in his television appearance that as to that he certainly was not frank. But about this sputnik, do you feel we actually got everything they had on that?

Dr. Brown. I don't believe by any means, no, that we got everything they had. I think we got on geodesy whatever it was possible to get by knowing the position of the satellite, treated as a purely passive satellite. I mean by tracking the orbit, and you can get a quite good orbit without getting any information from the people who put it up, you can tell something about the earth's field, and we did.

Mr. Miller. What we got out of it was not something that they would have gotten out of it. We just got it, it was up here, we took advantage of its being there.

Mr. RANDALL. The point I am trying to make, Was it their offer of help, did they make it?

Mr. MILLER. Oh, no.

Mr. RANDALL. All right. That is the point I am trying to get across.

Mr. MILLER. We were just able to take advantage of the situation of this satellite being there in orbit and we took advantage of it, put it to our usage and we weren't alone in this. They got a lot of information from it in England and other places.

Mr. RANDALL. And you will furnish us with the general agreement as to this area, if you can't give us the specific agreement between NASA and DOD as to ANNA?

Dr. BROWN. Yes, sir.

Mr. RANDALL. I believe that is all.

Mr. KARTH. Mr. Downing?

Mr. DOWNING. Doctor, is there any other feasible way of accomplishing the same ends without using space? I don't quite understand the importance of determining the center of the mass of the earth. It seems to me you could drop a ball here in Virginia and then go to Russia and drop a ball and take a difference in soundings and by some instrumentation determine that.

Dr. BROWN. I think it might be possible to do something like that, Mr. Downing. I am sure you couldn't get anything like the accuracy, because by having something up in space you can have two people looking at it at the same time from quite a large distance. What this essentially does is give you an enormous baseline which makes your triangulation errors smaller because there are fewer triangulations, to use civil engineering terms.

But this isn't the only way to do it. I think there are other ways, having to do with radio techniques—principally radio techniques, I would say.

Mr. DOWNING. Thank you very much. It is a very interesting statement.

Mr. KARTH. Doctor, this Project ANNA is really in its infancy, is it not?

Dr. BROWN. Yes. In fact, as you have heard, we haven't yet gotten one successful launch. However, a lot of the development has been done. In fact, the development of the three techniques is really complete, and now what we need is some data that will tell us how useful they are before we expand or correct the program.

Mr. KARTH. The follow-up program, though, is going to be much more significant in terms of size, isn't it?

Dr. BROWN. It is going to be more—a follow-on program would certainly be considerably more expensive. How much more it will contribute, you can't tell beforehand. In many cases the cream is skimmed off the top of a new scientific field or a new technique with a very little work and then you have to put in lots more effort to get very much more accuracy.

Mr. KARTH. That is pretty much the case insofar as Project ANNA is concerned, isn't it?

Dr. BROWN. I don't know. I really won't be able to tell until we get some data. I suspect that the first few flights are likely to be the most important, but you can really never tell in science. What happens is that you get a lot of data and you are sure you have got it all. Then you just refine it a little bit and you find things you just didn't know about it before.

Mr. KARTH. Up to this point we have no data.

Dr. BROWN. We have none.

Mr. KARTH. The reason I pursue this line of questioning, Doctor, is because it seems to me that on other programs where we have been much further advanced than we are in Project ANNA, management transfers have taken place, without encountering any difficulties. So the reason that I asked the question is to ascertain in my own mind whether or not the management transfer insofar as ANNA is concerned would, in fact, present any difficulties.

Quite frankly, I don't see that it would encounter any difficulties, but if you feel it would, I would ask you to address yourself to that specific phase at this moment, because I am not sure that we can get you back again. We know that you are very busy, and we don't want to disturb you too much.

Dr. BROWN. I think the coordination on ANNA has been good enough so that possibly a management transfer could take place. I think that having a management transfer take place when there has been one unsuccessful launch and another launch coming up is probably not the best time in the world to do it.

Mr. KARTH. It is probably better though, than if you get to a point further than that. Let's say you have two failures; wouldn't it even be more difficult then to transfer?

Dr. BROWN. I think it probably is—in fact, I consider it a DOD responsibility to keep at this until we get one up there. Once one is up there, then we can sit down with the NASA people after there is some data, see how the program looks after that and decide how to manage it.

Mr. KARTH. Mr. Casey?

Mr. CASEY. One thing, Dr. Brown. You state his time is limited. I am still not satisfied with answers I received. Of course, as he states the explanation, a lot of it would be classified. I don't want to be an alarmist or anything of that nature, but we did have, as you recall, one great scientific breakthrough that was in all the public libraries when we wanted to utilize it and had to go around picking it up.

I would like to suggest to the chairman that he might consider, whether it is Dr. Brown or whoever it may be, to give us a detailed explanation in classified language of why this should be unclassified. I would like for you to consider that.

Mr. KARTH. All right, Doctor, it may be that we will be asking you, then, within a very short period of time—certainly at your convenience—when you can return to give this information to the subcommittee, and I would ask that Mr. Hammill arrange a tentative time convenient for you, and also for the subcommittee members.

Dr. BROWN. If it is appropriate, Mr. Chairman——

Mr. KARTH. I think Mr. Casey has made a good point.

Dr. BROWN. I think we would even be glad to make a classified statement for the record which could be quite brief and could be handled by the subcommittee in a classified way.

Mr. KARTH. Well, it may be that during a classified briefing one of the subcommittee members would like to ask questions. Mr. Casey seems to be particularly interested in this area.

Dr. BROWN. Surely.

Mr. KARTH. I am sure that he would have some questions.

If there are no objections, Mr. Hammill will tentatively arrange with you to appear at a classified hearing, or any one whom you might assign to that project.

Dr. BROWN. Surely.

Mr. KARTH. Mr. Hammill, do you have something?

Mr. HAMMILL. I just wanted to follow up Chairman Karth's line of questioning on management.

In view of the declassification of the project, can we assume that there will be international cooperation in the program?

Dr. BROWN. Yes, I believe there will be, Mr. Hammill. In fact, NASA, which is the appropriate organization, no matter what the management, to handle the international aspects of it, made a report to the COSPAR meeting on this satellite and laid down a number of rules for international participation, the rules having to do with the criteria which would have to be met by the stations which would observe the satellite flashes.

What we would then do is arrange to have the flashing light work when in a given position with respect to stations which did meet these criteria.

Mr. HAMMILL. Now even recognizing that some of the data which is produced by this satellite system will be of interest and use to the military, still the fact of declassification indicates that it is primarily a scientific project.

Now, would the Defense Department have any objection to NASA taking over management of this program so that it might pursue the scientific ends, and also so that NASA might be in a primary position to engage in the international cooperation which might be envisioned?

Dr. BROWN. I think that that is something that we and the NASA management will have to discuss in view of NASA's other responsibilities, the interests not only of Defense, but of other Government agencies in this project. After all, as I said, it is a program principally about the earth. So the Coast and Geodetic Survey, I think, has a very considerable interest, and so on. Defense Department doesn't feel particularly proprietary about this, but I don't think that we can just make a transfer without thinking about the other problems concerned and the other agencies involved.

Mr. KARTH. Mr. Beresford?

Mr. BERESFORD. Mr. Chairman, my questions have all really been raised, except for those bearing on classification.

Mr. KARTH. Mr. Chairman?

Mr. MILLER. No further questions.

Mr. KARTH. Are there any further questions? Mr. Randall?

Mr. RANDALL. One brief question. The commander made reference to Meade's Ranch as a datum point in Kansas. Is that the central datum point that you are now using?

Dr. BROWN. I don't know.

Mr. RANDALL. I thought you might be familiar with that.

Dr. BROWN. I guess—it may very well be the central datum point for maps in the United States.

Commander MACOMBER. Yes. North American datum is based on that.

Mr. MILLER. Where is this located?

Mr. KARTH. He is wondering why it couldn't have been placed in Missouri.

Mr. RANDALL. It is very close to Missouri.

Mr. MILLER. I know there is one place in Kansas where they have a big sign along the road "Geographical Center of the United States Three-Quarters of a Mile Up," so I was wondering.

Mr. CASEY. You had me convinced that Alameda County was the center of the United States.

Mr. MILLER. No, no. All we are interested in is the contribution Alameda County can make with the very fine, intelligent people that live there.

Mr. CASEY. I was ready to agree with you.

Mr. KARTH. Before we adjourn, Mr. Hammill will announce the committee's hearing schedule on Project ANNA for the remainder of the week.

Mr. HAMMILL. Tomorrow morning the subcommittee will meet in this hearing room at 10 a.m., and we expect to hear from Dr. Homer Newell, the Director of the Office of Space Sciences of NASA; Mr. John Nicolaides, also of NASA, will testify, too. He probably has as long a history and association with this program as any man. They will be followed by Adm. H. Arnold Karo, Director of the Coast and Geodetic Survey, Department of Commerce.

On Wednesday morning we will meet again at 10 a.m., in this hearing room, and we will hear from Dr. Fred Whipple of the Smithsonian Astrophysical Observatory, Cambridge, Mass.

Would you like me to announce the Centaur hearings?

Mr. KARTH. Yes, if you will for the information of the subcommittee members, Mr. Hammill.

Mr. HAMMILL. Tomorrow afternoon we are scheduled to meet in this hearing room at 2 p.m. to began an investigation of the Centaur launch vehicle development program. We expect as witnesses Dr. Homer Newell, Director of the Office of Space Sciences of NASA and Dr. Wernher von Braun, Director of the Marshall Space Flight Center of NASA.

Those hearings will be continued on Friday morning in this hearing room at 10 a.m., and at that time we will hear from the program directors of the Centaur development program from the two major industrial contractors, General Dynamics/Astronautics, and Pratt & Whitney Aircraft Corp.

Mr. KARTH. Mr. Chairman, we would like to very much encourage you to attend if you can find time in your busy schedule.

Mr. MILLER. I wanted to talk to you about them.

Mr. KARTH. We would also like to invite the other members of the committee who might be interested in attending the hearings.

If there are no further questions at this time of Dr. Brown or Commander Macomber, the subcommittee will adjourn until tomorrow morning at 10 a.m.

(Whereupon, at 12:02 p.m. the subcommittee adjourned, to reconvene at 10 a.m., Tuesday, May 15, 1962.)

Commander MARQUARDT. Yes. Kleinl American Legion is active on that.

Mr. ALBERT. Where is it located?

Mr. [illegible]. It is [illegible] [illegible] county [illegible] [illegible] in [illegible].

Mr. [illegible]. It is very close to Missouri.

[illegible] Kansas [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] American [illegible] [illegible] [illegible] United States.

Mr. [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] people [illegible] [illegible]

[illegible] agree with you.

Mr. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

Mr. [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

Mr. ALBERT. [illegible] we would like to very much [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

(Whereupon, at 12:02 p.m. the subcommittee adjourned, to reconvene at 10 a.m. Thursday, May 16, 1963.)

PROJECT ANNA

TUESDAY, MAY 15, 1962

House of Representatives,
Committee on Science and Astronautics,
Subcommittee No. 3,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 10:15 a.m., in room 216–8, New House Office Building, the Honorable Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. Karth. The subcommittee will come to order. Dr. Newell, I want to thank you very much for coming here this morning.

Dr. Newell. Our pleasure.

Mr. Karth. I don't know that I have ever said this before, but I consider you one of the outstanding men in Government, and this is cause for double pleasure that you appear before us this morning. If you would like to proceed with your prepared statement, and Mr. Nicolaides will follow you with his prepared statement, then together you may submit to questions.

Any way you want to proceed, Doctor, is all right with us.

Dr. Newell. Thank you, Mr. Chairman.

The prepared statement I believe has been distributed.

STATEMENT OF HOMER E. NEWELL, DIRECTOR, OFFICE OF SPACE SCIENCES, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and members of the subcommittee, the concept of a geodetic satellite was born more than 5 years ago, when various payloads were being considered for flight during the International Geophysical Year. The geodetic satellite was conceived as a relatively small but heavy satellite, carrying a flashing light which could be easily observed against the nighttime background of stars.

Using well-known astronomical techniques, it is possible to determine the direction of such a satellite very accurately, and thereby determine the locations of the observing stations and the orbit of the satellite with great precision. Such precision is possible because a light which flashes only briefly can be seen at the same instant in widely different locations and, hence, can be used for triangulation to determine the distance between these widely separated locations. Having such detailed orbital and position data, information may be derived concerning the detailed gravitational field of the earth.

During and immediately after the International Geophysical Year, the Vanguard satellites were unable to carry such a flashing light because of the weight of such an instrument. However, the 6-inch diameter Vanguard I, with its electronic equipment, proved to be useful in making the first determination of the north-south asymmetry of the earth's gravitational field, more popularly known as the "pear-shaped earth."

In December 1957, a group of U.S. geodesists initiated an informal Committee on Geodetic Applications of Artificial Satellites which was soon sponsored officially by the American Geophysical Union. In September 1958 this committee made their recommendations for such a satellite to the National Advisory Committee for Aeronautics. A similar committee of the Space Science Board was formed at about the same time.

In recognition of the scientific importance of the geodetic satellite, such a satellite was included in the NASA fiscal year 1960 budget presentation to the Congress in April 1959. Preliminary studies of the satellite design continued through most of 1959, in order to meet the needs of competent geodesists throughout the international scientific community, including those in other Government agencies and in the universities.

Excellent cooperation was received from the Department of Defense, other Government agencies, and civilian organizations. It appeared that a program could be arranged which met the needs of each of these groups.

On this basis, NASA prepared specifications for the satellite, and requested proposals to meet these specifications. A detailed operating plan was developed to meet the needs of all interested groups, both civilian and military, and including the international geodetic community.

It was at this time in mid-1960 that the Department of Defense recommended that the data obtained from the geodetic satellite program should be classified. The Unmanned Spacecraft Panel of the NASA/DOD Aeronautics and Astronautics Coordinating Board confirmed this recommendation in August 1960.

In view of its charter for the peaceful exploration of space, NASA canceled its plans for a geodetic satellite at this time. The flashing light, together with its supporting technological and operational developments, were, of course, made available to the Department of Defense ANNA geodetic satellite project.

NASA remained in contact with the Project ANNA personnel, and, in general, continued to explore unclassified means by which the international scientific community might be able to participate effectively. No such effective means were found. Meanwhile, the scientific community intensified its quest for a flashing light geodetic satellite.

The classification of Project ANNA was maintained up until 18 days ago, when it was declassified during the meetings in Washington, D.C. of the Committee on Space Research (COSPAR) of the International Council of Scientific Unions. This action was most gratifying to the international geodetic community and also to NASA.

With the concurrence of the Department of Defense, NASA reacted quickly by inviting the COSPAR delegates and other members of the scientific community to utilize the ANNA satellite for widespread observations by competent geodesists and astronomers throughout the world.

I might interpolate here, Mr. Chairman, that the material provided to COSPAR was checked out with the Department of Defense and signed off on by Harold Brown, and a copy of this material has been made available.

Mr. KARTH. Thank you.

Dr. NEWELL. I might suggest that this could be inserted in the record here if you will.

Mr. KARTH. Yes. If there are no objections, it is so ordered.

(The material referred to is as follows:)

REPORT TO COSPAR ON GEODETIC SATELLITE

As announced at the "Symposium on the Use of Artificial Satellites for Geodesy" on April 27, the United States plans to launch a satellite carrying a light which can be flashed to make possible the accurate determination of the direction of the satellite during the hours of darkness. It is probable that approximately 20 sequences of five flashes each will be possible each day.

The purpose of the ANNA satellite will be to determine the variation in the gravitation field for the study of the earth's interior and to obtain improved geodetic locations for mapping and navigation. The intensity of the Xenon flashing light as seen by an observer will depend not only on his range from the satellite, but also on his direction with respect to the flashing lights which are oriented so as to give maximum intensity in a direction parallel to the earth axis. However, a camera capable of observing a 12th magnitude star with a 1 minute exposure should be able to observe the light under a wide range of conditions.

Further details about this satellite are given in the paper presented on April 27 by Commander Macomber.

The National Aeronautics and Space Administration plans to observe this satellite extensively with the cameras of its Minitrack network and with the Baker-Nunn cameras operated by the Smithsonian Astrophysical Observatory. The positions obtained from these observations, together with those from other U.S. observers, such as the Naval Observatory, the Coast and Geodetic Survey, and the Air Force, will be collected and published as soon as feasible. To permit other observations of this satellite, here as well as abroad, the orbital elements of the satellite and the times for which flashes are programed will be supplied to SPACEWARN for international distribution.

At first, it is hoped that information on times of flash and positions of flashes can be provided at least 24 hours in advance of the actual flashes. As time goes on and familiarity with the process and orbital accuracy increases, it is hoped to increase this advance notice to approximately 1 week.

Initially, the flashing lights will be scheduled at times optimum for stations within continental United States of America, with priority for calibration of radio tracking equipment. However, even during this period some flashes should be available each day for oversea locations.

After the satellite operation and observing problems become better understood, NASA intends to arrange for programing the satellite light flashes for a limited number of stations which can provide the greatest geodetic weight in supplementing the existing tracking network. Such stations will be expected to meet the following criteria:

(1) Be able to obtain a usable image from 1.7×10^{-9} lumen-seconds/meter ^{2} energy density at the telescope over a 2.5 ms flash (equivalent to a 1-minute exposure of a 12th magnitude star at zenith with 0.7 transmission). (Dependent on aperture, film sensitivity, and distortion characteristics.)

(2) Be able to measure the direction of a star with reference to other stars in its vicinity with a standard deviation of ±2 inches or less.

(3) Provide geodetic coordinates of the telescope with respect to the major datum for its country, or if the position on a major datum is not available, a full description of the datum to which the position has been referred.

(4) Agree to provide reduced positions from all usable observations for publication, within 6 months of the observed flash. A standard form will be stipulated for these data.

(5) Have telescope available to observe whenever scheduled as the primary observer of a flash by the control center, not to exceed 20 nights per month. If local weather situation indicates a high probability of clouds this information shall be transmitted to Goddard 36 hours in advance of the observation so an alternative flash time can be chosen.

(6) Have ready access to SPACEWARN. Interest in participating to this extent should be indicated in the statement described above.

In addition, NASA will be willing to publish reduced observations for observing stations meeting the first four of these criteria. Stations meeting such criteria and wishing to participate should submit in advance to NASA a description of the instruments which they have available, their staff experience, and the exact coordinates of the station.

As stated, the light will be flashed only for those stations which provide the highest geodetic weight in supplementing the present tracking networks. Thus, appreciable emphasis will be placed on the geographical location of the stations. However, those stations selected for participation to this extent will be included on equal basis with the NASA and SAO networks in planning the programing of the light flashes.

Stations which do not meet the specified criteria may nevertheless participate in observing the satellite if favorably situated. Such independent observers may compute the necessary look-angles by arranging to obtain from the nearest SPACEWARN station orbital elements and the times of scheduled flashes. Data will not, however, be expected from these stations.

Further contact concerning this project should be with Dr. Nancy G. Roman, National Aeronautics and Space Administration, 1520 H Street NW., Washington 25, D.C., United States of America.

LOCATIONS OF NASA CAMERAS

Minitrack stations:
- Santiago, Chile
- Antofagasta, Chile
- Lima, Peru
- Quito, Ecuador
- Fort Myers, Fla.
- Blossom Point, Md.
- St. John's, Newfoundland
- East Grand Forks, Minn.
- Goldstone, Calif. (Mojave)
- Fairbanks, Alaska (College)
- Johannesburg, South Africa
- Winkfield, England
- Woomera, Australia

Baker-Nunn (SAO):
- Arequipa, Peru
- Villa Dolores, Argentina
- Curaco, Netherlands West Indies
- Jupiter, Fla. (near West Palm Beach)
- Organ Pass, N. Mex.
- Maui, Hawaii
- Woomera, Australia
- Near Tokyo, Japan
- Maini Tal, India
- Chiraz, Iran
- Cadiz, Spain
- Johannesburg, South Africa

Dr. NEWELL. This will both enhance the usefulness of this satellite from a geodetic point of view, and project an international image of the United States as the country which consistently favors open access to the technology, as well as the results, of space research. Initial comments by COSPAR members were quite consistent with this image.

NASA and DOD representatives are currently working out details of plans for flashing the light at various locations and for collecting and publishing the resultant data. Naturally, not all of the details have been worked out in the limited time since the declassification.

However, it is fair to say that the difficulties seem to be of a routine technical nature. The interval between the unsuccessful first attemp to launch ANNA and the next attempt should afford adequate time to complete these arrangements to the satisfaction of all concerned.

Mr. KARTH. Thank you very much, Dr. Newell.

If Mr. Nicolaides would like to proceed at this point, we would be very happy to receive your testimony.

I might suggest, if there is no objection, that the biographical data of Mr. Nicolaides be copied into the record at this point.

(The biographical data of John D. Nicolaides is as follows:)

Mr. John D. Nicolaides is the Director of Program Review and Resources Management, Office of Space Sciences, National Aeronautics and Space Administration. Previously he served as the technical director for the Navy astronautics program in the Bureau of Naval Weapons, where he was responsible for such programs as Transit, ANNA, Lofti, Hydra, Caleb, among others. Prior to this he was the Chief Exterior Ballistician and later the Assistant for Aerodynamics, Hydrodynamics and Ballistics in the Navy's Bureau of Ordnance.

Prior to the Korean war, Mr. Nicolaides entered Government service with the Army's Ballistics Research Laboratories where he did original research in missile flight dynamics and exterior ballistics. At the conclusion of World War II, Mr. Nicolaides joined the General Electric Co. and served as aerodynamics project engineer on the guided missile Dragonfly (MX-802).

During World War II, Mr. Nicolaides served as a naval officer in the capacity of an aeronautical engineering specialist with the Naval Bureau of Aeronautics field activities.

Mr. Nicolaides is a native Washingtonian. His universities include Lehigh University (B.A.), Rensselaer Polytechnic Institute, Johns Hopkins University (M.S.E.), and the Catholic University of America (Ph. D. pending). Mr. Nicolaides is a lecturer in the graduate schools of both Maryland University and Catholic University of America where he teaches courses in missile flight and astrodynamics. He is an associate fellow of the Institute of the Aeronautical Sciences, a senior member of the American Rocket Society and a member of the Washington Philosophical Society.

He is the author of numerous scientific publications and articles. His hobbies include golf, tennis, and farming.

He is married to the former Mary Virginia Driscoll of Albany, N.Y., and has a 4-month-old daughter, Kathleen.

STATEMENT OF JOHN D. NICOLAIDES, DIRECTOR, PROGRAM REVIEW AND RESOURCES MANAGEMENT, OFFICE OF SPACE SCIENCES, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. NICOLAIDES. Thank you, Mr. Chairman. It is a particular honor and privilege for me to have this opportunity to appear before your committee today on the subject of Project ANNA.

One essential feature must characterize any geodetic satellite program. This essential feature is teamwork. No single group or single agency or single service or single country can carry to successful completion this truly worldwide job.

If this one point is clearly recognized then the geodetic satellite program will succeed. It may not be important who manages it, as long as it is recognized that an enthusiastic, cooperative, and unclassified team effort is involved. The manager must also recognize the need for additional satellites at different inclinations and altitudes in order to determine the various terms in the gravity force field expansion as well as to provide the independent intervisible determination of position.

Also, of extreme importance, the project manager must be able to muster up the support required to finance a continuing program. Any discontinuities of effort will reflect extremely unfavorably on this country's ability to carry out a sustaining, fully cooperative scientific program.

If it is decided that this program is to be done, then it must be also decided, at that instant, that we must see it through to a successful conclusion, and that it should be adequately funded and managed.

We are now on our way to an excellent start. In the time between now and the next launching later this year, we should be able to pull together such an excellent, sustaining team effort.

Thank you, Mr. Chairman.

Mr. KARTH. Thank you very much, Mr. Nicolaides.

Dr. NEWELL. I notice in the course of your testimony that ANNA did not start as a classified project. Did it?

Dr. NEWELL. The NASA portion of the project began before we had heard of ANNA. ANNA came into being after our initial thinking on this program, or at least it came to our attention in the Office of Space Sciences. I think Mr. Nicolaides can say whether ANNA itself, started as a classified project.

Mr. KARTH. Well, you are talking about a specific technical name for the project itself. But when the idea for a geodetic satellite was conceived, in the minds of the people attending IGY, and NASA people and everyone else concerned, it was not at that time considered to be a classified project, nor was it considered that it needed to be classified; is that correct?

Dr. NEWELL. That is correct.

Mr. KARTH. As I understand your testimony, when it became classified, NASA did not object to it becoming classified at that time, or at least your testimony doesn't indicate that they were dissatisfied with the project becoming classified.

Is this correct, or did I misunderstand your testimony?

Dr. NEWELL. Well, the testimony did not go into detail on that point.

Mr. KARTH. Do you care to address yourself to the question?

Dr. NEWELL. The unmanned spacecraft panel of the NASA-DOD Aeronautics and Astronautics Coordinating Board——

Mr. KARTH. Will you explain what the composition of this panel is?

Dr. NEWELL. Yes, sir. This is a panel which has been created by the Aeronautics and Astronautics Coordinating Board for consideration of scientific and applications satellite programs in which the NASA and DOD are either concerned or have mutual interests. The Coording Board consists of representation from both NASA and the Department of Defense, is jointly chaired. The cochairmen are Dr. Hugh Dryden, of NASA, and Dr. Harold Brown, of the Department of Defense.

The Board meets periodically to review common problems and to try to arrive at agreements on how to approach the solution of those problems. This Board has six panels covering various areas, such as vehicles, ground support, and, as I have mentioned, the Unmanned Spacecraft Panel for covering satellites and space projects.

The Unmanned Spacecraft Panel was asked to review this question of the classification of data. This question was reviewed at considerable length. Briefings were given by NASA personnel on the importance of this as a scientific project, on our feeling that what was being done for the scientific community should have no classification.

At the same time briefings were provided by the Department of Defense agencies on their needs for a geodetic satellite and a review of the reasoning behind the classification of the project.

As a result of these briefings, a report was made to the Aeronautics and Astronautics Coordinating Board. The final decision was that the Department of Defense's needs were overriding and that this should continue to be classified.

Mr. KARTH. Who were the members, Doctor, of the Unmanned Spacecraft Panel?

Dr. NEWELL. The Unmanned Spacecraft Panel at this time consisted of the following: I was chairman. Mr. Cortright of NASA, Mr. Clark of NASA, Mr. Wyatt of NASA were the other representatives from NASA. General Lewis represented the Army, and there were Adm. T. F. Connolly from the Navy, and General Curtin from the Air Force, and from the Department of Defense, Mr. John Rubel.

Mr. KARTH. So you have an equal number of people on the panel from NASA and from the Department of Defense?

Dr. NEWELL. That is correct.

Mr. RANDALL. I only find three from NASA. Was Dr. Dryden an ex officio member?

Dr. NEWELL. No. I was chairman, Mr. Cortright, John Clark.

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Mr. RANDALL. I missed John Clark.

Mr. KARTH. And at that time was it the unanimous opinion of this panel that Project ANNA should be classified?

Dr. NEWELL. It should be clear that this panel did not determine the classification. We reviewed the question and although, as scientists, the NASA people felt that there was not complete justification for classifying it, we also felt that we were not in a position to completely judge this question.

So there was in effect an agreement that we would not press this matter further.

Mr. KARTH. But you feel very strongly now that the proper action has been taken insofar as the declassification of Project ANNA is concerned?

Dr. NEWELL. As a scientist I do; yes.

Mr. KARTH. Mr. Nicolaides, you make quite a point of the fact that before a project such as ANNA could become successful it needs worldwide cooperation. Would you care to amplify on the reasons for that statement?

Mr. NICOLAIDES. Yes, sir. We are studying the earth, we are determining the center of gravity of the earth. To do this, we must know the location of a homogeneous matrix of stations located around the earth and we must also utilize the best brains and talent that are available in this country and abroad in order to carry out this job.

In studying the earth one must look at the entire earth and there is no question in my mind that you have to have a completely cooperative effort. On that point, let me state there has never been any question in anybody's mind at any time that the program shouldn't be a completely cooperative one.

When the IGY program was first conceived, it was at that time thought to be a completely cooperative effort. When NASA picked up the ball after its formation, NASA also engaged in a cooperative program with the Air Force, the Army and the Navy, the Coast and Geodetic Survey, and other countries to put together a sound effort. And I might say when the Department of Defense picked up the ball on the program, they also envisioned a completely cooperative effort.

The classification of the project, however, did eliminate the unclassified scientists from the program, and, as a result, did limit the potential for achievements that the project could come forward with.

Mr. KARTH. Has this resulted in a delay of any kind, Mr. Nicolaides, in your judgment?

Mr. NICOLAIDES. As you know, Mr. Chairman, I have been privileged to work on Project ANNA since its earliest days and I have been privileged to be informed on both the total DOD program as well as the NASA program, and in all sincerity, I think that the present ANNA effort represents the best that could have been done by the country at this time, and I make that statement not because NASA didn't have a very outstanding program—this is not the case—I make the statement only because ANNA is based upon existing, proven hardware. The satellite shell has been in orbit before, the telemetery and power systems have been in orbit before, the Doppler system is thoroughly tested, the Secor system has been in orbit and has had an opportunity to perform. The flashing light is the only new element, and there are many years of research behind that flashing light.

So, as a result, I do not think the country has lost any time or capability up to this point. I am concerned about the future. The Project Officer yesterday said that six satellites are required and I think that that is a clear judgment as to the scientific needs. I think this country should go forward with the geodetic satellite program now, which involves satellites at the inclinations and altitudes that are required. But I think the past performance has been outstanding.

I think the Defense Department, basing their work on much that the scientific community and NASA have done, and using their own outstanding capabilities, have done an excellent job. The recent failure is, of course, unfortunate.

Mr. Karth. Now that it has been determined that this has great scientific significance and that the military application it might have, whatever it be, is of at least secondary importance, who do you think should manage the project?

I noticed in your testimony you talked about management here in at least three or four different places in the space of one and a half pages. Who do you think should manage the project?

Mr. Nicolaides. Let me say I am already on record on that, Mr. Chairman. When the Department of Defense gave me the opportunity of putting together a joint program, I was of the view at that time that it should be managed by the Department of the Navy, primarily because the technology was based on the Transit satellite and because the Navy had the Transit tracking stations and also considerable experience in the optical tracking with the Naval Observatory, and they happen to be a neutral ground between the services for this particular effort.

I think that as an unclassified effort there is no question but that the Navy could continue to manage this program. There is also absolutely no question in my mind that NASA could manage this program. The only question that arises is to the motivation. I do think that NASA, being a scientific organization and highly motivated to do this kind of an effort involving worldwide cooperation, might be in a better position to get the funds necessary to do it. And I do view with alarm the fact that the present ANNA program has only one approved successful satellite in orbit, when as the project officer stated, at least six satellities are required. To mount an effort of this kind you must go forward with that complete effort now.

You have tracking stations to be developed, mobile sites which I am sure the Coast and Geodetic Survey is extremely capable of manning, and also the satellite itself needs to be improved for future shots to give more flashes of the light and reduce its weight in order that we can go to the higher altitudes that Dr. Whipple desires and others desire for the intervisible mode of operation.

Mr. Karth. From what you have just said, I have concluded that you are dissatisfied with the speed or the progress that has been made with Project ANNA.

Mr. Nicolaides. I am completely satisfied with the progress to date. I think, as Dr. Van Allen has stated, that the time is now to make a decision to go forward with this effort. I don't think we can afford to wait until after the results of the next shot are looked at, as was testified yesterday.

I think that by the spring of this year we should go forward with a sound geodetic program which is a truly cooperative effort.

Mr. KARTH. Who must make this decision?

Mr. NICOLAIDES. I am assuming that the Department of Defense is going to get together with NASA and will make such a decision, although from the testimony yesterday I am not entirely clear as to when this would occur. It was my understanding that NASA and Department of Defense were to get together in the very near future.

I had the impression from some of the remarks yesterday that consideration for a follow-on program would only be undertaken after a successful orbiting satellite and, of course——

Mr. KARTH. That is the way I understand the testimony of yesterday.

Mr. NICOLAIDES. And, of course, the chances of success in the future are no better than they were in the past. Your probability doesn't improve after you have had a failure or a success.

The chances this fall are once again 50 percent if you take an optimistic view of the Thor-Able Star vehicle.

Mr. KARTH. Would you say that the choice of the launch vehicle was a good one, Mr. Nicolaides? Let me ask you this, would you have chosen any different vehicle?

Mr. NICOLAIDES. That is a very difficult question for me to answer, Mr. Chairman. As you know, for a number of years I was the technical director for the Navy astronautics program and, as you also may know, the Navy made many efforts to choose their own launch vehicle. They were unsuccessful. They were informed that they were to use the Thor-Able Star and that is precisely the vehicle that they are constrained to use.

Mr. KARTH. This is having rather poor success record, isn't that a fact?

Mr. NICOLAIDES. I am only too well aware of that, sir. You are right.

Mr. KARTH. Couldn't the Thor-Able do the job?

Mr. NICOLAIDES. The Thor-Delta, sir.

Mr. KARTH. Thor-Delta, I am sorry.

Mr. NICOLAIDES. I have a curve on the Thor-Delta if you would care to see it, that indicates its performance capability.

Mr. KARTH. I think it would be good for the committee. But I do remember during the testimony that NASA witnesses gave to this subcommittee some 1½ months ago, that the success ratio of the Thor-Delta was extremely high.

Mr. NICOLAIDES. It is outstanding, sir.

Mr. KARTH. If you want to review that for the committee at this time, Mr. Nicolaides, you go right ahead.

Mr. NICOLAIDES. Thank you, sir.

The success of the Delta has been outstanding and it is outstanding for a very simple reason, that the country fixed on this vehicle and stayed with it. The only way you can achieve success is to pick a system and then follow it through to the bitter end.

Now on this Thor-Delta we have had nine shots, and the last eight shots have been completely successful. So naturally we are very happy with it. It is based upon the excellent Air Force technology on the Thor and the excellent work of the Navy in the Vanguard program. These two systems were coupled together to make the Delta vehicle.

Now with respect to the performance of the present Delta vehicle it is not significantly different from the Thor-Able Star. It does give a rougher ride to the satellite. So in that respect the Thor-Able Star is a better vehicle.

However, the satellite designers tell me that it is very easy to beef up the design of the satellite to take the slightly rougher ride which you get with the Delta. So the present Delta's performance is much the same as the Thor-Able Star.

Mr. KARTH. As I understand the testimony yesterday, Mr. Nicolaides, the Thor-Delta would be able to launch any one of these ANNA satellites into orbit with the exception of the 50-degree inclination satellite, is that correct?

Mr. NICOLAIDES. We checked back on that last night and this morning, Mr. Chairman, and the numbers—I am not sure about the weight of the satellite. Using a 300-pound weight, the Delta vehicle, the present Delta vehicle can lift the satellite to a 600-mile orbit in the polar case, and this is of course more difficult than the 50° that was mentioned yesterday.

In the case of an AMR launch at 30° inclination it can lift to an altitude of 800 nautical miles.

Mr. KARTH. I think the weight of the satellite is about 355 pounds. I don't know if that makes any difference.

Mr. NICOLAIDES. We would have to extrapolate the curves back. That would give us about 500 miles in the polar orbit, which is too low. And with respect to the AMR launching it would give us about 650.

So the remarks yesterday were accurate for that weight of the satellite.

Mr. KARTH. So do you arrive at the same conclusion as was arrived at by Lieutenant Commander Macomber when he said that four of the six ANNA shots could be handled by Delta?

Mr. NICOLAIDES. Mr. Chairman, the project manager's remarks yesterday were absolutely correct with respect to these curves. What the project manager may not have known yesterday, and I wasn't sure of myself, is that the improved Delta vehicle, which is going to be available in November 1962, has a capability of handling all the orbits that are discussed in the six satellites. And I might mention with the reduced weight in a satellite that Commander Macomber referred to, in a polar orbit we could get an altitude as high as 1,600 miles which would make Dr. Whipple and the Coast and Geodetic Survey extremely happy for their intervisible mode of operation.

So it looks like the improved Delta would be an excellent vehicle for launching the ANNA satellites.

Mr. KARTH. Isn't there a DOD–NASA agreement, Mr. Nicolaides, to the effect that scientific programs of this type should be handled by NASA?

Mr. NICOLAIDES. I am not aware of the specific agreement, sir. I have heard about it—let me defer to Dr. Newell if I may.

Mr. KARTH. Dr. Newell?

Dr. NEWELL. There is such an agreement. It was, however, a verbal agreement, not a written one. It was arrived at between the Cochairmen of the Aeronautics and Astronautics Coordinating Board during one of the meetings at which I was present, in which it was agreed that NASA has the ball on scientific programs, but this was not to be interpreted as meaning that the Air Force or the Army or the Navy would not participate in such scientific programs, but that NASA should be aware of all these and that they should fit an overall desirable national pattern.

Mr. KARTH. Well then, under the terms of that agreement, is it your judgment that Project ANNA should be under the management of NASA?

Dr. NEWELL. No, that was not the implication of the agreement. The implication of the agreement was that any such project should be coordinated with and fitted in with the total national space sciences program.

Mr. KARTH. But there was no agreement as to who should manage such a program, is that correct?

Dr. NEWELL. That is correct.

Mr. KARTH. How do you arrive at who should manage it, Doctor, if there was no agreement reached as to the responsibility of the management team or where the responsibility would lie?

Dr. NEWELL. In the event that for a specific project one cannot arrive at an agreement in the normal day-to-day exchange between the working levels as to who should manage the project, then this is referred to the Aeronautics and Astronautics Coordinating Board for agreement at that level.

Mr. KARTH. I see. And they make the determination as to who should have the management responsibility?

Dr. NEWELL. That is correct.

Mr. KARTH. Mr. Nicolaides, Dr. Van Allen described the classification of ANNA which apparently resulted in its slow pace as a "national dereliction." You apparently are in disagreement with him.

Mr. NICOLAIDES. Not really, Mr. Chairman. I think Dr. Van Allen was making those remarks in connection with what had been published in the open literature. At the time he made that statement Project ANNA was a classified effort and I am not aware that he knew about it in all of its details.

I think if Dr. Van Allen were informed of Project ANNA in detail, and I might say all of the details have not yet been publicly divulged, I think it would come out very clearly that an excellent U.S. effort in geodesy, using satellites, has been underway.

But we are, I think, at the point of decision on this program. If we don't make a decision to go into this program, the way in which the project officer pointed out yesterday, needing six satellites, I think that we will end up in the situation Dr. Van Allen mentioned.

Mr. KARTH. I assume you are in disagreement with Dr. Brown's statement of yesterday that there should be one successful flight before this cooperative effort is finally made between the services and NASA; is that correct?

Mr. NICOLAIDES. Yes, I am. Very definitely. I haven't seen his testimony, Mr. Chairman, but from what you have quoted there I am definitely in disagreement with that. I think now is the time to move forward. I don't think we can wait until a successful satellite is up. We have never done this in any other program, to my knowledge.

The NASA Tiros program did not wait until they had a successful satellite up, in laying out the program down the road. The Navy's Transit program did not wait until it had a successful satellite up.

It went forward, planning ahead. All of the Air Force programs are, of course, planned ahead.

I think that precisely the same thing should be done in the case of geodesy where it is a scientific program and you can predict ahead with very great accuracy.

We know what the instrumentation is going to do, we know what kind of results we are gong to get and we have clear statements on the part of a number of people on what improvements are going to be. So I think we can——

Mr. KARTH. Dr. Newell, would you express your opinion on that particular question?

Dr. NEWELL. I concur. I feel that we should move ahead from a scientific point of view, that we know the scientific importance of what we are looking for, we know that this technique will provide the data needed for the scientists, and we know how to plan projects of this type.

You will recall, Mr. Chairman, in our testimony before you on the NASA budget that in the small and medium-size satellites we pointed out that one is now in a position to plan very accurately total costs and schedules for satellites of this type.

So there is no real reason why, if we decide as a Nation this is an important thing to do, we can't map out a program right now.

Mr. KARTH. What is your estimate of the total cost of this program, Dr. Newell? Or Mr. Nicolaides, whoever wants to address himself to it.

Mr. NICOLAIDES. Our estimate of the cost does not differ materially from the cost that Commander Macomber cited yesterday. We estimate between $15 and $20 million a year, but we are assuming here——

Mr. KARTH. That is for how many years?

Mr. NICOLAIDES. Four to five years. And we are also assuming here that the Coast and Geodetic Survey and other outstanding organizations will fully participate in the program.

Mr. KARTH. Yesterday I think Dr. Brown indicated he would be happy indeed if NASA would participate financially. What arrangements would NASA have to make to participate financially at this point? Would you come to Congress requesting a supplemental, or could you transfer research and development funds to carry this thing on successfully?

Mr. NICOLAIDES. Mr. Chairman, let me answer that question in two parts. NASA continues to stand ready at any time to sit down with the Department of Defense and try to come out with a joint program to do this job, and I don't think that NASA is greatly concerned about who manages it as long as it is done correctly, but there are the qualifications that I mentioned previously.

Now on the funding, if I can be completely candid with you, sir as you know in the Office of Space Sciences my responsibility is for program review and resources management and I can state as an absolute fact that we do not have any money to put into this geodetic satellite program and I would like to point out, further, if I may, that we are extremely concerned in the Office of Space Sciences with our prospects for the future.

We see the Russians mounting a major effort in science with four satellites in a row over a period of a few weeks. We see the Soviets changing their entire program away from the more spectacular shots into this science area, which we judge in reading from their material that they now consider to be extremely important.

We have been fortunate in this country to have been recognized on a worldwide basis for the first and outstanding job that has been done under gentlemen like Dr. Homer Newell here on my right.

Now the recent cut by the Congress suggesting that the purpose of the cut is to improve efficiencies, let me state in all candor, comes as a complete shock to many of these outstanding scientists who have come out of the research laboratories, who have come out of the universities, who are working in this Washington environment, which isn't altogether stimulating to the scientists, I might add. These people are trying to make the country first in space, and in fact they have made this country first in space science, and when out of the entire NASA budget submission the only substantial program cuts were in science, I have to be perfectly frank with you and say, sir, the people are very upset and I have actually had some people come to me and say "Well, I am going to go back to the university. Why should I knock myself out with the program, if the funds are going to be cut back?"

So that in all honesty let me state we don't have any money for the geodetic program. We would love to do it. We would be happy to manage the program, if this is what the Department of Defense wants, but we couldn't possibly do it with the money we have.

As you know, Mr. Chairman, we also have the Centaur hearing this afternoon, and we must also provide out of our budget the funds necessary to carry that program forward to a successful completion. So that our problems——

Mr. KARTH. We authorized every penny for Centaur, Mr. Nicolaides, in case you have forgotten.

Mr. NICOLAIDES. Yes, sir; I am well aware.

Mr. KARTH. I might say this, we are not going to review the NASA budget at this hearing. I don't think it is appropriate. We have had plenty of opportunity to do that. But if you refer to 3½ percent as substantial, I would have to beg to differ with you because I am quite aware of the normal cuts that take place in most agency requests, not only in fields for scientific investigation but in areas where the national defense is concerned, and because the national defense is involved many people insist that no cuts at all should be made.

I think you are aware of the fact that even where the services and the Department of Defense talk about the great need for all of the dollars requested being authorized, and in most instances all of the dollars are not authorized, that truly a 3½ percent cut in any program is indeed a modest one, and not a severe one.

I would say this to you: this is the reason I ask the question, if you feel you want to participate in this program from a financial standpoint, and if the agreement you reach with the Department of Defense indicates, then I think all you have to do is to come before this committee with a supplemental request. And I am quite confident that after the report is written on these hearings, that the committee would certainly give very serious and, in my opinion, favorable consideration to your request.

Now this is just my judgment, but it happens to be my honest one.

Mr. NICOLAIDES. Mr. Chairman, I very much appreciate your remarks. The point that I was really leading up to was that if we were to be asked to participate in the program, that we do not have any funds budgeted in fiscal year 1963 for geodetic work. We just couldn't handle it within our own ceiling as things now are.

Mr. KARTH. I might say insofar as our reference in our report to efficiency is concerned, we were talking about the scientific group in NASA. We were talking about them establishing priorities and, again I repeat, we are not going to rehash the hearings we had while NASA was seeking authorization for their budget request, but quite frankly there is serious doubt in our minds that the resources of this Nation can be spent in a very vast and broad area, in all areas, in fact, that the scientific community or the scientific mind might feel is desirable at this point.

Actually what we are asking you people to do is to establish priorities, and certainly there was no malicious intent, nor was that statement in the report meant to be derogatory in any shape, manner or form. As I said at the opening of this hearing, I consider Dr. Homer Newell one of the most capable men in government, and I think that the U.S. Government indeed is fortunate to have a man of his caliber. I might say that we are very happy that you work for the Government too, Mr. Nicolaides.

Mr. NICOLAIDES. Thank you, Mr. Chairman. I would like to carry your remarks back to our people because there was a misunderstanding and I see now that it was completely unjustified. May I make one further remark?

There is a slight misunderstanding about the Nation's science effort in space. As you know, I worked for over a decade and a half in the Department of Defense and made the decision recently to go to NASA, and one of the reasons was very simple, that the Office of Space Sciences is the fountainhead for all future developments in space. This includes the military as well as the civilian applications.

What I am really saying is that it is extremely important to recognize that the Office of Space Sciences is really carrying a double load, it is carrying the load of basic science and data required for doing civilian work and is carrying the scientific load for the military.

Mr. KARTH. Yes, sir, and I think the subcommittee recognized that when the subcommittee recommended to the full committee approval of a request that increased some 35 or 40 percent over what was just last fiscal year.

Mr. NICOLAIDES. Yes, sir.

Mr. KARTH. This is not treating you in a haphazard manner, and one in which we did not recognize the importance.

Mr. NICOLAIDES. Yes, sir. We just misunderstood the remarks on efficiency. That was all, sir. I appreciate your comment on that and I would like to take it back and let our people know that we are completely supported by the Congress in our scientific efforts.

Mr. KARTH. Yes, sir.

Mr. NICOLAIDES. Thank you, Mr. Chairman.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. Mr. Chairman.

Dr. Newell, in connection with the chart up there and also on the first page of your testimony you said it would be a relatively small but heavy satellite. Then I heard—I believe yesterday—that efforts were going to be made to reduce the weight of the satellite.

Now, what is the range in there, in which direction are we going?

Dr. NEWELL. Mr. Randall, this refers to the thinking that was going on some time ago during the course of the International Geophysical Year when people were first thinking about a geodetic satellite. The idea of "relatively small but heavy" was to give the satellite an ability to overcome the effect of air density at the altitude at which it would have to go.

So that, unlike the Echo balloon which shows marked influence of air density effects, this would not.

Mr. RANDALL. What weight are we talking about then?

Dr. NEWELL. Well, at that time the people were thinking about the IGY-sized satellites of 20, 50 pounds or so.

Mr. RANDALL. What are we thinking about now?

Dr. NEWELL. Now we are thinking of some hundreds of pounds.

Mr. RANDALL. From 100 to 300?

Dr. NEWELL. Yes, sir.

Mr. RANDALL. All right.

Then on page 2 you mention the IGY. What specific request or recommendation did they make? I have never understood that, with respect to something like ANNA. At the conclusion of that year, what was that recommendation?

Dr. NEWELL. During the International Geophysical Year the National Academy of Sciences' Technical Panel on the Earth Satellite Program did several things. First it laid out a program that it recommended for carrying out during the IGY actually, and that program included, as you know, the Vanguard satellites.

Mr. RANDALL. Of course that is gone.

Dr. NEWELL. That is gone.

Mr. RANDALL. But what after that?

Dr. NEWELL. In addition, as they were going along, the Panel recognized that it would have to bequeath to whatever activity came on after IGY their thinking and experience. So they laid out a series of suggestions for scientific satellites, which included the suggestion that the country undertake a geodetic satellite program as soon as possible.

Mr. RANDALL. Just a simple recommendation?

Dr. NEWELL. Just a simple recommendation.

Mr. RANDALL. Not any more specific than that?

Dr. NEWELL. Nothing any more specific.

Mr. RANDALL. This Panel or Board of the Unmanned Spacecraft Panel of the Aeronautical and Astronautics Coordinating Board, you say they confirmed the recommendation in 1960 of this classification. And now it develops that the whole thing was declassified here just a while ago, 18 days ago, when COSPAR took place.

How often does this Panel or this Board meet, Unmanned Spacecraft? Have they met during the interim?

Dr. NEWELL. Oh, yes, the Panel meets every month or 2 months, depending on how much business comes before it. The normal meeting period is every 2 months.

Mr. RANDALL. And had this classification subject been considered at any of the meetings so far as you know? You say you are a member.

Dr. NEWELL. This classification subject was reconsidered once to my knowledge since the original review.

Mr. RANDALL. Only once?

Dr. NEWELL. Only once. Mr. Nicolaides says he has something.

Mr. NICOLAIDES. If I could just clear that up. I don't think it is a responsibility of the Board to determine what is classified and what is not classified. The Department of Defense has the responsibility to determine what is classified and what isn't and they simply advise the Board as to their determination as to what is classified and what is not. I would like to make that very clear, because the NASA people are not capable of making a decision for DOD on what is classified. That is the responsibility of the Department of Defense.

Mr. RANDALL. It seems to me at this time, and I suppose possibly maybe these hearings were conceived because of this declaration—in other words, we are back with NASA now. Now the declassification came entirely from the Department of Defense.

Mr. KARTH. Mr. Randall, if you would yield just for the purpose of keeping the record straight.

Mr. RANDALL. Certainly.

Mr. KARTH. This subcommittee had agreed to investigate Project ANNA before it was declassified.

Mr. RANDALL. I am glad to know that, Mr. Chairman.

Then I am trying to find out, did COSPAR make a recommendation to NASA, was it discussed at COSPAR? It seemed to have all happened while the meeting of COSPAR was going on.

Dr. NEWELL. The Committee on Space Research made no specific recommendation on the classification here of ANNA. However, the Committee on Space Research has in past meetings considered experiments such as the geodetic ones and has expressed its interest in these experiments.

Mr. RANDALL. There is nothing occult or mysterious, I am simply trying to find out if this declassification came about as a result of this knowledge that you say you believe that the Russians are going to make an all-out effort and whether or not there had been sufficient push under the Department of Defense. Is this declassification a part of the effort to make a bigger try? That is what I am trying to get at.

Dr. NEWELL. Well, I think in order to answer your question we shouldn't focus on the COSPAR, which is an international committee.

Mr. RANDALL. That was just a happenstance?

Dr. NEWELL. Yes. We should focus more on the interests of our own national scientific community and the National Academy of Sciences. They have, of course, been aware of this classification and have been very unhappy about it, and have been working continuously on this problem through the President's Science Advisory Board, through Jerry Wiesner, and others.

So I would say that this declassification was inspired and brought about in part by the efforts of these people to keep it under continuing review.

Mr. RANDALL. You simply said it was declassified during the meetings in Washington, D.C., of COSPAR.

Dr. NEWELL. That was incidental and fortunate.

Mr. RANDALL. Now, Mr. Nicolaides, you emphasize, and the chairman has called attention to the fact that you emphasized no single group, no single agency, no single country can carry on to successful completion this truly worldwide job.

Now, the question arises: What if we don't get good cooperation from the other countries, we are going ahead anyway, aren't we?

Mr. NICOLAIDES. Well, let me say, Mr. Randall, that we have already received as a result of Commander Macomber's excellent paper before COSPAR and the NASA release to COSPAR, we have already received letters from various countries indicating interest in this international program.

The Cospar committee, itself, which is Chaired by a Russian delegate, has submitted a resolution commending the United States for having such a program. I don't have that material here, but I will be glad to submit the Cospar recommendation for the record.

Mr. KARTH. If you would, yes.

RESOLUTION 5 OF WORKING GROUP 1 ON TRACKING AND TELEMETRY

Working Group 1 expresses its satisfaction at the intention of the USA to launch a geodetic satellite containing a flashing beacon for international use. It recommends that cooperation in tracking should be undertaken by stations having the necessary facilities. It welcomes the undertaking of NASA to supply the participants all information concerning the orbit and instants of flash sequences.

COSPAR.

Mr. RANDALL. Could you indicate what countries have offered to cooperate?

Mr. NICOLAIDES. Yes; for example the English, Dr. Cook in England has already written me a personal letter, and I don't see all the correspondence, I might say. We have a letter from Dr. Veis, representing the Greek Observatory. I talked to their people from India. I was told that one of the observatories there would like to track it.

Mr. RANDALL. Japan?

Mr. NICOLAIDES. I haven't heard, but I am sure they would. There is absolutely no question about the enthusiasm of all these countries to participate, particularly when it is recognized that this satellite, when flashed over their country, they can develop their own program for observing this satellite intervisibly.

If I may just show one chart here. If the satellite is over Europe, different countries in Europe and different observatories can simultaneously observe the flash of the satellite and for their own purposes they can do their own local geodesy.

One of the conditions that we have placed on flashing the light for them is that they also give us their data so that we can publish this throughout the world and that all other countries have the advantage of running mathematical analyses.

From our point of view we want to determine the three things that Commander Macomber mentioned yesterday, we want to get the location of the center of gravity of the earth, the location of key points on earth, and, of course, the gravity field of the earth.

So that as far as a cooperative program, they can use their own funds and their own equipment and what is extremely interesting here is that their best scientifically trained talent is working on the program. The astronomers and mathematicians are some of the world's outstanding scientific capability and it is these very highly capable people that are working on this program.

So for a very small amount of money we are getting the best scientific brains in the world working with us.

Mr. RANDALL. That raises the point, with our vehicle they can take advantage of it just by their observations as you have pointed out.

Mr. NICOLAIDES. If we make the flash available to them, which we propose to do on a cooperative basis, sir.

Mr. RANDALL. And you believe that they will in turn cooperate with their findings and furnish them back to us?

Mr. NICOLAIDES. That is the condition that we have placed upon flashing the light for them and we are sure they are going to cooperate.

Mr. RANDALL. You weren't here yesterday. There are a few of us a little suspicious. Now you didn't mention Russia here at all.

Mr. NICOLAIDES. I am not informed on what Russia would or would not do. I can only indicate that the Chairman of the Cospar committee is the scientific delegate from Russia, and they did pass a resolution without a vote, I understand, that the United States should be commended on doing this. I don't think they are in the habit of taking votes over there in the U.S.S.R.

Mr. RANDALL. At least it is a unanimous vote, isn't it?

Mr. NICOLAIDES. Yes, yes, it was.

Mr. RANDALL. All right.

Mr. Nicolaides, you made the observation that six satellites would be required and, of course, I don't know what is magic about six, but maybe you can tell us. Is that because of the needed inclinations and altitudes and would you enumerate what those six are?

Mr. NICOLAIDES. I would be very happy to. It is easy. It is a complicated subject, but it can be made simple by just drawing a chart, if I can just take a minute.

Mr. RANDALL. This member finds it most difficult to understand it, but we would like to know at least some indication as to why it is six.

Mr. NICOLAIDES. This is the earth, this is the polar axis, and this is the equator. Now, unfortunately, as Commander Macomber pointed out yesterday, the earth isn't round. The first order of accuracy it has a pear shape. And to be quite frank with you it isn't just a simple pear. What the earth really is, it is completely wrinkled like this, going around, and that is looking at it with respect to the polar axis. And we know these wrinkles, up to what are called the J–8 and J–9 terms for scientists who want to know what we are talking about here, are a very high order of wrinkling of the earth, even though it has rotational symmetry in this picture. However, if we look down at the earth from the North Pole, up until recently we were of the opinion that the earth had a circular equator, but the Transit satellite has shown that it isn't a circular equator. It is an elliptical equator.

And I might say Dr. Whipple, who has been observing all kinds of satellites under truly heroic circumstances, only at dawn and twilight, which is extremely difficult, his people have also come up with this same discovery. And actually, more recent data tends to indicate that the equator isn't at all this simple.

The equator, itself, is pear shaped, if you wish, and I can guarantee you that with the ANNA satellite we are going to discover that it is much more complicated than this.

Now as Commander Macomber pointed out yesterday, to understand the lack of rotational symmetry of the earth shown here you need an equatorial satellite. So that is one of the satellites you need.

With respect to looking at the earth this way, this is the polar axis here, to get these kinds of wrinkles or distortions in the surface of the earth and scientifically I am speaking of the gravity potential surface, but let's just call it the shape of the earth.

We need a polar satellite that goes around the earth in this way. Now it turns out that this bulge here is an extremely big effect and as Commander Macomber pointed out, you also need a satellite in this unique 63.4 degree orbit which happens to be the inclination which minimizes the effect of this big bulge turn and therefore lets you find some of these smaller things which normally would be hidden. And then lastly, of course, you need satellites at very high altitude to do the intervisible operations.

Mr. RANDALL. Intervisible?

Mr. NICOLAIDES. By intervisible, sir, I simply mean that these four stations shown here can see this satellite simultaneously.

Mr. RANDALL. In other words, triangulation to find absolute location on the earth of different points?

Mr. NICOLAIDES. Yes. And this doesn't depend on Newton's law in any way. It is just triangulation as you point out, sir. And this technique, if the satellite is high enough and if the light has a strong enough intensity, it can be seen between continents. This is the kind of thing that the Coast and Geodetic Survey is very much interested in doing.

Mr. RANDALL. You have enumerated four, a high one, 63.4, polar and equatorial. I thought I saw something about a 30 degree. You are still short two of your six.

Mr. NICOLAIDES. I was taking the optimum situation. In life one has to be realistic. We can't get the equatorial right away, so we would compromise for the 30 degree inclination out of Cape Canaveral.

Mr. RANDALL. Atlantic Missile Range, yes.

Mr. NICOLAIDES. Yes. And the other inclination mentioned yesterday was the present inclination of ANNA of 50 degrees. Now 50 degrees I would like to say is a very good optimization of all that I have discussed. It is not too polar, it is not too equatorial, it is not too far or too close to 63.4 degrees and what is more important you can get the satellite up there. That is if the Star vehicle works for us.

Mr. RANDALL. I had better stop while I am ahead.

Mr. KARTH. Mr. Van Pelt?

Mr. VAN PELT. No questions.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. Just one question. Did I understand you to say that there were certain specifics that this satellite can produce that have not been divulged?

Mr. NICOLAIDES. No, sir. I am not sure what you are referring to there. There are two points I wanted to make. One is that this satellite has a unique capability with these three types of instrumentation to do a real precision job, as Commander Macomber pointed out yesterday. You can go from 1,000 feet down to in my opinion considerably less than 100 feet. That is in the accuracy of location of points on the surface of the earth. And I might also say in connection with that question, sir, that it is very important to NASA and the other agencies including the military, to know where the center of the earth is. When you try to rendezvous in space and send a man to the moon, you have to know where the center of the earth is and you have got to know the gravity field.

So I would like to say in response to your question that this is an extremely important program. It is a scientific one, but it is also extremely important and there are numerous applications that come out of it that really haven't been fully discussed here.

Mr. DOWNING. Is there any particular urgency connected with this program?

Mr. NICOLAIDES. Well, in my view, I may be alone in this view, but I think there is an urgency. I think that we always find in science that we don't appreciate the need for new knowledge, but as soon as we get the new knowledge, we surge off into new applications. I think that is very close to Van Allen's remark that we can't afford not to go ahead with this program right away in a full-scale, responsible fashion. And I think it is important in the lunar man-to-the-moon project, it is important in many, many other areas.

Mr. DOWNING. Thank you very much. That is all, Mr. Chairman.

Mr. KARTH. Mr. Hammill?

Mr. HAMMILL. Yes, sir.

Dr. Newell, you testified that it has been 18 days since Project ANNA was declassified, but I think either you or Mr. Nicolaides stated that, as yet, the Department of Defense has not contacted NASA in order to determine what role NASA will play. Is that so or not?

Dr. NEWELL. Yes. Mr. Nicolaides has been following this. I would suggest he take this question.

Mr. NICOLAIDES. Mr. Hammill, we have been in contact with the Department of Defense with respect to the utilization of the present satellite, which we had hoped was going to go into orbit, and Commander Macomber has set up a small working group with a designated representative from NASA to come up with a plan on how that satellite will be utilized, including the exchange of data and the full participation of other countries, and to my knowledge that committee is meeting and they are working up the plan.

What has not been done to my knowledge is that the NASA and DOD have not gotten together with respect to a follow-on program, and as a result of yesterday's testimony I don't expect that they will, because it is my understanding, as the Chairman pointed out, that DOD intends to wait until a satellite is successfully in orbit, and then they propose to analyze the data and then make a determination as to what the program should be from that point forward.

Now, that means that there should be a delay in getting together with NASA, I would judge, until the next successful launching, which may be a while away.

Mr. HAMMILL. Now, if this program is fundamentally scientific and if it is of great interest to NASA, does NASA have to wait for DOD to approach the Office of Space Sciences, or would it be appropriate for NASA to initiate some negotiations with DOD in order to determine what role NASA is going to play and when?

Mr. NICOLAIDES. Mr. Hammill, we wrote a letter to Department of Defense some months ago, stating that we stood ready, willing and able to participate and aid in Project ANNA. This is the official correspondence.

Also, we have been in contact—Defense knows that we stand ready to work with them on a program.

Mr. HAMMILL. But they have not replied to your letter or indicated that they want you to join in at this point?

Mr. NICOLAIDES. Not with respect to the follow-on program, only this one shot has been approved, as the testimony bore out yesterday, and I am not at all clear on what the status of these additional five satellites are.

Mr. KARTH. Mr. Hammill, I wonder if you would yield at this point?

Mr. HAMMILL. Surely.

Mr. KARTH. Mr. Nicolaides, is there disagreement between you and the Department of Defense as to the importance of this program?

Mr. NICOLAIDES. There is absolutely no disagreement between what I have said and what the project officer said yesterday with respect to the need for additional satellites at other inclinations and altitudes. The only question that arises——

Mr. KARTH. Is there a difference of opinion as to the urgency, then?

Mr. NICOLAIDES. I couldn't answer that question. I can only judge by the delay in waiting until a successful satellite is put in orbit.

Mr. KARTH. On that basis, do you look upon this as a classified-unclassified project? What connotation are you putting on it?

Mr. NICOLAIDES. I am confused by that situation, sir.

Mr. HAMMILL. Dr. Newell, do you have anything to offer on this point?

Dr. NEWELL. Well, in picking up the question that Mr. Randall asked, and the one that is implied in your question, I would point out that there is some urgency to the NASA program in doing this sort of science, because the manned flight program is going to need to know the earth's gravitational potential just as thoroughly as they can know it.

Mr. HAMMILL. What is NASA doing then?

Dr. NEWELL. Well, we have been using the other satellites, the Vanguard I, observations on Echo, and so on, in what Mr. Nicolaides referred to as a heroic observational effort, because these weren't designed for this purpose, to get as much information out of them as we can. That is why we know the earth is pear-shaped, and so on.

Mr. KARTH. Doctor, if we don't proceed with the haste that Mr. Nicolaides would like to proceed with on Project ANNA, did I understand you to say that it might have the effect of slowing down the manned lunar flight project?

Dr. NEWELL. It could, it could be important to the manned space flight project. Whether it will slow it down or not, we don't know until we have found out.

Mr. KARTH. But if it is important it would have that effect, wouldn't it, Doctor?

Dr. NEWELL. I think this is a case where you have got to cover your bets so that you don't get slowed down by not knowing things you should know.

Mr. KARTH. Mr. Nicolaides, would you agree with that?

Mr. NICOLAIDES. Yes, I do agree with what Dr. Newell said, but I would like to amplify that.

Recently, as you know, we had, some years ago in NASA, a lunar orbiter program to get the gravity field of the moon, and we decided not to go with this smaller satellite, but rather to concentrate on our Ranger and our Surveyor programs.

More recently, the people in the Manned Space Flight Office have now recognized the extreme importance of knowing the gravity field of the moon, and we are now in the process of reevaluating our program in that area in order to come up with the gravity field of the moon at an earlier date. Let me suggest to you the gravity field of the moon isn't as critical, on the total flight mission, as the gravity field of the earth. What I think that I am suggesting here is that the recognition of the importance of the earth's gravity field is going to come just as the recognition of the importance of the moon's gravity field has now come.

Mr. KARTH. You feel knowledge about the gravity field of the earth is even more important than our knowledge about the gravity field of the moon, insofar as the manned lunar landing program is concerned, is that correct?

Mr. NICOLAIDES. I think the knowledge of the gravity field of the earth is much more important than the gravity field of the moon, because the gravity field of the earth has many important applications in both the civilian science as well as in the military programs.

As Dr. Brown mentioned yesterday, they are extremely interested in the gravity field of the earth, even though it is a scientific program.

Dr. NEWELL. Mr. Chairman, I might clarify this point that I made. If the manned flight program is going ahead with a rendezvous approach to getting to the moon, this rendezvous is going to be carried out in the gravitational field of the earth. This is one of the reasons why this must be known just as well as we can know it.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. I want to preface this remark with a caution, that I am not trying to get back into any science fiction or any Buck Rogers business here, but there has been some fiction written which is backed up by some very substantial facts, out east of the Florida Peninsula, or southeast, I should say, in connection with the loss periodically, over a period of 10 or 15 years, of aircraft which has been unexplained. Is it possible that there may be a variation of the gravitational field in that area?

Is that what you are talking about, the importance of the study of this gravitational field?

Mr. NICOLAIDES. Not that kind. There are variations in the gravity field around the earth, as the Coast and Geodetic Survey and Navy Hydrographic Office and others have carried out over the years. That kind of gravity anomaly is best done on the earth, if you have the instruments. The gravity field that I am talking about are these more generalized complications that affect the motion of satellites, missiles, spacecraft, et cetera, and also with the satellite, of course, you get the shape of the earth and positions on earth and center of gravity which you can't get by the other techniques that you are referring to.

Mr. RANDALL. I had best not pursue this any further.

Mr. KARTH. It is very interesting, Mr. Randall, and I wonder if Dr. Newell has read the same Buck Rogers story you read.

Mr. RANDALL. I would be very glad to be specific.

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Mr. KARTH. Which apparently has not been disputed.

Are you aware, Dr. Newell, of this phenomenon that apparently has occurred down there southeast of Florida, did you say?

Mr. RANDALL. Yes.

Back just after the close of World War II there was a whole group of Navy patrol planes lost and there has never been any possible explanation, except for the variation, possibly in either the gravitational field or just quite definitely a break in ordinary atmospheric conditions, there has never been a trace found of seven or eight of them.

Dr. NEWELL. Yes.

Mr. RANDALL. In this very same identical area there has been subsequently two or three large civilian aircraft losses over a period of years.

Dr. NEWELL. Yes.

Mr. RANDALL. In identically the same area. And only in January of this year, 1962, there is another completely unexplained loss, except possibly on the basis of some aberration in either the gravitational field or in the atmosphere, something of the kind. I mean this is a matter of the Navy, I think the CAB possibly has been on this, also.

Dr. NEWELL. In response to your question, I think that the gravitational field is not the culprit here. We are well aware that there are gravity excesses and gravity deficits around the world, but these are such a small percentage of the total gravitational field that they could hardly account for things of this sort.

I would be more inclined to look at variations in the atmosphere, maybe turbulence, incipient storms, and so forth, that have not yet become visible and therefore didn't appear on the weather charts, that sort of thing.

Mr. KARTH. Mr. Hammill would like to get us back on ANNA.

Mr. HAMMILL. Yes, I have a couple more questions I would like to clear up.

In view of the general agreement between Defense and NASA on scientific projects, and in view of the fact that ANNA, now unclassified, is primarily scientific in its objectives, and in view of NASA's responsibilities for international cooperation and its necessity for a succesful program, doesn't it make more sense to you that this program should be managed by NASA rather than Defense?

Dr. NEWELL. This is a matter of, really, aegis, rather than management. The scientific program should, I think, be under the aegis of NASA, but the Department of Defense has a management capability that we would like to see devoted to this program, just as we have asked them to undertake the management of our next ionosphere satellite attempts. So that I would concur with Mr. Nicolaides' remarks here that we would not want to shoehorn this out of the Department of Defense and thereby perhaps interfere with the progress of the program.

I would much rather see ourselves get together with the Department of Defense and strengthen the planning in the program so that we would have a continuing, adequate national program in this area.

Mr. HAMMILL. Are there any efforts planned by NASA to get together with the Department of Defense to plan a follow-on program?

Dr. NEWELL. We will do so. If there is no follow-up from the Department of Defense, we will again initiate contact.

Mr. HAMMILL. One last question. How many flashes is this flashing light capable of giving under the program as now provided?

Dr. NEWELL. It is my understanding that there are 20 per day for a lifetime of about half a year, hopefully twice that.

Mr. HAMMILL. And does this constitute a sufficient number of flashes for scientific purposes?

Dr. NEWELL. Yes, it would.

Mr. HAMMILL. And will they be flashed at the right places, so that they can be observed in various places around the globe for scientific purposes, or are the flashes programed simply for military purposes?

Dr. NEWELL. Well, they can be flashed at the appropriate places. That is a matter of arranging the programing which is something that we and the Department of Defense would have to agree on.

Mr. HAMMILL. I see.

Mr. KARTH. Gentlemen, this subcommittee would encourage NASA to make every effort to arriving at an agreement with the Department of Defense so that we could properly pursue what I think has developed to be a more important project than this subcommittee felt it was when they decided maybe they should take a look at the reasons why ANNA was classified and the objective of the project, itself. Inasmuch as today for the first time I learned that this has rather great significance for the successful completion of the manned lunar landing program.

And I would further request that you keep the subcommittee informed as to the progress or the lack of it that you make in your effort to negotiate a follow-on program on Project ANNA.

Dr. NEWELL. We would be glad to do so.

Mr. KARTH. Mr. Beresford?

Mr. BERESFORD. Yes, Mr. Karth, I would like to ask a couple following up what has been asked.

Mr. KARTH. Yes, sir.

Mr. BERESFORD. Dr. Newell, you were speaking about aegis as opposed to management. And it appears that a scientific program of this nature requiring international cooperation on a large scale is eminently suitable for a NASA rather than a Defense Department aegis. What is the mechanism of the ionspheric satellite, the management of that program; is it like the solid, the large solid propelled launch vehicles program, in which the money is in the NASA budget and is transferred by NASA to an executive agency, the Air Force in that case, of course, to do a job in conformity with NASA requirements? Is that the way it works?

Dr. NEWELL. The ionosphere satellite was budgeted for by NASA and the money to adapt a Transit-type satellite to an ionospheric beacon satellite was transferred to the Bureau of Weapons, for use by the Applied Physics Laboratory.

The management we are talking about here really is the management of the actual development, construction and launching of the satellite.

As is clear by the question you just phrased, there is more to the program than just this, because the observation of the ionospheric satellite, just as in the case of the geodetic satellite, is to be carried out by various countries around the world. And the organization of this observing program and part of the funding of it is under the direct management of NASA, not of the Applied Physics Laboratory. So to return to my previous question, there will be more to the management of the total geodetic program than just the management of the construction, development, launching, and so forth, of the geodetic satellite, and we would presume that NASA would handle the management of the international observing and viewing.

Mr. HAMMILL. Would it be possible if, after you have discussed this with the Defense Department and the roles and missions of the various agencies are determined, to furnish a copy of the agreement to the committee?

Dr. NEWELL. Certainly.

Mr. KARTH. Are there any further questions?

Mr. DOWNING. No. It has been a very interesting session, Mr. Chairman.

Mr. KARTH. If there are no further questions, Dr. Newell and Mr. Nicolaides, we want to thank you very much, and I assure you we have learned a great deal today about the importance of Project ANNA. And if there is anything that you want to file with the committee at a later date which today might have escaped your recollection on this project, why, please feel free to do so.

Dr. NEWELL. Thank you, Mr. Chairman.

Mr. NICOLAIDES. Thank you, Mr. Chairman.

Mr. KARTH. Thank you very much.

Admiral Karo, who is the Director of the Coast and Geodetic Survey, Department of Commerce is our next witness.

Admiral, if you are prepared to proceed at this time with your statement, you may proceed in a fashion which seems to be most appropriate in your opinion.

Admiral KARO. Thank you.

Mr. KARTH. Admiral, do you have someone here who you would like to have sit at the table with you?

Admiral KARO. Yes.

Mr. Whitman or Mr. Thomas, would you come up here, please, sir?

Mr. KARTH. Admiral, if you would just suspend for a moment, would the other gentleman identify himself, please, and state your position for the purpose of getting it accurately in the record?

Mr. THOMAS. My name is Paul D. Thomas. I am a mathematician in the Office of Research and Development, Coast and Geodetic Survey.

Mr. KARTH. Thank you.

Admiral, you may proceed.

Admiral KARO. Thank you, sir.

STATEMENT OF ADM. H. ARNOLD KARO, DIRECTOR, COAST AND GEODETIC SURVEY, DEPARTMENT OF COMMERCE, ACCOMPANIED BY PAUL D. THOMAS, MATHEMATICIAN, OFFICE OF RESEARCH AND DEVELOPMENT

Mr. Chairman and members of the committee, the Coast and Geodetic Survey actively participated in formulating the geodetic satellite program which the panel of the U.S. National Committee for the International Geophysical Year recommended in 1957, and worked with the Space Science Board of the National Academy of Sciences on its recommendations to NASA in 1959 for such a program.

This program was well advanced when it was taken over by the military in 1960. While opposed to its former security classification, the Coast and Geodetic Survey offered its services and cooperated with the ANNA project. As the Government agency with statutory responsibility for geodetic control and research in geodesy, we must stimulate scientific and technological projects in geodesy within both Government and private agencies.

The first two satellites under the ANNA program are committed for comparison of several electronic and optical tracking systems. If a geodetic satellite program analogous to the original one which ANNA replaced should be instituted, the improvements in boosters, solar cells, electronic components, the possible use of Lasers, etc., would put us in a better position to develop a flashing light satellite plus other instrumentation, designed specifically to extract the maximum geodetic information through both optical and electronic tracking systems. In order to gain the maximum benefit from the geometric method as well as the dynamic method, the geodetic satellite should have a perigee preferably of 1,500 miles, certainly not less than 1,000 miles. Probably six satellites (including backups) at different inclinations (some of which should be polar) would suffice.

The American Ephemeris lists, for the world, about 300 observatories and 30 radio installations. The research literature over the past 5 years shows that many of these are already observing satellites and some observatories have improvised systems of interrupting satellite trails to get time-correlated observations. The interest exists internationally and is reflected in the proceedings of such international meetings as the International Union of Geodesy and Geophysics meeting in Helsinki, in 1960, and the recent joint symposium, Committee on Space Research (Cospar) and International Association of Geodesy (IAG) in Washington.

Some of the problems which need to be considered on an international cooperative basis are: (1) the distribution of optical and electronic observing sites over the continents to effect geodetic datum ties and establish orbital positions relative to a satellite of specified perigee height and inclination, (2) coordination of observing programs for mobile tracking units and their planned location sequence, (3) the establishment of a data reduction center to handle the mass of observational records that will become available (similar to IGY operations), (4) quality control for observations, (5) standardized card or tape star references for optical observations, (6) arrangements for data acquistion and processing by the several U.S. Government agencies, foreign centers, etc., (7) maximum use of automation in data processing, (8) perhaps some standardization of ground tracking instrumentation.

The Coast and Geodetic Survey, because of its responsibility in geodesy and photogrammetry, and its activities in the international associations of geodesy and photogrammetry (the president of the International Association of Geodesy is a scientist of this bureau), is capable of directing and coordinating the mobile optical observing program, the photogrammetric reduction of the optical observations, and the mathematical analysis of the results.

To provide a more accurate scale for orbit calculation, to satisfy the increasing requests for accuracy in our geodetic net (particularly by the several missile ranges in continental United States) and, at the same time, to provide an accurate reference frame for crustal movement studies, we are planning to initiate a series of very accurate traverses, six crossing the country east and west, and nine north and south. Positions determined from these traverses will be 5 to 10 times more accurate than those available from the existing triangulation network.

We will follow the techniques used at the Atlantic Missile Range in establishing a baseline between Vero Beach and Homestead, Fla., a distance of about 150 miles where probable errors of 1 part in 3,500,000 for length and 0.09 second for azimuth were obtained. Precise levels will also be run over these transcontinental lines. Traverse stations will be triangulation stations in our geodetic net. A simultaneous adjustment of the entire net will give a framework of geodetic control extending across the entire country with unheard-of precision. Points on the west coast will be related to those on the east coast to within an accuracy of about 10 or 15 feet, and an elevation difference of less than 1 foot.

We expect to extend it to Alaska, the Aleutian Islands, Hawaii, and Puerto Rico, and with international cooporation to geodetic datums around the world through satellite triangulation.

Now, clearly, this will complement the international geodetic satellite program by providing a very accurate reference scale around the world for orbits. For the purpose of capitalizing on both the ANNA flashing light active satellite and the passive Echo or Sputnik type, the Coast and Geodetic Survey, with the help of Dr. Helmert Schmid (formerly with Ballistic Research Laboratories, now with Geodesy Intelligence and Mapping Research and Development Agency), has developed a highly accurate and versatile mobile optical system. This system is based on the BC–4 ballistic camera but with a specially designed lens for satellite photography, a very precise chopping shutter to allow interruption of passive satellite trails for time correlation, a capping shutter with precise electronics system for star programing, and an accurate timing system. At least three other Federal agencies and several European nations are now preparing to use this system.

We believe that in order to inject some quality control into the observations on a worldwide basis, at least five systems of four cameras each of this type would need to be assembled for use in North America; South America; Australia-Philippines-Thailand-Burma-India; Africa; and Europe. The North American system could be operated by the Coast and Geodetic Survey, the other four systems cooperatively with the foreign countries involved. These would be in addition to all existing camera systems and electronic systems. Such an international program must, of course, be planned with the cooperation of the State Department.

We believe that following the initial ANNA program, a new satellite program could be developed along the lines of the original NASA program—and I have here a release of ours, a technical bulletin, which I would like to give for the record, which describes the use of near-earth satellite orbits for geodetic information. If I may submit that?

Mr. KARTH. Thank you very much. Without objection, that will be put in the record.

(The document referred to is as follows:)

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary
COAST AND GEODETIC SURVEY
H. Arnold Karo, Director

Use of Near-Earth Satellite Orbits for Geodetic Information

PAUL D. THOMAS

TECHNICAL BULLETIN NO. 11
January 1960

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Technical Bulletin Series

This series of Technical Bulletins was inaugurated to present to the personnel of the Coast and Geodetic Survey and to others the results of research and development in the various fields of the Bureau's activities. Since many of the bulletins deal with new practices and new techniques, the views expressed are those of the authors and do not necessarily represent final Bureau policy.

Technical Bulletin No. 11 summarizes some of the preliminary background material and planning for the use of a geodetic near-earth satellite which is expected to be placed in orbit during the latter part of 1961. It covers the principal geodetic uses, the type of satellite most useful, the recommended program, and tracking methods. An appendix discusses energy requirements, accuracy of velocity, injection angles required to produce a near-earth satellite, and use of the satellite trajectory to determine geodetic data.

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Use of Near-Earth Satellite Orbits for Geodetic Information

PAUL D. THOMAS, Mathematician

U. S. Coast and Geodetic Survey

INTRODUCTION

EDWARD EVERETT HALE, better known as the author of "The Man Without a Country," wrote a fiction story (under the pseudonym Frederic Ingham) called "The Brick Moon," which was published by the ***Atlantic Monthly*** in installments from October 1869 to February 1870.

Hale proposed construction of an artificial moon for reasons which are surprisingly modern. One finds on page 30 of the October 1869 issue:

"If from the surface of the earth, by a gigantic peashooter, you could shoot a pea upward from Greenwich, aimed northward as well as upward; if you drove it so fast and far that when its power of ascent was exhausted, and it began to fall, it should clear the earth, and pass outside the North Pole; if you had given it sufficient power to get it half round the earth without touching, that pea would clear the earth forever. It would continue to rotate above the North Pole, . . . above the South Pole and Greenwich, forever, with the impulse with which it had first cleared our atmosphere and attraction. If only we could see that pea as it revolved in that convenient orbit, then we could measure the longitude from that, as soon as we knew how high the orbit was, . . . we must make it a very large pea . . . it must stand fire well . . . it must be brick . . . the pea shooter, of course, is only an illustration . . . we would build two gigantic flywheels . . . they should revolve, their edges nearly touching, in opposite directions, for years, . . . to accumulate power, driven by some water fall . . . one should be a little heavier than the other . . . the brick moon . . . should be gently rolled down a gigantic groove . . . till it lighted on the edge of both wheels at the same instant . . . it would be snapped upwards as a drop of water from a grindstone." It is interesting to note that the Navy Department has a current project for utilizing a satellite for navigational purposes, called "Transit." Azimuth and elevation of the radio beam from the satellite will be measured by surface ships and aircraft as to a star; line of position will be calculated by means of prepared tables of the satellite orbit.

The invention of rockets by the Chinese, in the 12th Century, and subsequent developments made possible the advent of artificial satellites. In the 1920's, the work of Hermann Oberth and his group in Germany was significant. Oberth, who is called the German father of modern rocketry, was the first to seriously consider the possibility of establishing an earth satellite, and in 1923 he proposed a manned space station to serve as an observatory. At the same time, in the United States, the experiments of Robert H. Goddard with the first liquid-fueled rockets were monumental. The German V-2 ballistic rocket, unleashed near the end of World War II, had a range of 118 miles and reached a height of 50 miles in its trajectory.

Thus, it was the development of large rockets and telemetering techniques during World War II which made feasible the practical consideration of artificial satellites, since it would be possible, if a satellite orbit could be achieved, to collect information in space without human observers and return it to earth by radio transmitter.

On February 24, 1949, at White Sands Proving Ground, N. Mex., the U. S. Army fired a two-stage rocket—combining the V-2 and the WAC Corporal—to a height of 250 miles, and that same year, Willy Ley, a former member of Oberth's group, proposed the firing into orbit of a 200-pound satellite by means of a 220,000-pound rocket. In 1953, S. Fred Singer, University of Maryland physicist, suggested an instrumented satellite which he called the "Mouse." The Office of Naval Research actually set up a satellite project in 1954 called the "Orbiter" which was to use a military rocket as the first stage. In connection with U. S. participation in the International Geophysical Year (IGY) program, Government satellite rocket research was separated in 1955 from the military missiles program and the well known satellite project "Vanguard" established.

In 1956, a three-stage rocket consisting of the Army Redstone and two smaller stages went to a height of 680 miles. With a directed booster as final stage, ***this rocket could have achieved a satellite orbit.*** Early in 1957, a test three-stage rocket fired by the Lockheed Aircraft Corp. ***reached 1,000 miles*** because of a firing malfunction. The last stages of the rocket were

TABLE OF ARTIFICIAL EARTH SATELLITES

Name		Launch date, life-time and descent date	Shape and weight	Size	Date	Orbital inclination (deg.)	Orbital period (min.)	Perigee height (n. miles)	Apogee height (n. miles)	Orbital eccentricity	Argument of perigee (deg.)
*Sputnik 1 instrumented sphere	1957α_2	1957 Oct. 4.8	Sphere	23 in. dia.	1957 Oct. 4.9	65.1	96.2	122	513	0.052	58
		? 92 days	184 lb.		1957 Oct. 25.8	65.1	95.4	120	471	0.047	49
		?1958 Jan. 4			1957 Dec. 25.1	65.0	91.0	110	254	0.020	23
*Sputnik 1 rocket	1957α_1	1957 Oct. 4.8	Cylinder?	------	1957 Oct. 4.9	65.1	96.2	122	513	0.052	58
		57 days	------		1957 Nov. 4.0	65.1	94.0	119	403	0.038	45
		1957 Dec. 1			1957 Nov. 24.3	65.0	91.0	110	254	0.020	36
*Sputnik 2	1957β	1957 Nov. 3.1	Payload	?70 ft. long.	1957 Nov. 4.00	65.33	103.760	122	902	0.0987	59
		162.0 days	1,120 lb.		1958 Jan. 4.00	65.29	100.505	119	739	0.0802	35
		1958 Apr. 14.08			1958 Feb. 21.00	65.26	97.105	114	570	0.0605	14
					1958 Mar. 25.00	65.23	93.785	107	402	0.0400	359
					1958 Apr. 9.00	65.21	90.780	97	253	0.0215	352
Explorer 1	1958α	1958 Feb. 1.16	Cylinder	80 in. long.	1958 Feb. 1.16	33.2	114.8	191	1,379	0.141	121
		4 years	30.8 lb.	6 in. dia.	1959 Jan. 3.05	33.2	111.7	189	1,228	0.125	139
					1959 Mar. 21.06	33.1	111.2	189	1,203	0.122	296
Vanguard 1 instrumented sphere	1958β_2	1958 Mar. 17.5	Sphere	6.4 in. dia.	1958 Mar. 17.5	34.3	134.18	353	2,140	0.191	129
		?100 years	3¼ lb.		1959 Mar. 12.5	34.3	133.94	353	2,129	0.190	274
Vanguard 1 rocket	1958β_1	1958 Mar. 17.5	Cylinder	4 ft. long.	1958 Mar. 17.5	34.3	134.18	353	2,140	0.191	129
		?100 years	50 lb.	20 in. dia.							
*Explorer 3	1958γ	1958 Mar. 26.73	Cylinder	80 in. long.	1958 Mar. 26.73	33.3	115.7	101	1,511	0.166	
		93 days	31 lb.	6 in. dia.	1958 May 15.0	33.3	104.8	97	970	0.110	
		1958 June 28			1958 June 14.13	33.3	96.8	93	565	0.063	326
Sputnik 3 instrumented cone	1958δ_2	1958 May 15.3	Cone	12.3 ft. long.	1958 May 15.3	65.19	105.97	122	1,015	0.111	58
		19 months	2,926 lb.	68 in. dia.	1958 Nov. 17.00	65.16	103.000	120	867	0.095	351
					1959 Mar. 2.9	65.13	100.750	118	754	0.082	310
*Sputnik 3 rocket	1958δ_1	1958 May 15.3	Cylinder?	------	1958 May 15.3	65.19	105.9	122	1,011	0.111	58
		202.4 days	------	------	1958 Aug. 15.10	65.14	102.000	119	816	0.089	26
		1958 Dec. 3.7			1958 Oct. 11.25	65.09	98.000	115	615	0.066	5
					1958 Nov. 13.66	65.04	94.000	108	413	0.041	347
					1958 Nov. 30.59	65.00	90.000	95	217	0.017	339
Explorer 4	1958ϵ	1958 July 26.63	Cylinder	80 in. long.	1958 July 26.63	50.3	110.18	142	1,193	0.128	50
		13 months	38.5 lb.	6 in. dia.	1958 Oct. 25.06	50.3	107.73	140	1,073	0.115	317
					1959 Mar. 21.02	50.2	102.37	138	805	0.085	60
*Atlas	1958ζ	1958 Dec. 18.96	Cylinder	80 ft. long.	1958 Dec. 18.96	32.4	101.47	104	796	0.089	130
		33.6 days	8,700 lb.	10 ft. dia.	1959 Jan. 1.78	32.4	98.12	95	627	0.070	249
		1959 Jan. 21.6			1959 Jan. 17.02	32.3	92.67	88	355	0.037	37

Vanguard 2 instrumented sphere	1959α_1	1959 Feb. 17.67 ?50 years	Sphere 21.5 lb.	20 in. dia.	1959 Feb. 17.67	32.9	125.7	301	1,790	0.166	135
Vanguard 2 rocket	1959α_2	1959 Feb. 17.67 ?50 years	Cylinder 50 lb.	4 ft. long. 20 in. dia.,	1959 Feb. 17.67	32.9	130.0	302	1,992	0.184	135
*Discoverer 2	1959γ	1959 Apr. 13.89 13 days 1959 Apr. 26.5?	1,300 lb.		1959 Apr. 13.9 1959 Apr. 24.6	90 90	90.4 88.9	130 103	190 132	0.008 0.004	160 96
Explorer 6	1959δ	1959 Aug. 7 1 year	142 lb.	29 in. long. 26 in. dia. 4 Solar Vanes 18 X 18 in.		46.9	756.9	135	22,680		
*Discoverer 5	1959ϵ	1959 Aug. 13 47 days 1959 Sept. 28	1700 lb.	Agena rocket and reentry capsule.		90	94.0	118	391		
*Discoverer 6	1959ζ	1959 Aug. 19 63 days 1959 Oct. 20	1700 lb.	Same as Discoverer 5		90		121	466		
Vanguard 3 (SLV-7)	1959η	1959 Sept. 18 30-40 years	Sphere with tube attached 100 lb.	20 in. sphere 26 in. attached tapered tube			130.0	275	2019		
Explorer 7	1959ι_1	1959 Oct. 13 20 years	2 cones joined at bases 91.5 lbs.	Cone base 30 in. dia. - Overall length 60 in.		50.3	101.2	300	584		
Explorer 7 Rocket Body	1959ι_2	1959 Oct. 13 20 years					101.2	298	585		
*Discoverer 7	1959κ	1959 Nov. 7 19 days 1959 Nov. 26	1700 lbs.	Same as Discoverer 5		90					
Discoverer 8	1959λ	1959 Nov. 20 3 months	1700 lbs.	Same as Discoverer 5		90	101.5	101	793		

NOTES: Dates are given in days and decimals of a day U.T. 1 nautical mile = 6,080 ft. = 1.853 km. Perigee and apogee heights for Sputniks are over an earth of radius 3,435 n.m. and for U.S. satellites over an earth of 3,442 n.m. Argument of perigee is the angle from northward crossing of the equator to perigee, measured along the orbit. The orbit values for the Sputniks are from British observations and theory. Those for the U.S. satellites have been compiled from a variety of sources. It is not known whether Discoverer 1, launched February 28, 1959, achieved orbit: it was, nevertheless, designated 1959β * Indicates satellites no longer in orbit.

FIG. 1.–World score of near-earth satellites as of December 1959.

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supposed to fire the missile downward to test the heating effect of its high-speed re-entry into the atmosphere, but they fired it upward instead.

The U.S.S.R. had been quietly pursuing rocketry studies and experiments for many years. In 1925, the Soviet Government published a voluminous report by the Rocket Subsection of the Committee for the Exploration of the Stratosphere. October 4, 1957, saw the successful launching of the first artificial earth satellite by the Russians (the Sputnik). The resulting chain of "explosive" events, culminated in vast organizational changes in Government and in expenditures in the race for the conquest of space. Since that memorable day, there have been many attempts and some successes in creating artificial satellites. The first American satellite, Explorer 1, was launched by the Army from Cape Canaveral, Fla., on January 31, 1958, using the Jupiter C rocket. The world score as of December 1959 is shown in figure 1. The space probe shots (Lunik 3 is of course an earth satellite but not a near-earth satellite) have not been included, nor the unsuccessful firings. We are all aware that the Soviet Coat of Arms was reportedly buried in the moon by Lunik 2 on September 13, 1959, and that the Russians claim to have photographed the back side of the moon with Lunik 3 on October 7, 1959. The artificial earth satellites still in orbit as of December 15, 1959, were Explorer 1 (1958 α); Vanguard 1 and its rocket (1958 β_1 and β_2); Sputnik 3 (1958 δ_2); Vanguard 2 and its rocket (1959 α_1 and α_2); Explorer 6 (1959 δ); Vanguard 3 (1959 η); Explorer 7 and its rocket (1959 ι_1 and ι_2); Discoverer 8 (1959 λ); and Lunik 3 (1959 ρ)—a dozen artificial earth satellites of which two are Russian. (See p. 36.)

THE MOTION OF AN ARTIFICIAL SATELLITE

The basic orbit of an artificial earth satellite is an ellipse, with the center of the earth at one focus, and to reference it to the earth we have the following terms and defintions: ***orbital inclination***—the angle between the orbital plane and the earth's equator; ***orbital period***—the time for the satellite to make one complete transit of its orbit; ***perigee height***—the distance from the earth to the satellite at its nearest approach; ***apogee height***—its greatest distance from the earth (apogee and perigee are the end points of the major axis of the elliptic orbit—also called the line of apsides); ***eccentricity***—the eccentricity of the elliptic orbit; ***argument of perigee***—the angle from the northward crossing of the earth's equator to perigee, measured along the elliptic orbit. These terms are shown in figure 1.

If the earth were spherical and had no atmosphere, the motion of a satellite would be relatively simple. It would be a fixed ellipse in a fixed plane with the center of the earth as one focus, the direct consequence of Kepler's first law of planetary motion: The orbit of a planet (a satellite) around the sun (the earth) is an ellipse, the sun (the earth) being situated at a focus. But the attraction of the noncentral mass of the earth's so-called equatorial bulge has a disturbing influence on the elliptic satellite orbit, and the resistance of the air "perturbs" its motion.

The effect of the noncentral gravitational field does not materially alter the general shape of the elliptic orbit, but changes continuously its orientation in space. Air drag distorts the ellipse with little influence on its orientation in space. Fortunately, the diurnal motion of the earth (its rotation) plays no part in the progress of the satellite itself but of course is important from the standpoint of the particular area of the earth from which the satellite is visible at any given time. The disturbing effects of the attraction of the sun, moon, and other celestial bodies are considered negligible for near-earth satellites.

Figure 2 portrays a portion of a satellite orbit. The effect of the attraction of the equatorial mass of the earth is to pull the satellite toward the equator, thus decreasing the inclination. But like a gyroscope the actual effect is to cause the plane of the orbit to precess westward for an eastward

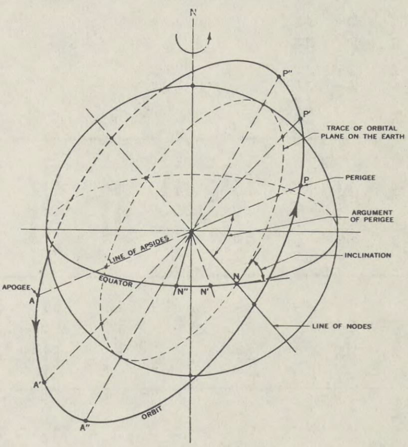

FIG. 2.—Graphic representation of a portion of the trajectory of a near-earth satellite.

launch about the focus (the center of the earth), maintaining the same inclination so that on a second revolution the line of nodes would be at N', on a third revolution at N", etc. Simultaneously, the perigee will have advanced correspondingly to the points P', P", etc. (The perigee moves in the direction of the satellite motion where the inclination is less than 63°.4, and in the opposite direction for inclination angles larger than 63°.4.) Thus, the "rigid" elliptic orbit rotates also about the focus (the center of the earth) in the plane of the orbit. It is the ability to determine the rates or periods of these nodal and perigee motions from observational data which make the artificial satellite useful for determining the shape of the earth. (See app., p. 32.)

Paradoxically, air resistance speeds up a satellite by forcing it to fall into a smaller orbit with a decreased major axis, decreased eccentricity, and corresponding decreased period. With each revolution, the apogee height decreases much more rapidly than the perigee height until the orbit is nearly circular. Thereafter perigee and apogee descend at nearly equal rates and the end of the satellite's celestial career is near as the satellite enters the lower denser atmosphere. While this is going on, the plane of the elliptic orbit is still revolving westward and the major axis of the ellipse is revolving in its plane, so viewing the satellite motion as a whole, the near-earth satellite actually traverses a continuous space trajectory around the rotating earth. It oscillates between a maximum north and south latitude corresponding to the inclination until it finally burns in the atmosphere. (See fig. 3.) Hence, if a satellite is to have long life, it is necessary that perigee be several hundred miles, probably not much less than 1,000 miles, since the early satellites showed that the effects of air drag were greater with altitude than had been indicated by the preflight empirical estimates based on exponential decay with altitude.

PRINCIPAL GEODETIC USES OF ARTIFICIAL SATELLITES

The principal geodetic uses of artificial satellites may be grouped as follows:

(a) For better geodetic positioning in areas of the earth not connected to continental networks of horizontal control, such as islands and intercontinental connections of geodetic datums.

(b) To deduce a more refined value for the flattening of the spheroidal representation of the earth (from the nodal motion of the satellite orbit).

(c) To obtain data on regional gravity anomalies from a long-term program using many satellites.

Better Geodetic Positioning

In connecting islands to continental geodetic datums or in intercontinental ties of geodetic

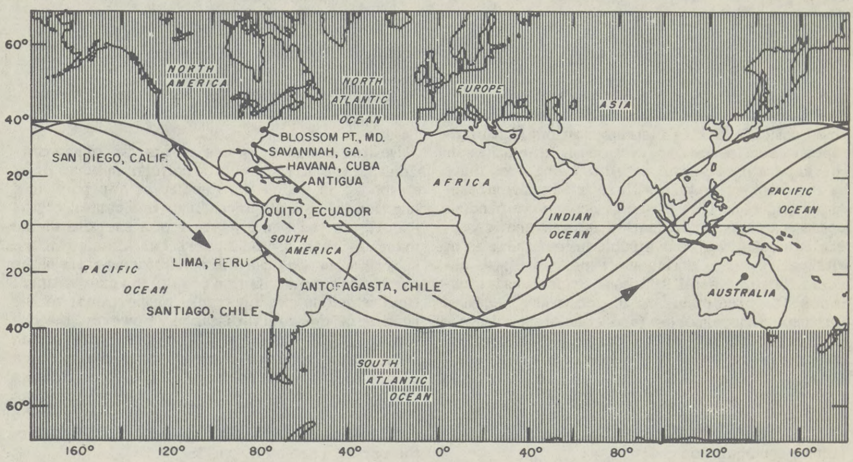

FIG. 3.—A partial trace over the earth of the trajectory of the first American artificial satellite showing its oscillatory motion in latitude and regression of the line of nodes of its orbit.

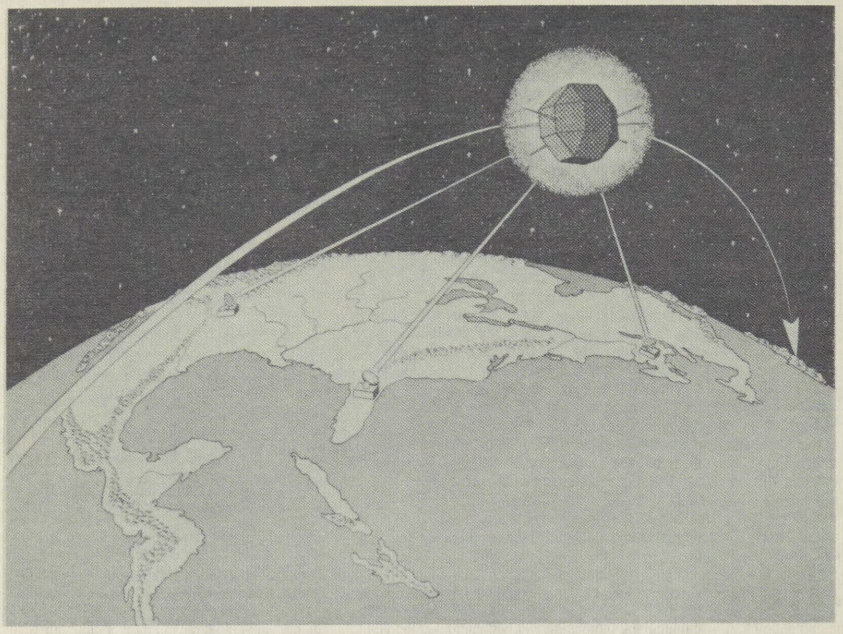

FIG. 4.--Simultaneous observations on a satellite to effect Geodetic datum ties.

datums separated by oceans, deserts, etc., there are at least two general methods using mobile or fixed optical tracking instrumentation: (1) Simultaneous continuous observations from stations in the separate nets, the satellite being used much as the flare in the known flare triangulation technique (fig. 4). This method imposes tremendous operational and coordinating efforts and is generally considered undesirable unless there is no alternative. (2) Continuous time-correlated observations of a satellite whose orbital characteristics are predictable to the accuracy required for geodetic purposes (and consistent with the inherent accuracy of the observing instrumentation), so that a usable ephemeris can be constructed of the satellite motion. The position as seen at one station can then be transferred to the equivalent time and position at another station, the calculated orbit providing a means of effective triangulation.

More Refined Value for Flattening of Earth

Newton deduced by use of his law of gravitation that the attraction of a uniform sphere, or of a sphere in which the density at any point is a function of its distance from the center of the sphere, is the same as that of a particle whose mass is that of the sphere but situated at the sphere's center. But the nonuniform nature of the earth's mass distribution results in a gravitational field which is not inversely proportional to the square of the radial distance. However, the external gravitational potential can be expressed as a series of spherical harmonics (and hence in a series of Legendre polynomials), the coefficients of each harmonic depending on the shape and mass distribution of the earth. If the coefficients can be determined, it is possible to deduce the figure of the earth. (See app., pp. 25-30.)

Several mathematical methods have been devised to evaluate the coefficients and were used with observational data from some of the past and existing satellites. In one method the second-order differential equations for the satellite motion are made integrable by including all of the zero-order term in the potential and just enough of the second-order term (there is no first-order term) to account for the constant (secular) nodal and perigee motions. The resulting equations can be integrated and the results are expressions for the nodal and perigee motions as series in the inclination of the orbit and the ellipticity or flattening of the earth. Various values have been published for the flattening as obtained from satellite data ranging from 1/297.9 to 1/298.32 although some of these admittedly were obtained from data in which the effects of air drag and asymmetry in the earth's gravitational field had not or could not have been accounted for. It is significant that most results tend to 1/298, as compared to 1/297 for the International Ellipsoid.

Regional Gravity Anomalies

If perigee of a near-earth satellite is high enough so that the perturbations due to air drag are negligible, and effects of the attraction of the sun and moon are negligible, then the chief source of irregularity in its motion will be the asymmetry of the earth's gravitational field. At the height of the satellite there is a certain averaging effect on the surface gravity anomalies and the motion of the satellite itself is so rapid that it tends to average the effects of many anomalies, so that the important quantity is the average value of the anomalies over rather large areas. Now, motion of the nodes in an artificial satellite depends on both the second harmonic (flattening) and on the fourth harmonic of the external gravitational potential and the two cannot be separated for any one satellite, but for two satellites with different inclinations and distances from the earth they can be separated. (See app., p. 32.) Hence, for adequate determination of the average value of the gravity anomalies over large areas, several satellites at different perigee heights and inclinations would be desirable and with all perigee heights great enough for air drag effects to be negligible, or accountable.

TYPE OF SATELLITE MOST USEFUL FOR GEODETIC PURPOSES

The geodetic satellite experiment differs basically from other types of satellite experiments. Most of the scheduled experiments use the satellite as a convenient vehicle for carrying specific instrumentation into otherwise inaccessible environments. Orbit information is necessary only to the extent that the approximate location of the flight path can be established. But the geodetic satellite experiment, as has been demonstrated, depends basically upon the laws governing the motion of the satellite in its orbit. That is, time correlated position data must be accurate enough to deduce mathematically the parameters of the motion, the effects of air drag and earth's asymmetric gravitational field so that reliable ephemerides of the motion can be constructed for further geodetic (or navigational) use. Hence, a satellite for geodetic purposes (chiefly for connecting widely separated geodetic datums) or navigational purposes should preferably have the following characteristics:

(a) Be spherical in shape. Although aerodynamically a sphere has high drag (one of the reasons the cannonball was abandoned long ago), it has always the same presentation area in the direction of motion. (The drag is a function of the area presented to the resisting medium in the direction of the motion. A tumbling cylinder, for instance, would have a constantly changing presentation area.)

(b) Have a perigee of not much less than 1,000 miles and a high density to surface area ratio so that air drag can either be ignored or minimized.

(c) Have an orbit of maximum inclination and minimum ellipticity. Maximum inclination would make possible its observation from higher latitudes and minimum ellipticity would assure an almost circular orbit which would tend to be more uniform and the motion more amenable to construction of an ephemeris. (For deducing the flattening from the perigee and nodal motions, an orbit of large eccentricity and minimum air drag is more desirable, since the line of nodes and the line of apsides are then better determined from the orbital position data.)

(d) Have the mass of the instrumentation symmetrically distributed spherically within the spherical shell, if possible, to eliminate any libration effect.

(e) Have a flashing beacon of sufficient brightness—brilliance of a fifth-order magnitude star at an altitude of 800 to 1,000 miles—to be registered photographically by a tracking camera, the flash source to be controlled by a command receiver. This would allow the satellite to be tracked when it was on the dark side of the earth.

(f) Have a radio beacon and a transponder (300 mc. or higher) for the determination of radio fixes. (Possibly Hiran-type distance measurements could be made.)

(g) Have an accurate clock to broadcast time signals perhaps coordinated with the flash mechanism. This would eliminate the maintenance of accurate clocks by the mobile tracking stations and aid in simultaneous observations from several stations.

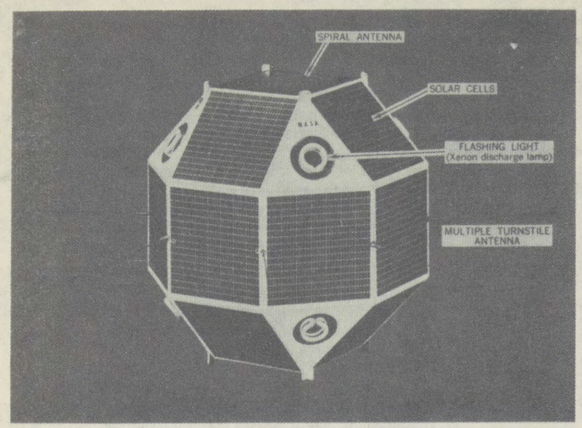

FIG. 5.—The geodetic satellite under development by NASA.

Consideration is being given to these features and others as they develop by the National Aeronautical and Space Administration (NASA), which has the responsibility for experimental satellites and plans to launch a geodetic satellite in 1961. Instrumentation availability, payload capabilities, mass-to-area ratio (this depends on latest atmospheric density information), requirements on surface area for control of internal temperature, or other technical considerations may compromise some of the desirable features, but the result should be the best that the state of the art permits. Figure 5 shows the geodetic satellite configuration as being developed by NASA. Present plans call for the Thor-Delta rocket configuration to put this satellite in orbit.

RECOMMENDED GEODETIC SATELLITE PROGRAM

The following is, in essence, the general plan presented by the Coast and Geodetic Survey, at the request of NASA, for observing the geodetic satellite on a worldwide basis.

Requirements

The geodetic satellite to be launched by NASA should provide a means for obtaining accurate geocentric coordinates of a network of points on the earth. Time-position observations on the satellite from more or less uniformly spaced points over the entire surface of the earth should give data for a precise determination of the size and shape of the earth. These data can also be employed in connecting existing geodetic datums into a unified system. Complete uniformity in coverage is impracticable, but should be approximated. It will be desirable to have carefully selected and more closely spaced points on large existing geodetic datums in order that these may be accurately positioned and oriented one to the other either by simultaneous observations on the satellite, where possible, or by use of the orbital theory, if this can be highly developed. For uniform spacing in all directions, roughly 100 points would provide for 1,500-mile spacing, 200 points for 1,000-mile spacing, and 400 points for 750-mile spacing.

The proposed program is international in scope and would require the joint efforts of many countries. The objectives are purely scientific, and not military, and the results should be freely available everywhere. Since existing knowledge of the size and shape of the earth and of the relationships between major geodetic datums is now, in general, adequate for military needs, it is emphasized that local military objectives, if any, should be in addition to and not part of the proposal herein outlined.

Considerations

Most of the details of the geodetic satellite, such as those related to acquisition both optically and electronically, the type of orbit, etc., have already been worked out by NASA.

The optical observing system recommended at this time is the BC-4 ballistic camera system or an equivalent. This system uses glass plates, not films.

The Baker-Nunn optical system and the Minitrack and Microlock electronic systems will be

FIGURE 6.

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operated independently from this program, under the direction of NASA. These systems will determine an approximate orbit needed in advance for the orientation of the ballistic cameras.

Operation of Program

To insure a better chance of success in the short time allotted for planning, cooperation will be necessary among geodesists and photogrammetrists, both national and international. Plans recommended by the Coast and Geodetic Survey to the National Aeronautics and Space Administration stressed the need of recognized competence in geodesy and photogrammetry, progressive activity in international organizations, and capacity to undertake the responsibility of directing and coordinating the observing program, the photogrammetric reduction of the observations, and the mathematical analysis of the results.

A major item for decision is the desired number of observing units and points from which observations are to be taken. As a start, a maximum of 100 observing units are suggested, each to occupy at least two points. If the satellite functions successfully over the period contemplated (400 days), many observing units could easily occupy more than two points. Central control is essential in directing the movement of the observing units in the field to insure maximum coverage compatible with adequate geometrical strength.

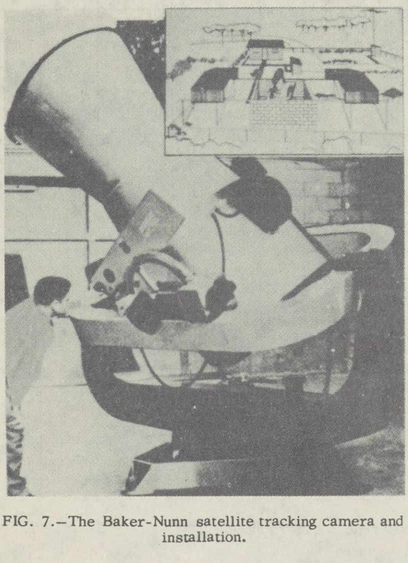

FIG. 7.—The Baker-Nunn satellite tracking camera and installation.

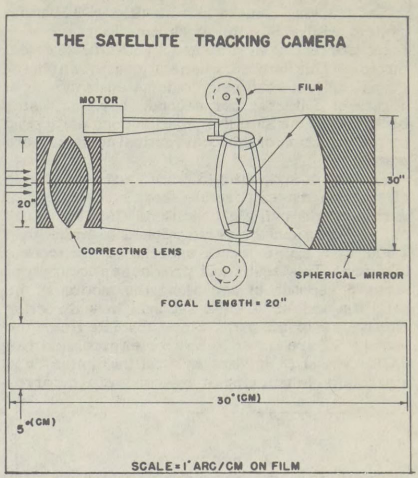

FIG. 8.—Schematic of lens system in the Baker-Nunn tracking camera. (Drawing not to scale.)

The United States military groups may wish to locate certain additional points for special purposes. Their program could be carried on independently and still have the benefit of the accurate worldwide network.

Figure 6 shows the known triangulation nets on the earth and a suggested net of observation points to effect a tie of the various geodetic datums.

SATELLITE TRACKING METHODS

For geodetic purposes, continuous optical and electronic tracking of the satellite is desirable. Positioning should be the order of 50-100 feet. As shown in figure 6, there should be enough mobile and permanent stations throughout the world so that complete connections of the various continental and other geodetic datums can be made.

Optical Techniques

Fixed Cameras.—The system used for the IGY optical tracking program (now under the cognizance of NASA) is the net of 12 Baker-Nunn satellite tracking cameras (5 additional units are being installed to obtain coverage in higher latitudes) and their associated Model III Norrman Crystal Clocks. These clocks provide absolute accuracy at all tracking stations to about one-thousandth of a second. (See fig. 7.)

The tracking camera is a modified F-1 Schmidt system with a 50-cm. apochromatic triple-element correcting system and an 80-cm. spherical mirror. This camera, when stationary, can photograph easily a sixth magnitude satellite moving at a rate of 1 degree per second. (Against a star background, the satellite position does not depend on the direction of the local vertical at the camera station.)

The use of strip film (55 mm.) and a third axis of rotation makes possible short exposure times during bright twilight conditions (fig. 8). Fifty cm. spheres can be photographed to more than 2,500 km. and 6-meter spheres to the moon's distance. This equipment provides an accuracy of about 5 seconds of arc along the motion of the satellite and at least 2 seconds in a direction transverse to the path. Since absolute times the world over are known to no greater precision than 0.001 second (8 meters in satellite motion), and a precision in tracking of 2 seconds of arc corresponds to a distance on earth of the order of 3 meters at a distance of 300 km., accuracy of a direction of the satellite from a tracking station is of the order of 10 to 15 meters. Figure 9 shows the location of the original 12 Baker-Nunn camera installations.

Mobile Cameras.—These are usually in the form of phototheodolites or kinetheodolites of which there are several types and makes. Probably most exploited at American test ranges are the Askania (originally from the German Askania plant). (See fig. 10.) This instrument is controlled by two operators, one tracking in azimuth and the other in elevation. An internal flash-camera periodically photographs the scales, thus recording azimuth and elevation angles; at the same time the satellite is photographed through a long-focus lens mounted on the kinetheodolite. The purpose of the latter operation is to allow for errors in tracking; the displacement of the satellite's image on the photograph enables a cor-

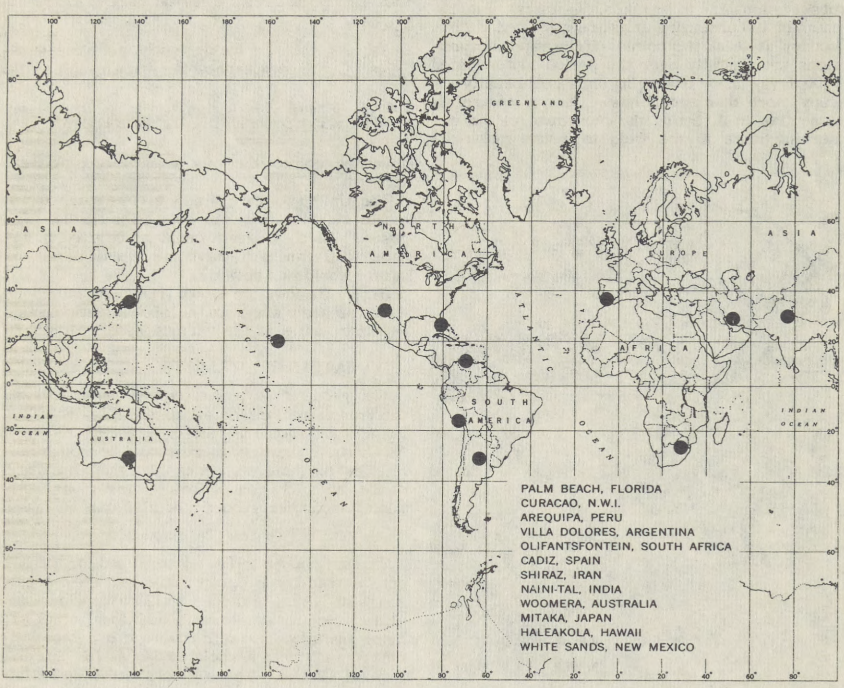

FIG. 9.--The original 12 Baker-Nunn camera sites.

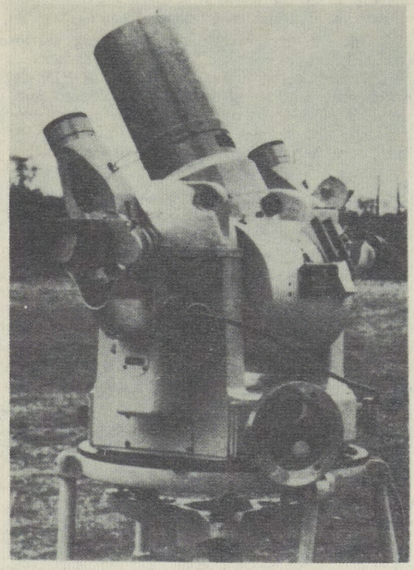

FIG. 10.—The Askania kinetheodolite.

rection to be made to the recorded azimuth and elevation angles. The exposures are controlled by accurate timing equipment at a rate of about 5 per second, so that during the course of a single transit of the satellite some hundreds of readings may be recorded. Under good operating conditions, an accuracy of 20 seconds of arc can be achieved with a timing error of about 20 milliseconds. Of course an accurate clock is also needed at such mobile stations unless the geodetic satellite is equipped with one. Kinetheodolites are not considered accurate enough for geodetic work but are useful for supplementary observations.

A type of mobile camera, usually used for missile tracking work, is called the ballistic camera. Several types exist as made by Zeiss, Wild, and other companies. Figure 11 shows the BC-4 ballistic camera as made by Wild. It is a phototheodolite featuring the movements and the graduated horizontal and elevation circles of the mount of the T-4 theodolite. Photographic plates 18 cm. square are used. Although several lens systems may be used, the Astrotar lens, of 304 mm. focal length and 117 mm. aperture appears to be especially suited for observing self-luminous satellites. The cameras are equipped with rotary between-the-lens disk shutters, supplemented by a capping shutter. The rotary disk shutters provide for chopping of continuous self-illuminated trajectory trails at specified intervals, controlling the length of individual exposures and accurately synchronizing widely separated cameras. The capping shutter provides an extended range of sequence selection and is used to record time-coded star trails for either lens calibration or camera orientation problems.

These cameras are used in pairs (or in larger numbers), actually treating the tracking problem as one in photogrammetric aerial triangulation, each camera obtaining a time correlated photograph (or sequence of photographs) of the missile or satellite against a star background. The position of the satellite is then determined from the known positions (with respect to time) of the stars by a least squares adjustment procedure, as is done with the Baker-Nunn fixed cameras. In order to do this, the distances on the plate from reference marks on it must be measured to the trace of the satellite and to the stars. Several types of machines exist for making such "plate measurements." Figure 12 shows the Mann machine (also

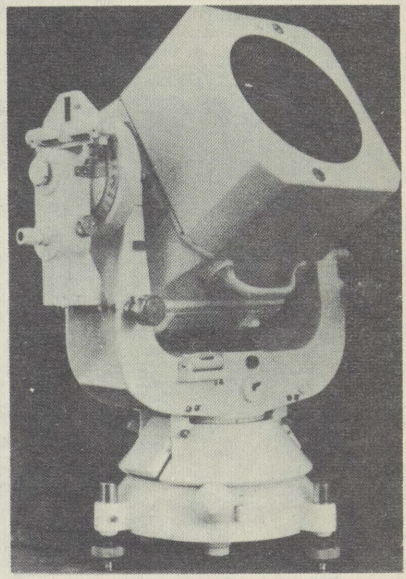

FIG. 11.—The Wild BC-4 ballistic camera.

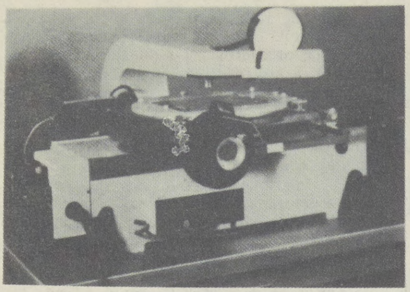

FIG. 12.--The Mann Comparator.

called a comparator), as owned by the Coast and Geodetic Survey. This machine has digitized counters and readout to an IBM punch-card machine. These cards may then be fed into a high speed computer which has had data from the star catalogs programed into it to aid in identifying the stars in the background of the satellite on the plate. Finally, through computations from these data an azimuth and elevation may be derived from each of the cameras to the satellite at a particular time and from the base lines between the cameras, the position at that time of the satellite can be computed by triangulation.

A mobile air-conditioned observing station (fig. 13) employing the Wild BC-4 camera is being built by the Instrument Corp. of Florida, which may also house plate development equipment; a plate measuring engine; and timing, recording, and communications equipment. The unit may be airlifted or transported by other means.

It is believed that mobile equipments, employing cameras of the Wild BC-4 type and properly operated with subsequent measuring and reduction procedures sufficiently controlled with respect to accuracy, will provide position data useful for geodetic purposes.

Investigation may show that use of longer focal lengths will make less critical the precision of the plate measurements making possible such measurements in the field and relieving to some extent the inevitable bottleneck in the data reduction procedures.

All optical equipment is sensitive to meteorological conditions, but for a long-lived geodetic satellite this should be a transient handicap. Optical observations have played the major role in establishing accurate orbits for those satellites which have been visible, although the data reduction from the photographic records has become a

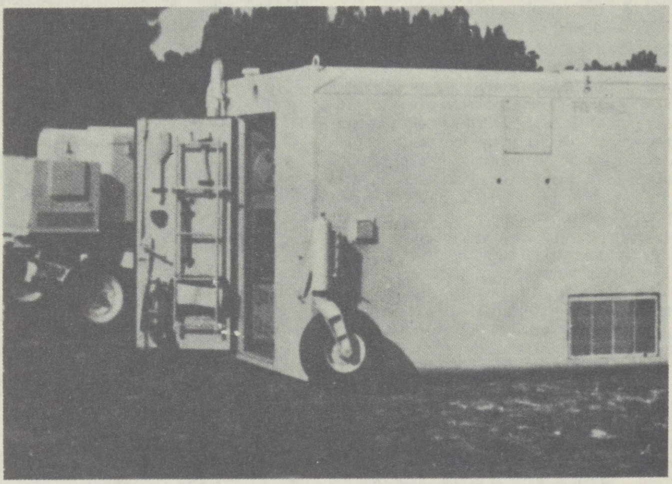

FIG. 13.—Mobile observing units as built by the Florida Instrument Co.

monumental bottleneck in spite of efforts to mechanize the process.

Electronic Techniques

During the early life of a space vehicle when little is known about its path, its transmitter advertises its position over a wide area, so that it can be located without previous knowledge of the approximate orbit. Orbital information can be obtained by means of the Doppler effect, interferometer techniques, and radar. Refraction of radio waves in the ionosphere can lead to considerable errors, particularly at low frequencies; hence, high frequencies are more desirable for tracking purposes (108 mc. or higher, as used in American satellites).

Doppler Effect.—If the satellite transmitter sends out a continuous, unmodulated wave at a fixed frequency, the signal received on the ground exhibits a change in frequency, due to the relative velocity of satellite and observing station. The receiver frequency is a function of the transmitted frequency, the velocity of radio propagation (the velocity of light), and the rate of change of the distance between satellite and observer (the radial velocity). If, then, the frequency is recorded as the satellite approaches and recedes, the radial velocity can be computed. And, since at the instant of closest approach the radial velocity will be zero (the relative velocity is then normal to the sight-line) it is possible to deduce the minimum distance and the relative velocity. (See app., p. 33.)

The orbital period can be found by observing successive transits at the same station. However, the period is not simply the difference between the times of closest approach; a correction must be made to allow for the fact that, in the intervening period, the rotation of the earth has altered the observer's position relative to the satellite orbit.

The accuracy with which the orbit can be determined from Doppler data alone depends, among other things, on the separation between the satellite and the observing stations, and between the stations themselves. For favorable triangulation these distances should be of the same order which requires a large number of operating ground stations. Over the distances involved, the curvatures of the orbit and of the earth are too large to be ignored, which complicates the analysis.

FIG. 14.—Minitrack stations and antennas.

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Interferometer Principle.—Unlike the Doppler system, which measures radial velocity, the interferometer provides direction information so that the two methods are complementary. As its name implies, the interferometer makes use of the interference pattern between the signals received at a pair of antennas, a pattern determined by the difference in the distance between the satellite and each of the receiving antennas. The separation between the antennas, usually 50 to 100 meters, is small compared with the satellite's distance, so that the waves from the transmitter may be considered to traverse parallel paths. The measured phase difference of the two antennas gives a continuous indication of the cosine of the direction of the satellite. Since the interferometer is insensitive to changes of a whole number of wave-lengths in the path difference, there are ambiguities in the measurement of the angle to the satellite which become more numerous as the antenna separation is increased. They can only be resolved from an approximate knowledge of the satellite's track obtained from another source, such as a second interferometer with a pair of antennas set closer together to give a "course" reading, or set at right angles to the first pair. In the latter case, it is possible to define then the direction of the line joining satellite and station during the satellite's transit. But to deduce the orbit, distance and relative velocity as supplied by Doppler data are needed, or the directions from other interferometers at different places. If neither is available, then some assumptions about the orbit must be made.

The Minitrack and Microlock Interferometer systems are standard electronic trackers for American satellites. (See figs. 14 and 15.) Although corrections for air drag and ionospheric refraction were included in orbit computations from the Minitrack system, average residuals

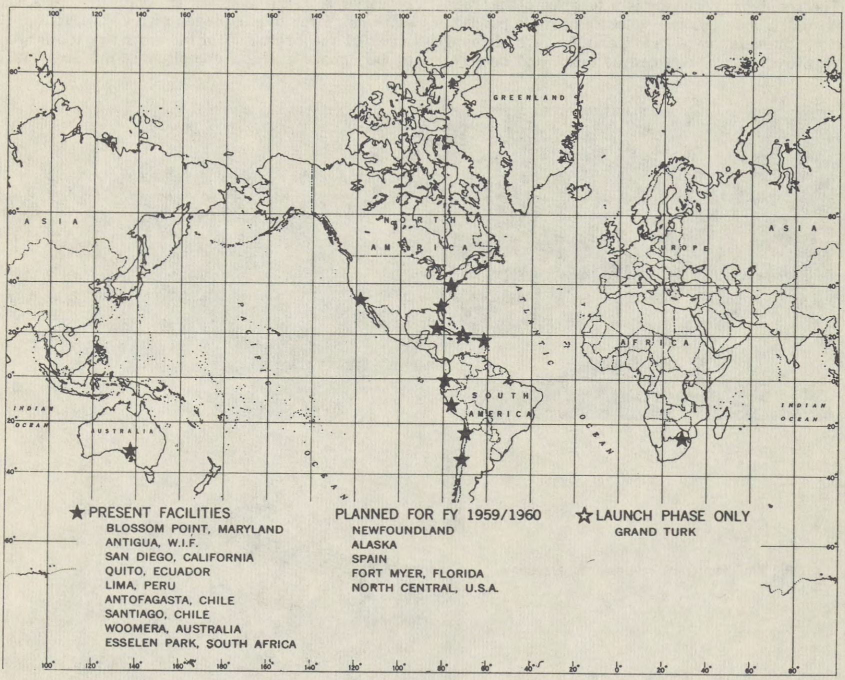

FIG. 15.—The Minitrack network.

were about 4 minutes of arc at each station, which is not considered good enough for geodetic accuracy.

Unfortunately, if the transmitter fails to operate in a satellite, so do the Doppler and interferometer stations on the earth. Hence, if possible, other types of tracking should always be used in addition to these.

Radar Tracking.—When the satellite is used as a reflector with a large radio-telescope, the advantages are freedom from use of the satellite-borne equipment and of ambient meteorological conditions, at the ground radar installation, which is not true of Doppler, interferometer, or optical techniques. Disadvantages are the small reflecting area of the satellite, with consequent narrow beam power concentration from a large antenna system with a small field of view. Unless the orbit is known fairly well, it is no easy matter to direct the radar beam to the right part of the sky at the right time. Large radio-telescopes are obviously not mobile.

Tracking radars to give azimuth and elevation angles to a satellite and distance are located in Bermuda, Hawaii, Texas, Woomera in Australia, and South Africa. These have moderately sized dishes (antennas) and are known as the FPS-16. Tracking radars are also located at the Pacific Missile Range on the west coast; White Sands Proving Ground, N. Mex.; and at Eglin Air Force Base and Cape Canaveral, Fla. The Naval Research Laboratory is operating tracking radars having 50-, 60-, and 84-foot diameter antennas. The National Science Foundation is sponsor for construction of 85- and 140-foot diameter instruments at Greenbank, W. Va.

An 85-foot radio-telescope is in use at the University of Michigan, under sponsorship of the Office of Naval Research, and a similar one has been installed at Goldstone, Calif. Present plans call for installation of 85-foot types at Woomera in Australia, South Africa, and in Spain. The largest operating radio telescope has a 250-foot antenna and is located at Jodrell Bank, England.

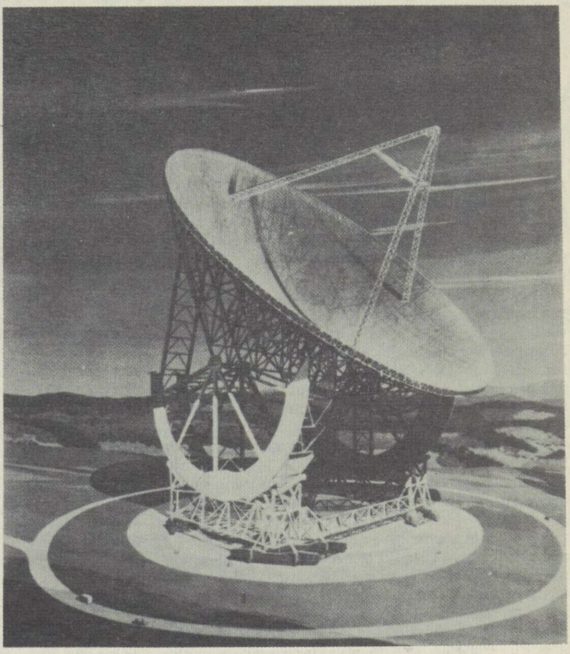

FIG. 16.—Steerable radio telescope under construction at Sugar Grove, W. Va.

The largest radio telescope in the world is under construction at Sugar Grove, W. Va., for the Office of Naval Research. The steerable parabolic antenna will be 600 feet in diameter and capable of altitude rotation from the horizon to the zenith. The entire structure will be able to rotate up to 450 degrees in a horizontal plane. Figure 16 shows this radio telescope as it will appear when completed.

Other types of satellite tracking are being investigated, for instance, infrared techniques where television techniques are being applied to improve sensitivity, selectivity, and rapid readout characteristics of the tracker (to provide selectivity to "chop off" the sky background and permit tracking in daylight as well as tracking of fainter objects at night). An investigation is being made of the shoran or hiran techniques for possible application to near-earth satellites.

SUMMARY CONCLUSION

The orbit of an artificial near-earth satellite has been discussed and the dependence of geodetic parameters, such as the flattening, on the nodal and perigee motions, which are deduced mathematically from time-correlated satellite position data; hence, the more exacting requirements for orbital data from a purely geodetic satellite. The requirements for a geodetic satellite have been discussed and tracking methods enumerated to obtain position data. While optical instrumentation still provides the most accurate and useful geodetic orbit information, improvements in electronic techniques may approach the optical results before the launching of the first geodetic satellite by NASA in 1961. The observational program should be on a coordinated international basis to make maximum use of the geodetic satellite. This will entail the provision of large numbers of mobile tracking stations.

APPENDIX

An artificial earth satellite is maintained in a circular (elliptic) orbit by precisely balancing the earth's gravitational attraction by centrifugal force produced by the satellite's tangential velocity. The kinetic energy behind this force is provided by the rocket propulsion system. The rocket vehicle must get through the denser air layer (about 100,000 feet) before accelerating to satellite speed to avoid excessive kinetic heating and the enormous drag forces.

The chief structural problem is the design of the integral propellant tanks, which are thin-walled cylindrical shells designed to withstand compressive end loads (from the rocket motor, missile inertia, and drag), shear forces and bending moments (from the guidance system), and internal pressure. The thin walls of these tanks may be stabilized by internal pressurization or by mechanical means or both. Obviously the materials used must have a high specific strength and stiffness and the ability to maintain these properties over a wide range of temperatures.

Some improvements in rocket engine performance over that of liquid oxygen-kerosene systems may be obtained by using various combinations of the oxidants (liquid oxygen, ozone, and fluorene) and the fuels liquid hydrogen, ammonia, hydrazine, and the boron hydrides, to increase the specific impulse. (The specific impulse is the thrust force delivered per unit weight of propellant consumed per second.) It is questionable whether the gain obtained in this way is worth the engineering effort required to make use of these "exotic" fuels almost all of which are either toxic, corrosive, or liable to detonation. Solid propellants, in light of recent developments, give specific impulses near those of liquid propellants, and simplify the engineering problem, but the associated structure weights are appreciably higher. Nuclear rocket propulsion, if feasible, will enable space travel beyond the capabilities of conventional rockets.

Table 1.—Specific impulses of several fuels (Sea level)

Fuel	Chamber Pressure	
	300 p.s.i.	1,000 p.s.i.
	seconds	*seconds*
Solid (best projected)	235	265
N_2O_4 - N_2H_4	250	280
H_2O_2 - N_2H_4	255	285
O_2 - Kerosene	260	300
F_2 - NH_2	312	355
O_2 - H_2	350	390
F_2 - H_2	365	410
O_3 - H_2	375	425

Note: The efflux velocity of the rocket nozzles is $V_E = g_0 I$, where g_0=32.2 ft./sec.^{2}, hence for V_E to be in ft./sec., the impulse I, which is actually a force, must be in seconds.

Guidance of a satellite vehicle consists of the determination of the position and velocity during its powered flight, and of computing the corrections to be made to the flight path to achieve the required satellite injection conditions. There are in general two kinds of guidance; radar measurement of position and velocity; measurement of acceleration by means of an inertial navigation system in the rocket.

The center of an inertial guidance system is the space-stabilized inertial platform (gyroscopic) carrying three orthogonally mounted accelerometers. A launch point reference is placed in the rocket by aligning this stable platform to the local vertical and local north. After inserting the data for satellite injection, the rocket can be directed to fly between launch site and point of injection. The accelerometers sense deviations from the precomputed flight path and through an associated system of integrators, commands are issued to the control system as steering commands, propulsion orders, firing signals, etc. Radio-inertial combination may be used. Command signals from the earth may be used to cause changes in the attitude of the rocket and consequent change in the trajectory.

With radar guidance systems there is the problem of noise in the system (due to variations in motor thrust and in the measuring system itself, and to ionization in the rocket flame).

The main problem with inertial guidance systems is in the design of gyroscopes and accelerometers of sufficient accuracy and stability.

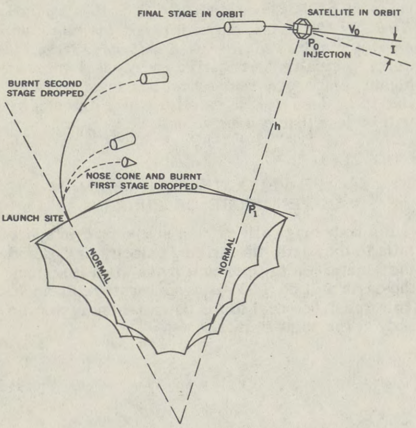

FIG. 17.—The satellite vehicle trajectory from launch to injection.

The wander of the gyroscopes, which usually have a spin rate of 12,000 to 24,000 r.p.m., can be minimized by using flotation gyroscopes.

The error characteristics of the radar and inertial guidance systems are to some extent complementary. The radar system has excellent long term stability but suffers from noise at higher frequencies, while the inertial system has little high frequency noise but suffers from long-term drift.

The main function of the control system in rocket fired satellites is to apply the corrections given by the guidance system to the flight path. The couples necessary to change the attitude of the rocket are usually produced by deflecting the efflux jets from the main rocket motors or by movable vanes in the jets. The control problem is complicated by any flexibility of the structure and by fuel sloshing. Small retrorockets or rockets placed on the satellite itself at proper angles (and fired from the earth by radio control) may be used to alter its orbit, raise the apogee, change its tangential velocity, etc.

SATELLITE INJECTION ACCURACY

The flight pattern of a multistage satellite vehicle, as depicted in figure 17, consists of a short stage of powered flight during which the missile climbs almost vertically out of the earth's atmosphere. At the end of this, the first stage and nose cone are dropped, the second stage fires and is dropped at its burnout, the process continuing to the final stage which may eject the satellite into orbit and then assume an orbit of its own.

The accuracy of placing a satellite in a desired orbit depends on its position and velocity at burnout of the final stage—in figure 17, the values of h, I, and V_o which are respectively the height above the earth at burnout, the angle which the trajectory makes with the horizontal at altitude h, and the speed at burnout. For instance, if h is 300 miles and a circular orbit is desired, V_o must be just over 17,000 m.p.h., and the angle I must be zero. An error in speed of ± 35 m.p.h. will cause a deviation in the orbit of 30 miles. An error of 1.5 degrees in I, when h is 300 miles, will cause an orbital deviation of 100 miles. With an h of 300 miles, a speed of 17,000 m.p.h. means success while 16,800 m.p.h. means failure! The allowable errors to achieve an orbit are 2 to 3 degrees in I, the injection angle, and 100 to 500 m.p.h. in the speed V_o. For specific elliptic orbits the error in I must be no more than 0.5 to 2 degrees and in Vo no more than 25 to 50 miles per hour. For precision orbits, as a 24-hour circular orbit, the error in I cannot be more than 0.1 to 0.25 degree and in V_o not more than 1 to 2 m.p.h.!

In summary, to launch a satellite vehicle so that the orbit will lie between altitudes of 200 and 1,500 miles, an injection speed, V_o, of about 17,400 m.p.h. is required and the injection angle, I, must be at least within 3 degrees of horizontal. If launching speed is 340 m.p.h. slower, the tolerance on the injection angle is approximately halved—it would have to be within 1.5 degrees of horizontal! ***At present any orbit within rather wide limits is a success!***

MINIMUM ENERGY REQUIRED TO LIBERATE A UNIT MASS FROM THE EARTH

The gross takeoff weight of Vanguard 1, launched March 17, 1958 (and still in orbit), was 22,600 pounds. The satellite itself is 6.4 inches in diameter and weighs 3.25 pounds. (Also placed in orbit was the 50-pound third stage rocket casing.) So it required 22,600 pounds of takeoff weight (most of this was fuel), to place 53.25 pounds in orbit with perigee 353 n.m., and apogee 2,140 n.m. Why does it require so much energy to place a satellite in orbit?

Newton's fundamental law of gravitation may be written

$$F = \frac{G m M}{r^2} \qquad (1)$$

where

m, M are the masses of two bodies in space

r is the distance between them

G is a constant.

If M and R are respectively the mass and mean radius of the earth (the earth is considered a radially homogeneous sphere) then at sea level the force, F_o, on a body of mass m is from (1)

$$F_0 = G m M / R^2 \qquad (2)$$

But from Newton's laws of motion, a force exerted by the earth on a mass m at earth's sea level is

$$F_0 = m g_0 \qquad (3)$$

where g_o is the acceleration of gravitation at sea level. Hence from (2) and (3)

$$G = R^2 g_0 / M \qquad (4)$$

and (1) may be written with the value of G from (4) as

$$F = g_0 m \left(\frac{R}{r}\right)^2 \qquad (5)$$

If $m = 1$, F is the force of gravitation at some point in space also the acceleration of gravitation, g, on a unit mass located at that point

$$F = g = g_0 \left(\frac{R}{r}\right)^2 \qquad (6)$$

Work or energy, E, is equal to force times distance, $dE = F\,dr$, or from (6)

$$E = g_0 \int_{r_1}^{r_2} \left(\frac{R}{r}\right)^2 dr \qquad (7)$$

To escape earth's gravitation, assuming the start at sea level, $r_1 = R$, $r_2 = \infty$ and (7) becomes

$$E = g_0 R^2 \int_R^{\infty} \frac{dr}{r^2} = g_0 R \qquad (8)$$

Equation (8) states that the minimum energy required to liberate a mass of 1 slug (32.2 lbs.) from the earth's attraction, is equal to that required to move a unit mass a distance equal to the mean radius of the earth under a constant force equal to the acceleration of gravitation at earth's sea level. If in (8) one places $g_o = 32.2$ ft./sec.^{2} (this value is actually that of gravity at sea level—gravity being defined as the resultant of the gravitational force and the centrifugal force of earth's rotation, the latter force is quite small and negligible as far as the stated numerical value of g_o is concerned), $R = 21 \times 10^6$ ft., then ***$E = 6.79 \times 10^8$ ft. lbs. per unit mass, the minimum energy required to liberate a unit mass from the earth.*** Actually the required energy is somewhat higher since air resistence has been ignored. But it is less for a satellite since its velocity will be less than escape velocity.

ESCAPE VELOCITY WITH MINIMUM EXPENDITURE OF ENERGY

If a body originally at rest at a point P in space falls to the earth, its striking velocity is V_{P_0} and the kinetic energy per unit mass when it strikes the earth will be $(1/2)V^2_{P_0}$ ignoring air resistance. This must be equal to the potential energy of the body at the point P, that is

$$\tfrac{1}{2} V_{P_0}^{\,2} = \int_R^{R+h} g\,dr \qquad (9)$$

where h is now the vertical distance from the surface of the earth to the point P in space. With the value of g from (6) placed in (9) find

$$V_{P_0}{}^2 = 2g_0 R^2 \int_R^{R+h} \frac{dr}{r^2} = 2g_0 Rh/(R+h) = g_0 H,$$

or

$$V_{P_0} = \sqrt{g_0 H}, \quad H = 2Rh/(R+h). \qquad (10)$$

Hence V_{P_0} *(the geometric mean* between g_0 and H, where H is *the harmonic mean* of h and R) is the velocity for a body to leave the earth in order to coast to a height h. If one lets $h \to \infty$ then $H = 2R$, and from (10)

$$V_{e_0} = \sqrt{2g_0 R}. \qquad (11)$$

With $g_0 = 32.2$ ft./sec.^{2}, $R = 21 \times 10^6$ ft. find from (11) that $V_{e_0} = 36{,}700$ ft./sec. which is about 7 miles/sec. or 25,200 m.p.h. as the minimum velocity a body must attain at sea level if it is to escape the earth's attraction *with the minimum expenditure of energy.*

The gravitational velocity of escape, V_e, at any distance h from the surface of the earth is then from (10) and (11)

$$V_e{}^2 = V_{e_0}{}^2 - V_{P_0}{}^2 = 2g_0 R - 2g_0 Rh/(R+h) = 2g_0 R^2/(R+h)$$

or

$$V_e = R\sqrt{2g_0/(R+h)} = \sqrt{g_0 RH/h}, \qquad (12)$$

where H is the *harmonic mean* of h and R.

VACUUM ORBIT OF A NEAR EARTH SATELLITE

Beginning with the elements at the injection point Po, as shown in figure 17, one can establish the differential equation of the motion (consider the earth a sphere and neglect air resistance). Kepler's second law may be used which states that the rate of description of area by a moving radius vector (r in fig. 18) is constant for all parts of the orbit, and write (from fig. 18)

$$r^2 \frac{d\omega}{dt} = k$$

Now when P is at Po,

$$r\frac{d\omega}{dt} = \frac{ds}{dt} \cos I = V_0 \cos I$$

and $r = R + h$, hence

$$r^2 \frac{d\omega}{dt} = (R+h)V_0 \cos I = k \qquad (13)$$

If V is the speed of the satellite at P, note from figure 18 that

$$V^2 = \left(\frac{ds}{dt}\right)^2 = \left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\omega}{dt}\right)^2. \qquad (14)$$

But $\frac{dr}{dt} = \frac{dr}{d\omega}\frac{d\omega}{dt}$ and from (13) $\frac{d\omega}{dt} = \frac{k}{r^2}$

so that $\frac{dr}{dt} = \frac{k}{r^2}\frac{dr}{d\omega}$ and (14) may be written

$$V^2 = \left(\frac{ds}{dt}\right)^2 = \frac{k^2}{r^4}\left(\frac{dr}{d\omega}\right)^2 + \frac{k^2}{r^2}. \qquad (15)$$

From the integral used to obtain (10), with the sign changed, one has the integral of the velocity from P_0 to P

$$\left[V^2\right]_{V_0}^{V} = -2g_0 R^2 \int_{R+h}^{r} \frac{dr}{r^2} \qquad (16)$$

or

$$V^2 = V_0{}^2 + 2\mu/r - 2\mu/(R+h) = q + 2\mu/r, \qquad (17)$$

where $q = V_0{}^2 - 2\mu/(R+h)$, $\mu = g_0 R^2$.

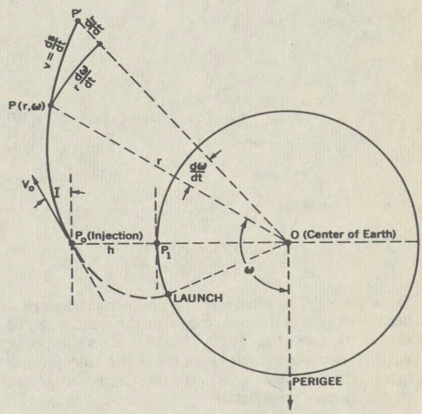

FIG. 18.—Polar representation of trajectory elements from injection.

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From (15) and (17) one may now write

$$V^2 = \frac{k^2}{r^4}\left(\frac{dr}{d\omega}\right)^2 + \frac{k^2}{r^2} = q + \frac{2\mu}{r},$$

and solving for $d\omega$, one finds

$$d\omega = k\,dr / r^2 \, (q + 2\mu/r - k^2/r^2)^{1/2}, \qquad (18)$$

which is the polar differential equation of the orbit.

By completing the square on the terms in r under the radical of (18) one may write the radical as

$$\left[q + \mu^2/k^2 - (k/r - \mu/k)^2\right]^{1/2}$$

$$= (q + \mu^2/k^2)^{1/2}\left[1 - \left\{\frac{k/r - \mu/k}{(q + \mu^2/k^2)^{1/2}}\right\}^2\right]^{1/2}$$

whence (18) may be written

$$d\omega = -d\left(\frac{k/r - \mu/k}{(q + \mu^2/k^2)^{1/2}}\right) \Bigg/ \left[1 - \left\{\frac{k/r - \mu/k}{(q + \mu^2/k^2)^{1/2}}\right\}^2\right]^{1/2},$$

which integrates directly to give

$$\omega - \omega_0 = \arccos\left[(k/r - \mu/k)/(q + \mu^2/k^2)^{1/2}\right]$$

or

$$r = p \Big/ \left[1 + e\cos(\omega - \omega_0)\right], \qquad (19)$$

where

$$p = k^2/\mu, \quad e = (1 + q k^2/\mu^2)^{1/2},$$

$$q = V_0^2 - 2\mu/(R+h), \quad \mu = g_0 R^2$$

Equation (19) is clearly the polar equation of a conic section with one focus at the center, o, of the earth (see fig. 18). If $\omega_0 = o$, then the polar axis of the coordinate system is the line joining the perigee to the center of the earth and equation (19) may be written

$$r = p/(1 + e\cos\omega) \qquad (20)$$

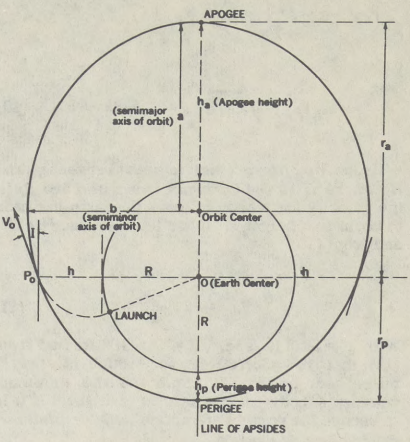

FIG. 19.—Elliptic orbit elements.

Equation (20) represents a circle if $e = o$; an ellipse, parabola, or hyperbola according as $e \lesseqgtr 1$. From figure 19 and equation (20) it is seen that when $\omega = 0, \pi$ one has

$$r_p = p/(1+e) = R + h_p,$$
$$r_a = p/(1-e) = R + h_a, \qquad (21)$$

where r_p and r_a are the values of r at perigee and apogee; h_p and h_a are perigee and apogee heights. Also $r_p + r_a = 2a$ where a is the semi-major axis of the orbit. Hence from (21) $p/(1+e) + p/(1-e) = 2a$, whence

$$p = a(1 - e^2), \qquad (22)$$

and (20) may be written

$$r = a(1 - e^2)/(1 + e\cos\omega). \qquad (23)$$

From (23) when $\omega = \pi/2, 3\pi/2$, then $r = a(1-e^2)$ and from figure 19 and equation (23) it is seen that

$$r_{\pi/2} = r_{3\pi/2} = a(1 - e^2) = R + h. \qquad (24)$$

From (19) $p = k^2/\mu$ where $k = (R+h)\,V_0 \cos I$ from (13) and $\mu = g_0 R^2$. From these values and equations (22) and (24) one finds

$$
\begin{aligned}
p &= a(1-e^2) = R+h = k^2/\mu \\
&= (R+h)^2 V_0^2 \cos^2 I / g_0 R^2 \\
&= 2(R+h)\cos^2 I\, V_0^2/V_e^2 \\
&= 2(R+h)\cos^2 I/k_0^2,
\end{aligned} \tag{25}
$$

where $V_e^2 = 2\, g_0 R^2/(R+h)$ as given by (12), and $k_0 = V_e/V_0$. From the third and last member of (25) find

$$\cos I = k_0/2^{1/2}, \quad k_0 = V_e/V_0 \tag{26}$$

Again from (21) and the second term of (25) find

$$h_p = a(1-e) - R, \quad h_a = a(1+e) - R \tag{27}$$

and from (27) solving for a and e

$$a = R + \tfrac{1}{2}(h_a + h_p), \quad e = \tfrac{1}{2}(h_a - h_p)/a. \tag{28}$$

Now from (19)

$$
\begin{aligned}
e &= (1 + q\, k^2/\mu^2)^{1/2} \\
&= \left\{ 1 + (R+h)^2 V_0^2 \cos^2 I \left[V_0^2 - 2\mu/(R+h) \right] /\mu^2 \right\}^{1/2} \\
&= (1 + 4 V_0^2 \cos^2 I (V_0^2 - V_e^2)/V_e^4)^{1/2} \\
&= (2 - k_0^2)^{1/2}/k_0
\end{aligned} \tag{29}
$$

where

$$V_e = R\,[2 g_0/(R+h)]^{1/2}, \quad k_0 = V_e/V_0, \quad \cos I = k_0/2^{1/2}.$$

From (29), $e = 0$ if $k_0 = 2^{1/2}$, whence $\cos I = 1$, and $I = 0$.

$$V_0 = V_e/2^{1/2}, \quad V_e = R\,[2 g_0/(R+h)]^{1/2}. \tag{30}$$

Equations (30) are the conditions for a circular orbit at altitude h. For instance suppose h = 300 miles = 1.584 x 10^6 ft. and place g_0 = 32.2 ft./sec.^{2}, R = 21 x 10^6 ft. Then $V_e = \sqrt{12.58} \times 10^4$ = 3.55 x 10^4 ft./sec. or 6.72 miles/sec. or 24,190 m.p.h. Then V_0 = 0.7071 x 24,190 = 17,100 m.p.h. This value was cited earlier for a circular orbit at 300 miles altitude under Satellite Injection Accuracy.

Again from (29) $e = 1$ when $k_0 = 1$, then $V_0 = V_e$ and *the satellite escapes* from the earth *along a parabolic orbit*. When $0 < k_0 < 1$, $e > 1$, $V_0 > V_e$ and *the satellite escapes* the earth *along a hyperbolic orbit*. When $1 < k_0 \leq 2^{1/2}$ then $0 \leq e < 1$ and the satellite describes an *elliptic orbit* including the circular limiting orbit ($e = 0$). Not all values of $1 < k_0 \leq 2^{1/2}$ will give useful elliptic orbits (from a geodetic view point) since the orbit may intercept the earth.

An absolute lower limit for k_0 may be obtained from (24) and (27), $h + R = a(1 - e^2)$ and $h_p + R = a(1 - e)$ which by division gives $1 + e = (h + R)/(h_p + R)$ and if $h_p = 0$ (the elliptic orbit tangent to the earth), then $e = h/R$. From (29) $e = (2 - k_0^2)^{1/2}/k_0$ or $k_0 = [2/(1 + e^2)]^{1/2}$ and the value of $e = h/R$ gives $\left[2/\left(1 + \frac{h^2}{R^2}\right)\right]^{1/2}$ as the absolute lower limit (tangent trajectory).

THE PERIOD OF THE MOTION AND THE ORBITAL VELOCITY

Since the area of an ellipse is $\pi a b$ one may write from equation (13), Kepler's second law,

$$
\begin{aligned}
r^2 \frac{d\omega}{dt} &= k = \frac{2\pi a b}{T} \\
&= (R+h) V_0 \cos I \\
&= a(1-e^2) V_0 \cos I,
\end{aligned} \tag{31}
$$

and with the aid of equations (24) to (30) one may write from (31)

$$
\begin{aligned}
T &= \frac{2\pi a b}{(R+h) V_0 \cos I} \\
&= 2\pi \frac{[R + \tfrac{1}{2}(h_a + h_p)]^{3/2}}{(R+h)^{1/2} V_0 \cos I} \\
&= \frac{\pi (R+h)}{V_e} \left(1 - \frac{V_0^2}{V_e^2}\right)^{-3/2} \\
&= \frac{2\pi g_0 R^2}{V_e^3} \left(1 - \frac{V_0^2}{V_e^2}\right)^{-3/2} \\
&= \frac{2\pi g_0 R^2}{k_0^3 V_0^3} \left(1 - \frac{1}{k_0^2}\right)^{-3/2}
\end{aligned} \tag{32}
$$

From (17), (23), and useful relations in equations (24) to (30) one can write the orbital velocity as

$$
\begin{aligned}
V &= \left(V_0^2 + \frac{2 g_0 R^2}{r} - \frac{2 g_0 R^2}{R+h} \right)^{1/2} \\
&\doteq [1 + 2e\cos\omega/(1+e^2)]^{1/2} V_0,
\end{aligned} \tag{33}
$$

where

$$
\begin{aligned}
e &= (2 - k_0^2)^{1/2}/k_0 = \tfrac{1}{2}(h_a - h_p)/a, \\
V_0 &= V_e/k_0 \\
a &= R + \tfrac{1}{2}(h_a + h_p).
\end{aligned}
$$

Now the maximum and minimum values of V occur at perigee and apogee respectively, that is when $\omega = 0, \pi$ respectively. (This can be determined simply from (33) by placing $\frac{dV}{d\omega} = 0$). From

(33) with $\omega = 0$, π and $\cos I = k_0/2^{1/2} = 1/(1+e^2)^{1/2}$ find

$$V_p = (1+e)V_0/(1+e^2)^{1/2} = (1+e)V_0 \cos I,$$
$$V_a = (1-e)V_0/(1+e^2)^{1/2} = (1-e)V_0 \cos I. \qquad (34)$$

For the circular case, equations (30), $a = b = R + h$, $e = 0$, $\cos I = 1$ and from (32) and (33),

$$V = V_0 = 2\pi(R+h)/T. \qquad (35)$$

SUMMARY OF VACUUM ELLIPTIC ORBIT FORMULAS

From equations (21) to (35) one may write:

$$\cos I = k_0/2^{1/2} = 1/(1+e^2)^{1/2}$$
$$= (2R + h_a + h_p)^{1/2}/2^{1/2}(R + h_a + h_p - h)^{1/2},$$
$$V_0 = V_e/k_0 = (V_e \sec I)/2^{1/2},$$
$$k_0 = 2^{1/2}/(1+e^2)^{1/2},$$
$$V_e = R(2g_0)^{1/2}/(R+h)^{1/2}$$
$$= R(2g_0)^{1/2}/a^{1/2}(1-e^2)^{1/2},$$
$$h = a(1-e^2) - R,$$
$$h_p = a(1-e) - R,$$
$$h_a = a(1+e) - R,$$
$$r = a(1-e^2)/(1+e\cos\omega),$$
$$e = (2-k_0^2)^{1/2}/k_0 = \tfrac{1}{2}(h_a - h_p)/a,$$
$$a = (R+h)k_0^2/2(k_0^2-1)$$
$$= (R+h)/(1-e^2)$$
$$= R + \tfrac{1}{2}(h_a + h_p),$$
$$b = a(1-e^2)^{1/2} = a^{1/2}(R+h)^{1/2}$$
$$= (R+h)^{1/2}[R + \tfrac{1}{2}(h_a+h_p)]^{1/2}$$
$$T = 2\pi ab/(R+h)V_0 \cos I$$
$$= 2\pi[R + \tfrac{1}{2}(h_a+h_p)]^{3/2}/R g_0^{1/2} \qquad (36)$$
$$= \frac{\pi(R+h)}{V_e}\left(1 - \frac{V_0^2}{V_e^2}\right)^{-3/2}$$
$$= \frac{2\pi g_0 R^2}{V_e^3}\left(1 - \frac{V_0^2}{V_e^2}\right)^{-3/2}$$
$$= \left(\frac{2}{1-e^2}\right)^{1/2}\frac{2\pi a}{V_e}$$
$$= \frac{2\pi g_0 R^2}{k_0^3 V_0^3}\left(1 - \frac{1}{k_0^2}\right)^{-3/2}$$
$$= \frac{2\pi}{\sqrt{V_a V_p}}[R + \tfrac{1}{2}(h_a+h_p)],$$
$$V = [1 + 2e\cos\omega/(1+e^2)]^{1/2} V_0,$$
$$V = V_0 = 2\pi(R+h)/T \quad \text{(circular orbit)}$$
$$V_p = (1+e)V_0 \cos I,$$
$$V_a = (1-e)V_0 \cos I,$$
$$V_a V_p = g_0 R^2/[R + \tfrac{1}{2}(h_a+h_p)],$$
$$V_p/V_a = (1+e)/(1-e) = (h_a+R)/(h_p+R),$$

and where for useful elliptic orbits

$$[2/(1+\frac{h^2}{R^2})]^{1/2} \le k_0 \le 2^{1/2}.$$

A GEODETIC SATELLITE ORBIT (VACUUM)

Suppose that it is desired to have a geodetic satellite with a perigee of 1,000 miles and apogee of 1,500 miles. Assume the radius of the earth to be 3,959 statute miles. (This is the radius of the sphere equivalent in area to the International Ellipsoid of reference.) Then from equations (36)

$$a = R + \tfrac{1}{2}(h_a + h_p) = 3{,}959 + 1{,}250 = 5{,}209 \text{ miles}$$
$$e = \tfrac{1}{2}(h_a - h_p)/a = (250)/(5209) = 0.048,$$
$$e^2 = 0.0023$$
$$k_0 = [2/(1+e^2)]^{1/2} = 2/(1.0023)^{1/2} = 1.4126$$
$$h = a(1-e^2) - R = (5209)(0.9977) - 3{,}959$$
$$= 5{,}197 - 3{,}959 = 1{,}238 \text{ miles}$$
$$V_e = R[2g_0/a(1-e^2)]^{1/2}$$
$$= (3{,}959)[(64.4)/(5{,}280)(5{,}197)]^{1/2}$$
$$= 6.0665 \text{ miles/sec} = 21{,}840 \text{ m.p.h.}$$
$$V_0 = V_e/k_0 = (21{,}840)/(1.4126) = 15{,}460 \text{ m.p.h.}$$
$$\cos I = 0.7071\, k_0 = (0.7071)(1.4126) = 0.99885,$$
$$I = 2°45'.$$
$$T = [2/(1-e^2)]^{1/2}(2\pi a/V_e)$$
$$= [2/(0.9977)]^{1/2}[(6.2832)(5{,}209)/(6.0665)]$$
$$= (1.4158)(5{,}395) = 7{,}638.2 \text{ sec.}$$
$$= 2 \text{ hours } 7.3 \text{ min.}$$
$$V_p = (1+e)V_0\cos I = (1.048)(15{,}460)(0.99885)$$
$$= 16{,}185 \text{ m.p.h.}$$
$$V_a = (1-e)V_0\cos I = (0.952)(15{,}460)(0.99885)$$
$$= 14{,}700 \text{ m.p.h.}$$

Hence for a satellite orbit of perigee 1,000 miles and apogee 1,500 miles, one must have at injection h = 1,238 miles, V_0 = 15,460 miles,

Table 2

ko	Vo	V_p	V_a	cos I	I	h_p	h_a	a	e	T	
	m.p.h.	m.p.h.	m.p.h.		°	miles	miles	miles		hrs.	min.
1.3498	16,180	20,270	10,615	0.95444	17 21.5	0	3,600	5,760	0.3127	2	28.2
1.3552	16,115	20,050	10,835	0.95826	16 36.5	50	3,460	5,715	0.2984	2	26.4
1.3606	16,050	19,815	11,065	0.96208	15 50.0	100	3,310	5,665	0.2834	2	24.6
1.3681	15,965	19,490	11,400	0.96738	14 40.5	200	3,150	5,635	0.2618	2	23.1
1.3810	15,815	18,850	12,040	0.97651	12 26.5	300	2,710	5,465	0.2205	2	16.8
1.4000	15,600	17,650	13,235	0.98994	8 08.0	588	2,105	5,305	0.1429	2	10.2
1.4082	15,510	16,875	14,010	0.99574	5 17.5	800	1,770	5,245	0.0927	2	08.6
1.4126	15,460	16,185	14,700	0.99885	2 45.0	1,000	1,500	5,209	0.0480	2	07.3
1.4140	15,445	15,710	15,175	0.99984	1 01.0	1,150	1,330	5,198	0.0173	2	06.9
1.4142	15,443	15,443	15,443	1.0000	0 0	1,238	1,238	5,197	0	2	06.9
Based on an injection altitude of 1,238 miles and velocity of escape at 1,238 miles of 21,840 m.p.h.											

$I = 2°45'$ and correspondingly a = 5,209 miles, e = 0.048, T = 2 hours 7.3 min., V_p = 16,185 m.p.h., V_a = 14,700 m.p.h.

If the injection altitude, h = 1,238 miles, is attained but the required values of I and V_o are not, a useful orbit may or may not be achieved. If a useful one is to be obtained then with h = 1,238, R = 3,959 one finds from (36) that $1.3498 \leq k_o \leq 1.4142$. Table 2 lists the elements of several possible orbits from the tangent orbit to the limiting circular orbit.

While the figures of table 2 are only approximate their orders of magnitude are correct and indicate again the precision with which the injection quantities I and V_o for a particular h must be controlled in order to have any usable orbit and particularly to achieve a specified orbit. Figure 20 shows the orbits drawn to scale from table 2 for the values of h_p = o, 1,238 miles. All geodetically useful orbits must lie between these. (Obviously the tangent orbit, for which h_p = o, would be of no practical value. It is doubtful if much useful information could be obtained for an h_p under 100 miles.)

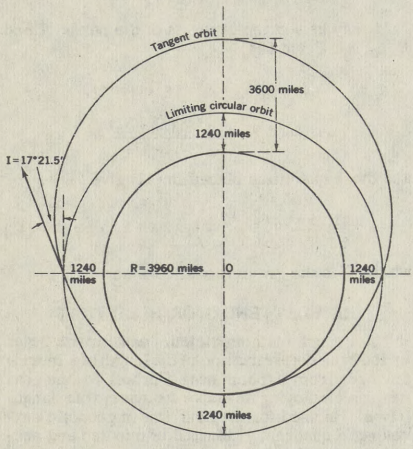

FIG. 20.—Range of achievable orbits based on injection elements of a desired orbit for geodetic purposes. (See Table 2.)

AN ESTIMATE OF ROCKET TAKEOFF WEIGHT

Let us suppose that the geodetic satellite, as shown in figure 5, weighs 200 lbs., and that the orbit desired is that already discussed—perigee 1,000 miles, apogee 1,500 miles. Suppose also that the fuel to be used is oxygen-kerosene which has a specific impulse of 260 (assuming a chamber pressure of 300 p.s.i.) as shown in table 1.

Now if V_E is the efflux velocity or discharge velocity through the rocket motor nozzles, then $V_E = g_o I$. (This is not quite true since V_E actually increases with altitude because of decrease in atmospheric pressure.) I, the specific impulse, is a force measured in seconds since g_o = 32.2 ft./sec.^{2} and V_E is in ft./sec. If the rocket has mass m and velocity V then

$$m\frac{dv}{dt} = -V_E\frac{dm}{dt} = g_o\left(-I\frac{dm}{dt}\right) \qquad (37)$$

Equation (37) states that the change in the momentum of the rocket is equal to the momentum of the discharged gas which is the product of the efflux velocity V_E of the gas relative to the rocket and mass rate of discharge of the gas $\left(-\frac{dm}{dt}\right)$

Also from (37) since $V_E = g_o I$, the quantity

$$F = \left(-I\frac{dm}{dt}\right)$$

is a force called the thrust.

Integrating equation (37) considering the jet velocity V_E as constant

$$V_0 = \int_0^{V_0} dv = -V_F \int_{m_0}^{m_f} \frac{dm}{m}$$

$$= V_E \ \ln \frac{m_0}{m_f} = g_0 \ I \ln \frac{m_0}{m_f}, \qquad (38)$$

Where m_0 is the initial mass of the rocket and m_f the final or residual mass after the propellant has burned. For simplicity consider a multistage rocket of n stages equal in size, with equal structure to total stage weight in each of K. If W_T is the gross rocket vehicle weight, W_P the useful payload weight, one may write in the light of (38)

$$V_0 = n g_0 . I \ln m_n$$

$$W_T = \left[\frac{m_n (1-K)}{1-m_n K}\right]^n W_p, \qquad (39)$$

where $m_n = m_0/m_f$ is now the mass ratio per stage. Now the injection velocity required is V_0 = 15,460 m.p.h. or 4.295 mi./sec. Assume m_n = 2.5 and K = 0.317. From the first of (39), placing $g_0 = [(32.2)/(5{,}280)]$ mi./sec.^{2} = 6.1 x 10^{-3} mi./sec.^{2}

$$n = V_0 / g_0 \ I \ln m_n$$

$$= (4.295)/(6.1 \times 10^{-3})\,(260)\,(0.91629)$$

n = 2.96 or 3 stages are required.

From the second of (39)

$$W_T = 200 \left(\frac{0.683 \times 2.5}{1-(2.5)(0.317)}\right)^3$$

$$= 200(8.2)^3 = 200 \times 551$$

$$= 110{,}200 \text{ lbs.}$$

These are of course hypothetical figures. The actual Thor-Delta configuration with which NASA plans to place the geodetic satellite in orbit is a three stage rocket system. The first stage is a production Thor missile with the nose cone and guidance removed. The second stage uses a modified version of the Vanguard second stage rocket engine. The Thor guidance system is installed in the second stage to provide attitude control. The coast-phase guidance thus affords much higher orbits than with previous vehicles since a prescribed vehicle attitude can be maintained up to 2,000 seconds after second-stage burnout. An ABL X-248 solid propellant rocket motor is used as the Delta third stage. Prior to ignition, this stage is spun up to 150 r.p.m. to obtain spin stability after separation, since neither guidance nor autopilot is carried in the third stage. The takeoff weight is estimated at 112,000 lbs.

ESTIMATES OF THE MEAN RADIUS AND MASS OF THE EARTH FROM RADAR AND DOPPLER MEASUREMENTS

Suppose that the maximum and minimum heights on the orbit have been determined say by radar measurements, and the corresponding minimum and maximum orbital velocities have been obtained from Doppler data. That is h_a, h_p, V_p, V_a have been determined. From (36) the relation $V_p/V_a = (h_a + R)/(h_p + R)$ gives

$$R = (V_a h_a - V_p h_p)/(V_p - V_a) \qquad (40)$$

Now the mass M of the earth can be estimated from the energy conservation relation

$$\frac{GMm}{h_a + R} + \tfrac{1}{2} V_p^2 m = \frac{GMm}{h_p + R} + \tfrac{1}{2} V_a^2 \ m,$$

where G is the gravitational constant. Solving for M find

$$M = \frac{1}{2G} \frac{(V_p^2 - V_a^2)(h_p + R)(h_a + R)}{(h_a - h_p)} \qquad (41)$$

M may be written in terms of the period T and R, h_a, h_p. From (36)

$$(h_p + R)(h_a + R) = a^2(1-e^2),$$

$$V_p^2 - V_a^2 = \frac{8\pi^2 a(h_a - h_p)}{T^2(1-e^2)},$$

and these quantities placed in (41) give

$$M = \frac{1}{2G} \frac{8\pi^2}{T^2} a^3 = \frac{1}{2G}\left(\frac{\pi}{T}\right)^2 (2R + h_a + h_p)^3, \qquad (42)$$

where G is the gravitational constant.

THE FLATTENING OR ELLIPTICITY

The French mathematician, Jean Picard, began in 1669 the determination of the length of a meridian arc from a point near Corbeil to one near Amiens employing an elaborate system of triangulation. He used for the first time in geodetic surveying, a quadrant graduated in minutes and seconds, mounting telescopes whose oculars had cross hairs for sighting instead of the usual pinhole alidades. The Cassinis (also French mathematicians but of Italian descent) improved Picard's methods and extended his arc southward to the Pyrenees and northward to Dunkerque. Because of certain inaccuracies in their work, it appeared that the length of the degree of the meridional arc decreased from the equator to the pole, which of course implied that the earth was elongated at the poles (like a football). But these conclusions were contrary to the developments of mechanics by Newton, Huyghens, and their contemporaries which showed that a surface of revolution as the earth would necessarily have to be flattened at the poles (like a door knob). The result was a controversy between two groups of geodesists—one favoring elongation at the poles, the other flattening at the poles. To settle the dispute, the Royal Academy of Paris organized two geodetic expeditions, one to Lapland, the other to Peru (the site of the present country Ecuador). The arc measurements of the two expeditions were finished in 1737 and 1743, respectively; the results proved inclusively that the earth was flattened at the poles and incited Voltaire's quip that Maupertuis (the leader of the Lapland expedition) had "flattened the poles and the Cassinis!" Since that time a principal objective of geodesy has been the determination of the flattening from triangulation arc lengths, gravity or combinations of these. Presently it is being determined from near earth satellite orbits.

If a_e, b are the semimajor, semiminor axes of the earth, then the flattening is defined as $f = (a_e - b)/a_e$, and $F = 1/f$. Table 3 lists the principal published determinations from 1799 to 1960. Principal values of F as obtained from satellite data are:

Author	*F*
O'Keefe	298.38±0.07
Eckels	298.32±0.05
Cook	298.24
King-Hele	298.4
Jacchia	298.29±0.11

These values suggest the adoption of $F = 298.3 \pm 0.1$.

Now table 3 will be seen to contain six determinations near this value and two, that of Helmert and Krassovsky, are exactly this value. Helmert's value, obtained in 1907 from pendulum gravity measurements alone, was considered by him to be more accurate than any value which can be obtained from geodetic arc measurements even though the arcs of more recent decades be used.[1]

In 1956, in the determination of the Hough ellipsoid from arcs[2], F was assumed to be 297 ± 1 and the value of a_e as computed on this basis was taken to be $6,378,270 \pm 100$ meters, the uncertainty in large measure due to the uncertainty in F. In the published report of this work[3], a graph of a_e versus F is given and if one enters this graph with $F = 298.3$, and interpolates (linearly) between the isostatic and free air curves (lines), a_e is found to be 6,378,145 meters. Now table 3 shows that Helmert had 6,378,140 meters in 1907. This illustrates how greatly the determination of a_e from arcs depends upon F. And satellites give values of the flattening quite independent of any surface measurements! It is interesting to note that the value of $a_e = 6,378,175$ meters was obtained from radar measurements of the distance to the moon.[4] In the next few sections the methods by which the flattening is determined from orbital data will be described.

Table 3

Year	Author	F = 1/f	a_e
			m
1799	Gen. Comm. for weights and measures.	334.29	6,375,739
1810	DeLambre..........	311.5	6,376,428
1810	DeLambre..........	308.65	6,376,523
1819	Walbeck.............	302.78	6,376,895
1828	Schmidt.............	297.65	6,376,959
1838	Everest.............	300.80	6,377,253
1841	Bessel...............	299.15	6,377,397
1847	Everest.............	311.04	6,376,634
1849	Airy..................	299.32	6,377,491
1856	James and Clarke	297.72	6,377,936
1858	Clarke...............	294.26	6,378,294
1863	Clarke...............	294.36	6,378,288
1863	Pratt.................	295.36	6,378,245
1866	Clarke...............	294.98	6,378,207
1868	Fischer.............	288.50	6,378,338
1880	Clarke...............	293.47	6,378,249
1891	Harkness...........	300.20	6,377,972
1907	Helmert.............	298.3 ± 0.7	6,378,140
1907	Hayford.............	297.8	6,378,283
1909	Hayford (1) (International).	297.0	6,378,388
1909	Hayford (2)........	298.2	6,378,062
1942	Krassovsky........	298.3	6,378,245
1948	Jeffreys.............	297.1	6,378,099
1956	Hough................	297.0 ± 1	6,378,270
1958-1959	Satellite Determinations.	297.9 to 298.32	

[1]The figure of the earth and isostasy from measurements in the United States by J. F. Hayford, *U. S. Gov. Print. Off.*, 1909.

[2]A new determination of the earth from arcs by B. Chovitz, I. Fischer; *Transactions, American Geophysical Union*, October 1956.

[3]*Ibid.*, page 542.

[4]Echos from the moon at a wavelength of 10 cm. by B. S. Yaplee, R. H. Bruton, K. J. Craig, and N. G. Roman, *Proceedings of the Institute of Radio Engineers*, January 1958.

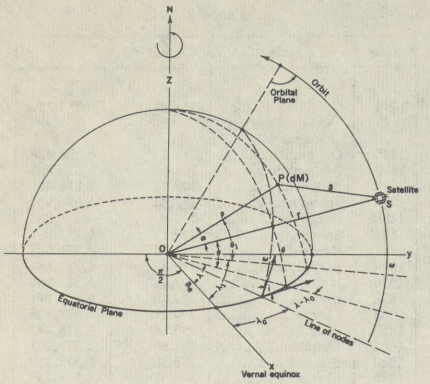

FIG. 21.—The satellite referred to a geocentric inertial system of coordinates.

THE GRAVITATIONAL POTENTIAL

Actually the flattening, as determined from gravity data (although the measurements are made on the topographical surface which is not an equipotential surface), is that of the geoid which is the equipotential surface at sea level and is very closely an exact spheroid. The geoid is somewhat irregular, deviating from a mean ellipsoid at any one of its points by probably not more than ± 50 meters. The mean ellipsoid is very near the equilibrium figure of a rotating body. Now the potential, of which the geoid is an equipotential surface, is the geopotential W, the sum of the purely gravitational potential U and a centrifugal term, that is

$$W = U + (x^2 + y^2)\,\omega^2/2$$

The geopotential W is appropriate to a coordinate system rotating with the earth at the angular velocity ω and hence for geodesy. The gravitational potential U is appropriate for inertial coordinates and thus for satellite orbits.

To find an expression for the gravitational potential in terms of observable elements or elements which can be inferred from observations, the position of the satellite and an attracting mass dM in the earth are referred to an inertial geocentric system of coordinates which for simplicity have been taken as follows (fig. 21).

The x-axis is in the plane of the equator and directed toward the vernal equinox. The y-axis is 90° from the x-axis in the plane of the equator, and the axis of rotation, the z-axis, is orthogonal to the x and y axes at their intersection. The assumptions are that these axes are the principal axes of inertia of the earth; that the axis of rotation passes through the center of mass of the geoid and that the earth displays rotational symmetry about the polar axis. In figure 21, θ is the geocentric latitude, λ is right ascension, and r is the geocentric distance. The satellite orbit relative to the coordinate system is such that ω_0 is the argument of perigee and i is the inclination of the plane of the orbit to the equator (the dihedral angle between the plane of the equator and the plane of the orbit). From figure 21, one has the coordinates of a point P of mass dM and those of the satellite at S:

$$\begin{aligned} &P(dM):\ (x_m,\ y_m,\ z_m) \\ &S:\ x_s = r\cos\theta\cos\lambda \\ &\quad\ y_s = r\cos\theta\sin\lambda \\ &\quad\ z_s = r\sin\theta \end{aligned} \tag{43}$$

From (43) one has

$$\begin{aligned} &x_s^2 + y_s^2 = r^2 - z_s^2 = r^2(1-\sin^2\theta), \\ &\rho^2 = x_m^2 + y_m^2 + z_m^2 \end{aligned} \tag{44}$$

If s is the distance PS as shown in figure 21,

$$\begin{aligned} s^2 &= (x_s - x_m)^2 + (y_s - y_m)^2 + (z_s - z_m)^2 \\ &= \rho^2 + r^2 - 2\rho r\cos\alpha, \end{aligned} \tag{45}$$

$$\cos\alpha = (x_s x_m + y_s y_m + z_s z_m)/\rho r \tag{46}$$

From (45)

$$\frac{1}{s} = \frac{1}{r}\left[1 + \left(\frac{\rho}{r}\right)^2 - 2\frac{\rho}{r}\cos\alpha\right]^{-1/2} \tag{47}$$

One has but to place $t = \left(\frac{\rho}{r}\right)^2 - 2\frac{\rho}{r}\cos\alpha$ in the binominal expansion

$$(1+t)^{-1/2} = 1 - \frac{1}{2}t + \frac{3}{8}t^2 - \frac{5}{16}t^3 + \frac{35}{128}t^4 \ldots$$

to obtain the following series expansion for (47)

$$\begin{aligned} \frac{1}{s} = \frac{1}{r}\Big[&P_0(\cos\alpha) + \frac{\rho}{r}P_1(\cos\alpha) + \left(\frac{\rho}{r}\right)^2 P_2(\cos\alpha) \\ &+ \left(\frac{\rho}{r}\right)^3 P_3(\cos\alpha) + \left(\frac{\rho}{r}\right)^4 P_4(\cos\alpha) + \ldots\Big] \end{aligned} \tag{48}$$

where the coefficients P_0, P_1, P_2, P_3, P_4 are the so called Legendre polynominals: $P_0(\cos\alpha) = 1$, $P_1(\cos\alpha) = \cos\alpha$, $P_2(\cos\alpha) = (1/2)(3\cos^2\alpha - 1)$, $P_3(\cos\alpha) = (1/2)(5\cos^3\alpha - 3\cos\alpha)$, $P_4(\cos\alpha) = (1/8)(35\cos^4\alpha - 30\cos^2\alpha + 3)$, ...

Let the potential U be given as usual by

$$U = G \int dM/s. \qquad (49)$$

Then from (48) and (49) one has (with the equatorial radius of the earth a_e)

$$U = U_0 + a_e U_1, + a_e^2 U_2 + a_e^3 U_3 + a_e^4 U_4 + \ldots \qquad (50)$$

where

$$U_0 = \frac{G}{r} \int P_0 (\cos \alpha)\, dM = \frac{G}{r} M$$

$$U_1 = \frac{G}{r^2} \int \rho P_1 (\cos \alpha)\, dM = \frac{G}{r^2} \int \rho \cos \alpha\, dM$$

$$U_2 = \frac{G}{r^3} \int \rho^2 P_2 (\cos \alpha)\, dM = \frac{G}{2r^3} \int \rho^2 (3\cos^2 \alpha - 1)\, dM$$

$$U_3 = \frac{G}{r^4} \int \rho^3 P_3 (\cos \alpha)\, dM$$

$$= \frac{G}{2r^4} \int \rho^3 (5 \cos^3 \alpha - 3 \cos \alpha)\, dM, \text{etc.}$$

U_0 is the potential of the given mass to spherical order (approximates a sphere that is homogeneous in layers). U_1, U_2, ... U_4, ... represent the departures and will produce accelerations which may be regarded as perturbations. The pertubations will be small if spherical asymmetries are small, or if the distance r to the satellite is great.

Because of the assumptions made as to the rotating mass, the first harmonic term U_1 is necessarily zero. Since the coordinate axes are also the principal axes of inertia, the products of inertia are zero, namely

$$\int x_m y_m\, dM = \int x_m z_m\, dM = \int y_m z_m\, dM = 0. \qquad (51)$$

Define arbitrarily

$$A = \int x_m^2\, dM = \int y_m^2\, dM,$$

$$B = \int z_m^2\, dM, \qquad (52)$$

$$C = \int z_m^3\, dM,$$

$$D = \int z_m x_m^2\, dM = \int z_m y_m^2\, dM.$$

The moments of inertia about the x, y, z axes are then $I_x = A + B = I_y$, $I_z = 2A$.

Since $U_1 = 0$, one begins with U_2, whence from (44), (46) and (50)

$$2\frac{r^3}{G} U_2 = \int \rho^2 (3 \cos^2 \alpha - 1)\, dM$$

$$= \int \left[\frac{3(x_m x_s + y_m y_s + z_m z_s)^2}{r^2} - \left(x_m^2 + y_m^2 + z_m^2\right) \right] dM$$

$$= \left(\frac{3}{r^2} x_s^2 - 1\right) \int x_m^2\, dM \qquad (53)$$

$$+ \left(\frac{3}{r^2} y_s^2 - 1\right) \int y_m^2\, dM + \left(\frac{3}{r^2} z_s^2 - 1\right) \int z_m^2\, dM$$

+[3 product of inertia terms which are zero by (51)]

From (52), the three remaining integrals of (53) may be written

$$2\frac{r^3}{G} U_2 = \left[\frac{3}{r^2}\left(x_s^2 + y_s^2\right) - 2\right] A + \left(\frac{3}{r^2} z_s^2 - 1\right) B,$$

and from (43) and (44)

$$x_s^2 + y_s^2 = r^2 (1 - \sin^2 \theta),$$

$$z_s^2 = r^2 \sin^2 \theta$$

so that

$$2\frac{r^3}{G} U_2 = \left[\frac{3}{r^2} \cdot r^2 (1 - \sin^2 \theta) - 2\right] A + \left(\frac{3}{r^2} \cdot r^2 \sin^2 \theta - 1\right) B$$

$$= A - 3A \sin^2 \theta + 3B \sin^2 \theta - B$$

$$= (A - B) - (A - B) 3 \sin^2 \theta$$

$$= (A - B)(1 - 3 \sin^2 \theta)$$

or finally

$$U_2 = \frac{G(A-B)}{2r^3}(1 - 3 \sin^2 \theta) = \frac{GM}{r} \cdot \frac{J}{3r^2} (1 - 3 \sin^2 \theta)$$

where

$$J = \frac{3}{2M}(A - B).$$

Continuing in this way find

$$U_3 = \frac{1}{2} \frac{G}{r^4} \sin \theta [(3D - C)(3 - 5 \sin^2 \theta)]$$

$$= \frac{GM}{r} \cdot \frac{H}{5r^3} (3 - 5 \sin^2 \theta) \sin \theta$$

where

$H = \frac{5}{2M}(3D - C)$, etc. so that one may write (50) finally as

$$U = \frac{\tau}{r}\left[1 + \frac{J a_e^2}{3r^2}(1 - 3\sin^2\theta) + \frac{H a_e^3}{5r^3}(3 - 5\sin^2\theta)\sin\theta + \frac{K a_e^4}{30 r^4}(3 - 30\sin^2\theta + 35\sin^4\theta) + \cdots\right] \quad (54)$$

where

$$J = \frac{3}{2M}(A - B),$$

$$H = \frac{5}{2M}(3D - C),$$

$$\tau = GM,$$

r is the radial distance from the center of the earth to the satellite, and θ is the geocentric latitude of the satellite.

THE COEFFICIENTS OF THE GRAVITY POTENTIAL AS FUNCTIONS OF THE FLATTENING

The polar equation of an oblate ellipsoid of revolution in terms of the minor semiaxis b and geocentric latitude θ is

$$r = b(1 - e^2\cos^2\theta)^{-1/2}, \quad (55)$$

and from the elliptic parameters (f is the flattening), $b = a_e(1-f) = a_e(1-e^2)^{1/2}$, $e^2 = 2f - f^2$, so that (55) may be written

$$r = a_e(1 - f)[1 - (2f - f^2)\cos^2\theta]^{-1/2} \quad (56)$$

Using the binominal expansion

$$(1 - k^2)^{-1/2} = 1 + (1/2)k^2 + (3/8)k^4 \cdots$$

where $k^2 = (2f - f^2)\cos^2\theta$, equation (56) may be written (ignoring powers of f above the second) as

$$r = a_e(1 - f\sin^2\theta - \tfrac{3}{2}f^2\sin^2\theta + \tfrac{3}{2}f^2\sin^4\theta), \quad (57)$$

and by division

$$a_e/r = 1 + (f + \tfrac{3}{2}f^2)\sin^2\theta - \tfrac{1}{2}f^2\sin^4\theta, \quad (58)$$

also to second order terms in the flattening one finds from (57)

$$r^2 = a_e^2(1 - 2f\sin^2\theta - 3f^2\sin^2\theta + 4f^2\sin^4\theta). \quad (59)$$

Assuming the spheroid is a bounding equipotential then (54) and (57) must satisfy the geopotential

$$W = U + \tfrac{1}{2}\omega^2 r^2(1 - \sin^2\theta) = \text{constant} \quad (60)$$

Hence if the value of U from (54) and the value of r from (57) are substituted in (60), retaining only powers of f as high as f^2 and ignoring small negligible terms; then if the sums of the coefficients of the second and fourth powers of $\sin\theta$ are equated to zero, one can solve the two equations for J and K in terms of the flattening.

From (54), neglecting the term in H,

$$U = \frac{\tau}{r}\left[1 + \frac{J}{3}\frac{a_e^2}{r^2}(1 - 3\sin^2\theta) + \frac{K}{30}\frac{a_e^4}{r^4}(3 - \sin^2\theta + 35\sin^4\theta)\right]. \quad (61)$$

Since J and K are small quantities and $K < J$, it is not necessary to include terms of orders Jf^2, Kf, or Kf^2. Hence for the term in J one can let $\frac{a_e^2}{r^2} = 1 + 2f\sin^2\theta$ from either (57) or (59), and in the K term $\frac{a_e^4}{r^4} = 1$. Equation (61) can be written then with the value of $1/r$ from (58) as

$$U = \frac{\tau}{a_e}\left[1 + \left(f + \frac{3}{2}f^2\right)\sin^2\theta - \frac{1}{2}f^2\sin^4\theta\right]\left[1 + \frac{J}{3}(1 - 3\sin^2\theta)(1 + 2f\sin^2\theta) + \frac{K}{30}(3 - 30\sin^2\theta + 35\sin^4\theta)\right]$$

and in multiplying by the external factor, multiply only the first two terms retaining all in the first, and only those to f in the second term, that is

$$U = \frac{\tau}{a_e}\left[1 + \left(f + \frac{3}{2}f^2\right)\sin^2\theta - \frac{1}{2}f^2\sin^4\theta + \frac{J}{3}(1 + 2f\sin^2\theta)(1 + f\sin^2\theta)(1 - 3\sin^2\theta) + \frac{K}{30}(3 - 30\sin^2\theta + 35\sin^4\theta)\right]$$

or finally

$$U = \frac{\tau}{a_e}\left\{1 + \left(f + \frac{3}{2}f^2\right)\sin^2\theta - \frac{1}{2}f^2\sin^4\theta + J\left[\frac{1}{3} + (f - 1)\sin^2\theta - 3f\sin^4\theta\right] + K\left(\frac{1}{10} - \sin^2\theta + \frac{7}{6}\sin^4\theta\right)\right\} \quad (62)$$

For the term $\frac{\omega^2 r^2}{2}(1 - \sin^2\theta)$ of W, use the value of r^2 from (59) and write

$$\frac{\omega^2 r^2}{2}(1 - \sin^2\theta) = \frac{\omega^2}{2}a_e^2(1 - 2f\sin^2\theta - 3f^2\sin^2\theta + 4f^2\sin^4\theta)(1 - \sin^2\theta)$$

$$= \frac{\omega^2}{2}a_e^2[1 - (1 + 2f + 3f^2)\sin^2\theta + (2f + 7f^2)\sin^4\theta]. \quad (63)$$

Now

$$\omega^2 a_e^2 = \frac{\tau}{a_e}\left(\frac{\omega^2 a_e^3}{\tau}\right) = \frac{\tau}{a_e} m,$$

hence (63) can be written

$$\frac{\omega^2}{2} r^2 (1-\sin^2\theta)$$
$$= \frac{\tau}{a_e}\frac{m}{2}[1-(1+2f+3f^2)\sin^2\theta+(2f+7f^2)\sin^4\theta],$$

and neglecting in this last, terms in mf^2, one has

$$\frac{\omega^2 r^2(1-\sin^2\theta)}{2}$$
$$= \frac{\tau}{a_e}\frac{m}{2}[1-(1+2f)\sin^2\theta+2f\sin^4\theta]. \quad (64)$$

From (62) and (64) one has finally

$$W = \frac{\tau}{a_e}\left\{1+\left(f+\frac{3}{2}f^2\right)\sin^2\theta - \frac{1}{2}f^2\sin^4\theta\right.$$
$$+J\left[\frac{1}{3}+(f-1)\sin^2\theta - 3f\sin^4\theta\right]$$
$$+K\left(\frac{1}{10}-\sin^2\theta+\frac{7}{6}\sin^4\theta\right)$$
$$\left.+\frac{m}{2}[1-(1+2f)\sin^2\theta+2f\sin^4\theta]\right\} \quad (65)$$

From (65) add the coefficients of the $\sin^2\theta$ terms and place the sum equal to zero; similarly for the $\sin^4\theta$ terms to obtain the two equations:

$$f+\frac{3}{2}f^2+J(f-1)-K-\frac{m}{2}(1+2f)=0,$$
$$-\frac{1}{2}f^2-3fJ+\frac{7}{6}K+mf=0. \quad (66)$$

From the first of equations (66), with $K = fm = f^2 = 0$, one has to a first approximation $J = f - \frac{m}{2}$ and this value of J placed in the second of (66) gives $K = 3f^2 - \frac{15}{7}fm$. Now this value of K placed in the first of (66) gives

$$J = \frac{1}{1-f}\left(f-\frac{3}{2}f^2+\frac{8}{7}fm-\frac{m}{2}\right)$$
$$=(1+f+f^2)\left(f-\frac{3}{2}f^2+\frac{8}{7}fm-\frac{m}{2}\right)$$

and retaining terms up to f^2, neglecting terms in mf^2, find

$$J = f-\frac{3}{2}f^2+\frac{8}{7}mf-\frac{m}{2}+f^2-\frac{fm}{2} = f-\frac{1}{2}f^2+\frac{9}{14}mf-\frac{m}{2}$$

or finally

$$J = f-\frac{1}{2}f^2+\frac{9}{14}mf-\frac{m}{2},\quad K = 3f^2-\frac{15}{7}mf \quad (67)$$

where $m = \omega^2 a_e^3/\tau$

CORRESPONDING GRAVITY FORMULAS

Now gravity on the surface is given by

$$g^2 = \left(\frac{\partial W}{\partial r}\right)^2 + \frac{1}{r^2}\left(\frac{\partial W}{\partial\theta}\right)^2, \quad (68)$$

and from (60)

$$\frac{\partial W}{\partial r} = \frac{\partial U}{\partial r} + \omega^2 r\cos^2\theta,$$
$$\frac{\partial W}{\partial\theta} = \frac{\partial U}{\partial\theta} - \omega^2 r^2\sin\theta\cos\theta. \quad (69)$$

From (68) and (69)

$$g^2 = \left(\frac{\partial U}{\partial r}\right)^2 + \frac{1}{r^2}\left(\frac{\partial U}{\partial\theta}\right)^2$$
$$+2\omega^2\cos\theta\left(r\cos\theta\frac{\partial U}{\partial r} - \sin\theta\frac{\partial U}{\partial\theta}\right)$$
$$+r^2\omega^4\cos^2\theta, \quad (70)$$

and from (54), neglecting the H term,

$$-\frac{\partial U}{\partial r} = \frac{\tau}{r^2}\left[1+J\frac{a_e^2}{r^2}(1-3\sin^2\theta)\right.$$
$$\left.+\frac{Ka_e^4}{6r^4}(3-30\sin^2\theta+35\sin^4\theta)\right], \quad (71)$$

$$-\frac{\partial U}{\partial\theta} = \tau\frac{2a_e^2}{r^3}\sin\theta\cos\theta\left[J\right.$$
$$\left.+K\frac{a_e^2}{r^2}\left(1-\frac{7}{3}\sin^2\theta\right)\right]. \quad (72)$$

From (72), it is seen that when $\theta = 0$, $\frac{\partial U}{\partial\theta} = 0$, and gravity on the equator is then from (70)

$$g_e^2 = \left(\frac{\partial U}{\partial r}\right)^2 + 2\omega^2 a_e\frac{\partial U}{\partial r}$$
$$+a_e^2\omega^4 = \left(\frac{\partial U}{\partial r}+\omega^2 a_e\right)^2,$$

or

$$g_e = -\left(\frac{\partial U}{\partial r}\right)_{\substack{r=a_e\\ \theta=0}} - \omega^2 a_e. \quad (73)$$

From (71)

$$-\left(\frac{\partial U}{\partial r}\right)_{\substack{r=a_e\\ \theta=0}} = \frac{\tau}{a_e^2}[1+J+K/2]. \quad (74)$$

From (73) and (74)

$$g_e = \frac{\tau}{a_e^2}[1+J+K/2] - \omega^2 a_e$$

$$= \frac{\tau}{a_e^2}\left[1+J+K/2-\frac{\omega^2 a_e^3}{\tau}\right]$$

$$g_e = \frac{\tau}{a_e^2}[1+J+K/2-m], \; m = \omega^2 a_e^3/\tau. \quad (75)$$

Substituting the values of J and K from (67) in (75) gives

$$g_e = \frac{\tau}{a_e^2}(1+f+f^2) - \frac{\tau}{a_e^2}\, m\left(\frac{3}{7}f+\frac{3}{2}\right)$$

$$= \frac{\tau}{a_e^2}(1+f+f^2) - \omega^2 a_e\left(\frac{3}{7}f+\frac{3}{2}\right),$$

and solving this last equation for τ

$$\tau = \frac{a_e^2}{1+f+f^2}\left[g_e + \omega^2 a_e\left(\frac{3}{7}f+\frac{3}{2}\right)\right]$$

$$= (1-f)\, a_e^2\left[g_e + \dot{\omega}^2 a_e\left(\frac{3}{7}f+\frac{3}{2}\right)\right]. \quad (76)$$

To derive the general formula for gravity from (68), the formulas (69) through (72) are used with the values of r/a_e and a_e/r from (57) and (58), negligible terms being rejected in the process to find

$$-\frac{\partial W}{\partial r} = \frac{\tau}{a_e^2}\left[1+f+f^2-\frac{3}{7}mf-\frac{3}{2}m\right.$$
$$+\left(\frac{5}{2}m-f-f^2+\frac{2}{7}mf\right)\sin^2\theta$$
$$\left.-\frac{1}{8}(11f^2-15mf)\sin^2 2\theta\right],$$

and to order f, (77)

$$\frac{1}{r}\frac{\partial W}{\partial \theta} = \frac{\tau}{a_e^2} f \sin 2\theta$$

From (68) by taking the square root and expanding to two terms by the binominal formula one finds

$$g = -\frac{\partial W}{\partial r}\left[1+\frac{1}{2}\left(\frac{1}{r}\frac{\partial W}{\partial \theta}\right)^2 \Big/ \left(\frac{\partial W}{\partial r}\right)^2\right].$$

From the first of (77)

$$\left(\frac{\partial W}{\partial r}\right)^2 = \tau^2/a_e^4$$

ignoring small terms and this value with the value of

$$\left(\frac{1}{r}\frac{\partial W}{\partial \theta}\right)^2 = \tau^2 f^2 \sin^2 2\theta / a_e^4$$

from the second of (77), one may write

$$g = -\frac{\partial W}{\partial r}\left(1+\frac{1}{2}f^2\sin^2 2\theta\right), \quad (78)$$

and then from the first of (77) substituted in (78) one finds

$$g = \frac{\tau}{a_e^2}\left[1+f+f^2-\frac{3}{7}mf-\frac{3}{2}m\right.$$
$$+\left(\frac{5}{2}m-f-f^2+\frac{2}{7}mf\right)\sin^2\theta$$
$$\left.+\frac{1}{8}(15mf-7f^2)\sin^2 2\theta\right]. \quad (79)$$

When $\theta = 0$, (79) gives

$$g = \frac{\tau}{a_e^2}\left(1+f+f^2-\frac{3}{7}mf-\frac{3}{2}m\right) = g_e$$

as seen from (67) and (75), and (79) may be written

$$g = g_e[1+C_1\sin^2\theta + C_2\sin^2 2\theta],$$

where

$$C_1 = \frac{1}{g_e}\left(\frac{5}{2}m-f-f^2+\frac{2}{7}mf\right) = \frac{5}{2}m+\frac{15}{4}m^2-f-\frac{26}{7}mf$$
$$C_2 = \frac{1}{g_e}\left(\frac{15}{8}mf-\frac{7}{8}f^2\right) = \frac{15}{8}mf-\frac{7}{8}f^2, \quad (80)$$

Now formulas (80) are in terms of geocentric latitude, θ, and to change to geodetic latitude ϕ, in an expression like (80), one has

$$g/g_e = 1+C_1\sin^2\theta + C_2\sin^2 2\theta$$
$$g/g_e = 1+C_1\sin^2\phi + (C_2 - fC_1)\sin^2 2\phi$$

where C_1, is of order f and C_2 of order f^2, hence

$$C_2 - fC_1 = \frac{15}{8}mf - \frac{7}{8}f^2 - \frac{5}{2}fm + f^2 = \frac{1}{8}f^2 - \frac{5}{8}fm$$

and

$$g = g_e[1 + A\sin^2\phi + B\sin^2 2\phi], \qquad (81)$$

where

$$A = C_1 = \frac{5}{2}m + \frac{15}{4}m^2 - f - \frac{26}{7}mf$$

$$B = C_2 - fC_1 = \frac{1}{8}f^2 - \frac{5}{8}fm$$

Now the geodetic formulas (54), (57), (67), (75), (76), and (81) are essentially the ones used in the determination of the flattening from the orbit of 1958 β_2 (Vanguard 1, instrumented sphere)[5].

GEOCENTRIC COORDINATES OF A POINT ON THE SATELLITE ORBIT (KEPLERIAN)

Note in figure 21 the spherical right triangle whose sides are ω, θ, $\lambda - \lambda_0$. One can write

$$\sin\theta = \sin\omega\ \sin i$$

$$\tan(\lambda - \lambda_0) = \tan\omega\cos i \qquad (82)$$

$$\cos\theta = \cos\omega\ \sec(\lambda - \lambda_0) = \cos\omega(1 + \tan^2\omega\cos^2 i)^{1/2},$$

and with r from (19), considering ω_0 the argument of perigee, one can write from (43) and (82) the geocentric coordinates of the satellite, S, the orbit being considered a Keplerian ellipse:

$$x_s = \frac{a(1-e^2)(\cos\lambda_0\cos\omega - \sin\lambda_0\sin\omega\cos i)}{1 + e\cos(\omega - \omega_0)}$$

$$y_s = \frac{a(1-e^2)(\sin\lambda_0\cos\omega + \cos\lambda_0\sin\omega\cos i)}{1 + e\cos(\omega - \omega_0)} \qquad (83)$$

$$z_s = \frac{a(1-e^2)\sin\omega\ \sin i}{1 + e\cos(\omega - \omega_0)}$$

Equations (83) are in terms of only one parameter, ω, since λ_0, ω_0, a, e, and i are considered constant for the undisturbed orbit. The Keplerian orbit lies in the plane

$$x\sin\lambda_0 - y\cos\lambda_0 + z\cot i = 0, \qquad (84)$$

which is fixed, since λ_0 and i are considered fixed for an undisturbed orbit, and contains the line of nodes and the radius vector r. (See fig. 21.) Since the asymmetrical gravity field causes the line of nodes to regress the plane (84) continually rotates about the earth's axis, and its rate of rotation is simply related to the angular rate of travel of the satellite in the plane. From the second of equations (82), $\lambda_0 = \lambda - \arctan(\tan\omega\cos i)$, whence

$$\frac{d\lambda_0}{dt} = \frac{d\lambda}{dt} - \frac{\cos i}{1 - \sin^2 i\sin^2\omega}\frac{d\omega}{dt}. \qquad (85)$$

Actually an instantaneous ellipse or osculating ellipse is used as a basis for defining the coordinates x_s, y_s, z_s of the satellite, although the actual trajectory of the satellite will not be in the plane of the orbit but inclined at a slight angle to it.

DIFFERENTIAL EQUATIONS OF MOTION

The satellite problem may be considered as essentially a ballistics problem and comparison orbits have been computed from this view point from the differential equations:

$$\ddot{x} = U_0\frac{x}{r} - B\rho V\dot{x}$$

$$\ddot{y} = U_0\frac{y}{r} - B\rho V\dot{y} \qquad (86)$$

$$\ddot{z} = U_1\frac{z}{r} - B\rho V\dot{z}$$

where U_0, U_1, are derived from the potential for a point external to the spheroid, B is the drag function, ρ is mass density of air at satellite altitude, r is the radial distance from center of the earth to satellite, V is the orbital velocity of the satellite; x, y, z are geocentric inertial coordinates.[6]

The commonly used method is to neglect the air resistance problem or account for it separately, and consider the motion of the satellite as a disturbed elliptic orbit, the oblateness effects disturbing or altering the Keplerian parameters a, e, λ_0, ω_0, i, t_0 where t_0 is the time when the satellite passes through perigee. That is, the continuous nonplanar space trajectory curve is approximated by an ellipse of best fit or osculating ellipse for each transit period, multiple or submultiple of the period. There are several methods of doing this and the literature on them is becoming quite voluminous.[7] The basic principles are found in any treatise on celestial mechanics.[8]

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[5] *Journal of Geophysical Research*, February 1959, page 211.

[6] The effect of the earth's oblateness and atmosphere on a satellite orbit by J. DeNike in Vistas in Astronautics, *Pergamon Press*, London, 1958.

[7] Some recent papers are: Application of Hansen's theory to the motion of an artificial satellite in the gravitational field of the earth by P. Musen, *Journal of Geophysical Research*, December 1959; Separate papers by B. Garfinkle, Y. Kozai, D. Brouwer, J. P. Vinti, *Astronomical Journal*, November 1959. *Journal of Research*, NBS, B. Math. and Math. Physics, Vol. 63B., Oct.-Dec. 1959; Motion of a satellite in the earth's gravitational field by G. V. Groves, *Proceedings of the Royal Society*, Series A, 19 January 1960.

[8] For instance: Celestial mechanics by W. M. Smart; *Longmans, Green and Co.*, New York, 1953.

If from (54) one writes

$$R = U - \frac{\tau}{r} = \tau a_e^2 \frac{J}{r^3}\left(\frac{1}{3} - \sin^2\theta\right), \qquad (87)$$

including only the term in J, and eliminating thus the purely spherical term $\frac{\tau}{r}$, where $\tau = GM$ (G the gravitational constant and M the mass of the earth), then R may be considered the gravitational "disturbing" function. Now in the first of equations (82), let $\omega = v + \omega_0$, or equivalently in (19) let $v = \omega - \omega_0$, (v is called the true anomaly), and write $\sin\theta = \sin(v + \omega_0)\sin i$, whence

$$\sin^2\theta = \sin^2 i \sin^2(v + \omega_0)$$
$$= \frac{1}{2}\sin^2 i\,[1 - \cos 2(v + \omega_0)]. \qquad (88)$$

with the value of $\sin^2\theta$ from (88) placed in (87)

$$R = \tau \frac{a_e^2}{a^3}\left(\frac{a}{r}\right)^3\left[\frac{1}{3} - \frac{1}{2}\sin^2 i + \frac{1}{2}\sin^2 i \cos 2(v + \omega_0)\right]. \qquad (89)$$

Now the mean angular velocity of the satellite is given by $n = 2\pi/T$ where T is the orbital period. If t_0 is the time when the satellite passes through perigee, and t is the time when the satellite is at some other point of its orbit, then the angle

$$M_0 = n(t - t_0), \qquad (90)$$

is called the mean anomaly. By means of the relation $\frac{dv}{dM_0} = \left(\frac{a}{r}\right)^2(1 - e^2)^{1/2}$, the disturbing function R of (89) may be transformed to a function of M_0 and ω_0. If this transformation is made then terms depending neither on M_0 or ω_0 are called ***secular*** (constant or cumulative), those depending on ω_0 but not on M_0 are ***long-periodic***, and terms depending on M_0 are ***short-periodic***. Hence from (89) the ***secular*** terms of R will be given by

$$R_s = \tau \frac{a_e^2}{a^3} J \left(\frac{a}{r}\right)^3\left(\frac{1}{3} - \frac{1}{2}\sin^2 i\right), \qquad (91)$$

and

$$R_0 = \frac{1}{2\pi}\int_0^{2\pi} R_s\, dM_0$$
$$= \frac{J}{2\pi}\tau \frac{a_e^2}{a^3}\left(\frac{1}{3} - \frac{1}{2}\sin^2 i\right)\int_0^{2\pi}\left(\frac{a}{r}\right)^3 dM_0. \qquad (92)$$

Now if $\left(\frac{a}{r}\right)^3$ is expanded in terms of M_0,[9] one has

$$\left(\frac{a}{r}\right)^3 = \left(1 + \frac{3}{2}e^2 + \frac{15}{8}e^4 + \frac{35}{16}e^6 + \ldots\right) + \sum_{j=1}^{\infty} f_j(e)\cos jM_0$$
$$= (1 - e^2)^{-3/2} + \sum_{j=1}^{\infty} f_j(e)\cos jM_0,$$

whence

$$\int_0^{2\pi}\left(\frac{a}{r}\right)^3 dM_0 = \int_0^{2\pi}(1 - e^2)^{-3/2}\, dM_0 + \sum_{j=1}^{\infty} f_j(e)\int_0^{2\pi}\cos jM_0\, dM_0$$
$$= 2\pi(1 - e^2)^{-3/2} + 0,$$

so finally

$$R_0 = J\tau \frac{a_e^2}{a^3}\left(\frac{1}{3} - \frac{1}{2}\sin^2 i\right)(1 - e^2)^{-3/2}. \qquad (93)$$

The differential equation for $\frac{d\lambda_0}{dt}$ is of course not (85) but must be expressed in terms of R_0,

$$\frac{d\lambda_0}{dt} = \frac{1}{na^2(1 - e^2)^{1/2}\sin i}\frac{\partial R_0}{\partial i} \qquad (94)$$

and the argument of the perigee rate is[10]

$$\frac{d\omega_0}{dt} = -\frac{\cot i}{na^2(1 - e^2)^{1/2}}\frac{\partial R_0}{\partial i} + \frac{(1 - e^2)^{1/2}}{na^2 e}\frac{\partial R_0}{\partial e} \qquad (95)$$

From (93), (94), and (95) are then obtained the secular perturbations of first order. From (93)

$$\frac{\partial R_0}{\partial i} = -J\tau \frac{a_e^2}{a^3}(1 - e^2)^{-3/2}\sin i \cos i,$$
$$\frac{\partial R_0}{\partial e} = 3J\tau \frac{a_e^2}{a^3} e\left(\frac{1}{3} - \frac{1}{2}\sin^2 i\right)(1 - e^2)^{-5/2} \qquad (96)$$

From the first of (96) and equation (94)

$$\frac{d\lambda_0}{dt} = -\frac{nJ\tau a_e^2 \cos i}{n^2 a^3 a^2 (1 - e^2)^2} \qquad (97)$$

Now $n^2a^3 = GM = \tau$, and letting $p^2 = \frac{a^2}{a_e^2}(1 - e^2)^2$ then $\frac{d\lambda_0}{dt} = -\frac{nJ\cos i}{p^2}$, and since $n = 2\pi/T$, one can write (97) finally as

$$\frac{\delta\dot{\lambda}}{2\pi} = -\frac{J\cos i}{p^2}, \qquad (98)$$

[9] *Ibid.*, pages 41, 378.

[10] *Ibid.*, page 69.

where $\delta \dot{\lambda}$ is in radians per period.

From (95) and (96) one finds

$$\frac{d\omega_0}{dt} = \frac{nJa_e^2}{a^2(1-e^2)}\left(\cos^2 i + 1 - \frac{3}{2}\sin^2 i\right)$$
$$= \frac{nJ}{p^2}\left(2 - \frac{5}{2}\sin^2 i\right),$$

$n = 2\pi/T$, or finally

$$\frac{\delta\dot{\omega}_0}{2\pi} = \frac{J}{p^2}\left(2 - \frac{5}{2}\sin^2 i\right), \qquad (99)$$

where $s\dot{\omega}_0$ is in radians per period.

Note the factor $(2 - \frac{5}{2}\sin^2 i)$ in (99). This term is zero when i = arc sin (0.89444) = 63°26ʹ.2 = 63°.4. That is when $i < 63°.4$, the motion of perigee is in the direction of the motion of the satellite. When $i > 63°.4$ the motion of perigee is opposite or retrograde with respect to that of the satellite.

Formulas (98), (99) together with additional ones to include secular terms of second order, were used to determine J and K and hence f from equations (67).[11] Analogous differential equations for the other elliptic elements are used with (94) and (95) and when the "osculating" or approximating ellipse is found for a particular time, the geocentric coordinates are found from equations analogous to (83).

Since the number of terms in considering higher order perturbations is large and their evaluation cumbersome, the more practical approach may be that from the ballistic problem as symbolized in equations (86). Air density at altitude is becoming better known and if satellites are spherical in shape (the drag function for spheres is well known), the equations should be more amenable to iterative numerical integration techniques. In attempting to avoid the more cumbersome perturbative techniques the method recently proposed by J. P. Vinti of the National Bureau of Standards should be investigated since it reduces the problem of satellite motion to quadratures, with use of a potential field that is much closer to the empirically accepted one for the earth than any used thus far as the starting point of calculations and may thus make possible the development of the gravitational theory of a satellite orbit very accurately without use of perturbation theory.[12] Air drag effects will have to be accounted for separately.

Equation (54) expresses U as a function of geocentric latitude, θ, and the radial distance, r, from the center of the earth. This form is adequate for studying the coefficients J, H, K relative to the flattening. But for detailed studies of the gravity field of the earth, U must be also a function of the right ascension (longitude) and higher order terms will have to be included. Their separation and evaluation will then depend on data from several satellites at different angles of inclination. Their evaluation will also depend on comparison of the observed and predicted positions of each satellite. While the motion of the line of nodes (the rotation of the plane (84) about the rotation axis of the earth) can be deduced from the observations, the motion of perigee in the instantaneous plane of the orbit cannot readily be determined from the observations and no detailed comparison of observation with theory has been published.

The inclination, i, is to a first approximation at least, theoretically unaffected by either atmospheric resistance or gravitational asymmetry. But the actual inclinations are observed to decrease gradually. This is attributed to a component of the air drag, normal to the direction of motion, caused by the rotation of the atmosphere with respect to the orbital plane. Such effects should be investigated and allowed for in the secular variations of the node and perigee ***before coefficients derived from the observations are adopted.***

SOME VALUES OBTAINED FROM SATELLITE OBSERVATIONS

Some published values of $F = 1/f$, where f is the flattening, which have been determined from satellite data were given in the discussion of table 3. The results indicated adoption of $F = 298.3 \pm 0.1$. The corresponding value of $J = 1623.4 \pm 4 \times 10^{-6}$ has been deduced.

The coefficients H and K in equation (54) have been determined by O'Keefe, Echels, and Squires[13] from the orbit of $1958\beta_2$ (Vanguard) as $H = 6 \times 10^{-6}$, $K = 6.4 \times 10^{-6}$. The undulation of the geoid corresponding to H is about 15 meters which is of course negligible when compared to a mean earth radius of about 6,371,000 meters. But the work is important from the standpoint of the methods used to eliminate the effects of air drag from the observations; and the possible indications of the crustal loadings of the earth.

By combining the data from Sputnik 2 and Vanguard 1, King-Hele and Merson[14] find $J = (1624.6 \pm 0.3) \times 10^{-6}$, $K = (6 \pm 1) \times 10^{-6}$ and with the aid of

[11] *Journal of Geophysical Research*, February 1959, pages 209-216.

[12] New method of solution for unretarded satellite orbits by J. P. Vinti, *Journal of the National Bureau of Standards*, B. Mathematics and Mathematical Physics, October-December 1959.

[13] The gravitational field of the earth by O'Keefe, Eckels, and Squires, *The Astronomical Journal*, September 1959.

[14] A new value for the earth's flattening derived from measurements of satellite orbits by D. G. King-Hele and R. H. Merson, *Nature*, March 28, 1959, page 882.

orbital data from Explorer 4 (1958 ϵ), they find as a preliminary estimate that the coefficient of the 6th harmonic in the potential is $(0.1 \pm 1.5) \times 10^{-6}$. Their revised estimate of F is 298.2 ± 0.03.

GENERAL REMARKS ON OBSERVATIONS

From figure 21, if an observer is at P, then in order to obtain the geocentric coordinates of the observing site, it will be necessary to know the geocentric latitude, the longitude and height above or below the geoid of the site. The observations from such a site are thus necessarily "topocentric" with reference to the local horizon or local equator system. For optical data obtained from such a site, where the position of the satellite is photographed against a star background, the geocentric coordinates of the site may have to be corrected for precession and nutation.[15]

ORBIT INFORMATION FROM DOPPLER, INTERFEROMETER, AND RADAR DATA

In the Doppler system if the received and transmitted frequencies are F and F_0, they are related by

$$F = F_0 \left(1 + \dot{d}/c\right) \tag{100}$$

where d is the distance between the satellite and the observer and c is the velocity of light (or radio waves). If the frequency is recorded as the satellite approaches and recedes, the radial velocity $\dot{d}$ can be calculated from

$$\dot{d} = c\,(F - F_0)/F_0 \tag{101}$$

At the instant of closest approach the radial velocity will be zero, for then the relative velicity, V, is orthogonal to the track line (see fig. 22). After t seconds the satellite will have moved a distance Vt from the point of closest approach whence

$$d^2 = d_0^{\,2} + V^2 t^2 \tag{102}$$

where d_0 is the minimum distance as shown in figure 22. If equation (102) is differentiated with respect to time one has

$$d\dot{d} = V^2 t,$$

and squaring this result

$$d^2 \dot{d}^2 = V^4 t^2,$$

[15]See Triangulation—A precise method for satellite tracking by P. G. Kirmser and I. Wakabayashi, *Journal of the Franklin Institute*, November 1959; and Geocentric coordinates from lunar and satellite observations by W. Markowitz, *Bulletin Geodesique*, No. 49, 1958.

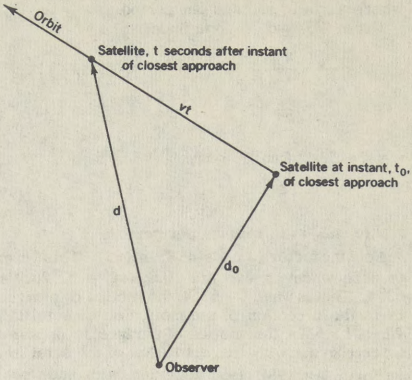

FIG 22.—Relation between distance and relative velocity in Doppler reductions.

or

$$\frac{t^2}{\dot{d}^2} = \frac{d^2}{V^4} \tag{103}$$

Substituting the value of d^2 from (102) in (103) obtain

$$\frac{t^2}{\dot{d}^2} = \frac{t^2}{V^2} + \frac{d_0^{\,2}}{V^4} \tag{104}$$

Now if in (104) one lets $y = \left(\frac{t}{s}\right)^2$ where from (101) $s = F_0\,\dot{d}/c = F - F_0$, and $x = t^2$, then (104) may be written

$$y = mx + h, \tag{105}$$

where

$$m = \left(\frac{c}{F_0}\right)^2 \frac{1}{V^2}, \quad h = \left(\frac{C}{F_0}\right)^2 \frac{d_0^{\,2}}{V^4},$$

or (106)

$$V^2 = \left(\frac{C}{F_0}\right)^2 \frac{1}{m}, \quad d_0^{\,2} = \left(\frac{C}{F_0}\right)^2 \frac{h}{m^2}.$$

It is seen that by fitting the line (105) to the sets of values $x_i = t_i^2$, $y_i = \left(\frac{t_i}{s_i}\right)^2$, $i = 1, \ldots, n$ by the method of least squares the slope m and intercept h can be determined whence the relative velocity, V, and minimum distance, d_0, can be computed from (106). Initially the time, t_0, of closest approach and the transmitted frequency, F_0, are estimated from the symmetry of the frequency-time curve. The observed frequency, F, can then be reduced to a table of $\dot{d}$ versus t, where $\dot{d}$ is given by (101), and t is measured from t_0, the

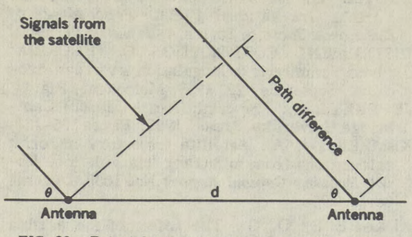

FIG. 23.—Principle of the interferometer technique.

estimated time of closest approach. In the least square fitting of the line (105), the time t_0 is varied until the mean square error is a minimum. Obviously the values of t_0, V, and d_0 are all the information that can be extracted by the Doppler technique from a single transit of the satellite at one station.

The technique suffers from the effects of ionospheric refraction particularly at lower frequencies. The orbital period can be found by observing successive transits at the same station but a correction must be applied to allow for the change in the observer's position relative to the satellite orbit due to the rotation of the earth in the intervening period.

If the orbit is to be obtained from Doppler data alone, the accuracy will be affected by the separation distances between the observing stations, and between the observing stations and the satellite; the curvatures of the earth and of the orbit must be taken into account in the analysis.

The interferometer technique makes use of the interference pattern between the signals received at a pair of antennas, the pattern determined by the difference in the distance between the satellite and each of the receiving antennas. The separation distance, d, is small compared with the satellite distance and hence the waves from the transmitter may be considered to traverse parallel paths as shown in figure 23.

When the satellite is at an angle, θ, such that the path difference is exactly equal to half a wave length,

$$\text{Path difference} = \frac{\lambda}{2} = d \cos \theta \qquad (107)$$

then the combined output from the two antennas is zero, since the separate waves interfere completely, and this will occur whenever the path difference is equal to an odd number of half wave lengths. As the satellite transits its orbit, the change in direction of incoming radiation (the angle θ) causes a succession of such nulls or zeros, the pattern depending on the direction of the track with respect to the line joining the two antennas. During the interval between successive nulls, the increase in $\cos\theta$ is λ/d, so that a record of the times at which the nulls occur gives immediately the rate of change of the direction cosine. If the phase difference of the signals at the two antennas is measured, instead of simply adding the signals at the two antennas, a continuout indication of $\cos\theta$ is available, and the measurement is practically independent of amplitude fluctuations.

The interferometer is insensitive to changes of a whole number of wave lengths in the path difference and ambiguities occur in the measurement of the angle θ. These amgibuities may be resolved by means of a second interferometer with a pair of antennas placed much closer together giving in effect coarse and fine indication.

A second direction cosine can be obtained from a similar set of antennas placed at right angles to the first set, whence it is possible to define the direction of the line joining the satellite to the observing station during the satellite transit. If the distance and relative velocity are obtained simultaneously from Doppler data, the orbit may then be deduced.

The principal American tracking systems employing the interferometer principle are the Minitrack and Microlock.[16] Although the accuracy of Minitrack data is only about 3 to 4 minutes of arc, the continuous orbit data can be averaged through several orbit transits and the results used in the determination of the flattening. Such data has been the major basis for the recently published determinations of the flattening.

The use of large radio telescopes for tracking purposes is very difficult because of the problem of locating the satellite even when its general position is predictable, and because of the confusion introduced by echos from other sources as meteors, aurorae, etc.

The geometrical limitations relative to intercepting the satellite are shown in figure 24 where E is the elevation of the radio telescope, 2θ its beam width, h the altitude of the satellite, R the ground range. Typical relative values are as follows:

Frequency *(mc./s.)*	θ *(deg.)*	E *(deg.)*	R *(km.)*	Δh *(km.)*	ΔR *(km.)*
120	1.25	10	1,500	30	75
36	4	30	500	30	70
36	4	90	500	∞	30

Hence for certain contact with a satellite its position must be predictable to approximately 30

[16] Tracking satellites by radio by J. T. Mengel and Paul Herget, *Scientific American*, January 1958. Microlock by H. L. Richter, Jr., et al in Vistas in Astronautics, *Pergamon Press*, London, 1958.

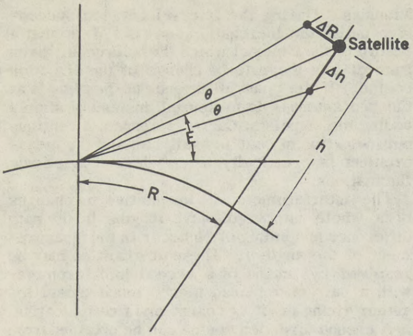

FIG. 24.—Geometry involved in locating a satellite using a radio telescope with beam width 2θ.

km. in height and to about 70 km. in ground range. (This data is relative to operation of the 250-foot radio telescope of the Jodrell Bank Experimental Station).[17] However, the radio telescope has the two unique advantages of being independent of satellite-borne equipment and of ambient meteorological conditions.

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Satellite	Code name	Launch date	Status	Period	Inclination	Apogee	Perigee	Transmitter frequencies
				(min.)	*(deg.)*	*(n.m.)*	*(n.m.)*	*(mc.)*
1958 δ_2	Sputnik 3	15 May 58	Down 6 Apr. 60					
1959 λ	Discoverer 8	20 Nov. 59	Down 8 Mar. 60					
1958 α	Explorer 1	31 Jan. 58	In orbit	108.1	33.22	1054	186	
1958 β_1	Rocket body	17 Mar. 58	do	138.2	34.26	2327	352	
1958 β_2	Vanguard 1	17 Mar. 58	do	134.0	34.27	2134	352	108.022
1959 α_1	Vanguard 2	17 Feb. 59	do	125.5	32.87	1784	302	
1959 α_2	Rocket body	17 Feb. 59	do	129.7	32.89	1986	300	
1959 ϵ_2	Capsule	13 Aug. 59	do	101.5	78.94	787	105	
1959 η	Vanguard 3	18 Sept. 59	do	129.9	33.33	2020	275	19.9904
1959 ι_1	Explorer 7	13 Oct. 59	do	101.2	50.31	585	299	
1959 ι_2	Rocket body	13 Oct. 59	do	101.1	50.30	580	298	
1960 β_1	Rocket body	1 Apr. 60	do	99.1	48.41	406	373	
1960 β_2	Tiros 1	1 Apr. 60	do	99.2	48.41	407	373	108.03; 107.997
1960 γ_1	Rocket body	13 Apr. 60	do	95.0	51.29	389	173	
1960 γ_2	Transit 1 B	13 Apr. 60	do	95.7	51.28	399	202	54; 162; 216; 324
1960 γ_3	Metal object	13 Apr. 60	do	94.0	51.29	361	151	
1960 δ	Discoverer 11	15 Apr. 60	Down 26 Apr. 60					
1960 ϵ_1	Sputnik 4	15 May 60	In orbit	94.3	64.89	357	164	19.995
ϵ_2	Rocket body	do	do	94.1	do	193	164	
ϵ_3	None	do	do	94.3	do	358	164	
ϵ_4	do	do	do	94.3	do	371	151	
ϵ_5	do	do	do	94.4	do	368	157	
ϵ_6	do	do	do	94.4	do	370	157	
ϵ_7	do	do	do	94.5	do	375	156	
ϵ_8	do	do	do	94.5	do	365	169	
ϵ_9	do	do	do	94.5	do	377	157	
1960 ζ	Midas 2	24 May 60	do	94.1	32.62	264	260	

NOTE: As of 1 June 1960 there were 24 artificial earth satellites in orbit, 9 of which (1960, ϵ_1-ϵ_9) resulted from the one launching of Sputnik 4.

FIG. 25.—Abstracted satellite status as of June 1, 1960. (From U. S. Air Force Cambridge Space Track report.) Compare with Figure 1.

Admiral KARO (continuing). But capitalizing on new developments and with the cooperation of the responsible groups in other participating countries.

The Coast and Geodetic Survey stands ready to work with NASA and other agencies of Government in formulating the specifications for a complete program to provide a maximum of information for geodetic purposes.

We believe that mobile optical observation systems as developed by the Coast and Geodetic Survey could be provided for use in the United States and in participating countries to provide a measure of quality control and adequate coverage.

The Coast and Geodetic Survey is willing to undertake the responsibility of directing and coordinating the mobile observing program, the photogrammetric reductions of the optical observations, and the mathematical analysis of the results.

The Coast and Geodetic Survey anticipates that a comprehensive geodetic satellite program would extend geodetic control throughout the world and contribute to the advancement of knowledge about our earth.

This statement has been cleared with the Bureau of the Budget, Mr. Chairman.

Mr. KARTH. Admiral, could you give us the reason, or those reasons why the Coast and Geodetic Survey group opposed the security classification of Project ANNA?

Admiral KARO. Well, we felt that for worldwide information in geodesy, that it took all the scientists operating together. The world belongs to many, many people, and certainly if you are going to obtain truly worldwide geodetic information you must get the cooperation of everyone. We felt, also, that for normal purposes, except for scientific investigation endeavor, that the data relationship around the world was sufficiently known, and so we could not see, as a civilian scientist, the necessity for the classification.

Now, that is our judgment as scientists, and not in the other areas of which we do not have the responsibility.

Mr. KARTH. Do you feel this program, then, is primarily scientific rather than military? Is that right?

Admiral KARO. That was the initial proposed geodetic satellite; it was for scientific purposes.

Mr. KARTH. Now that it has been declassified, which indicates it is strongly oriented toward the scientific rather than the military, whom do you think should manage the project?

Admiral KARO. Well, I am kind of on the horns of a dilemma there, Mr. Chairman. You have two reasons:

1. NASA, being a civilian agency and, of course, peaceful agency, might be able to get better cooperation or enlist the cooperation of everybody around the world; on the other hand, you have the Defense Department, with a logistics support and the mechanics, we will say, already set up to operate this. So it is a question in my mind which would be the most beneficial. Certainly it requires the joint efforts of everyone, Defense Department, NASA, all the civilian and other governmental agency scientists, in order to make this work, as well as the scientists around the world. So I think it will just take the full-fledged cooperative effort.

The prime manager, I am not in a position to say, because we have reasons for both areas.

Mr. KARTH. Except one or the other has to manage it?

Admiral KARO. That is the way it would seem to me, yes, for the overall management of the total program.

Mr. KARTH. As long as that is true, which one, in your opinion, would be equipped to do the better job? Which one, in your opinion, would pursue this thing with the vigor which you apparently feel it must be pursued?

Admiral KARO. Based on some of the prior testimony, it would appear that the Defense Department wants to proceed more cautiously than the space agency feels is required, and I think most scientists feel we should push ahead on this. We are about in the area where we can make significant breakthroughs, enough of the hardware, the methodology has been proven so that we should proceed with all speed to capitalize on the knowledge that exists, and also the imagination of the people around the world. I mean a cooperative program in space for peaceful uses I believe has a very significant part to play in our friendship and bringing people together for other cooperative missions.

Mr. KARTH. Admiral Karo, were you here yesterday?

Admiral KARO. I was not, sir.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. I haven't had a chance to digest your statement. Just one or two questions. On page 1, down near the end, you refer to the possible use of Lasers.

Admiral KARO. Lasers.

Mr. RANDALL. That is the new optical scissors, or optical knife, or something?

Admiral KARO. That is correct, sir, and its possible use as distance measuring, and so forth. It is just a recent breakthrough, and it is something which could possibly be applied to this type of work.

Mr. RANDALL. On page 2 you refer to the "American Ephemiris List." What is the history of that, what is that, the volume, itself, on page 2, the second paragraph, 300 observatories and 30 radio installations. Tell us about that.

Admiral KARO. You want to know what the volume is?

Mr. RANDALL. Yes.

Admiral KARO. It is the official publication put out by the Naval Observatory on data for astronomers and others. It lists stars and the motions of the moon and all of that. And in this, one of the sections is a listing of the world observatories.

Mr. RANDALL. An authoritative volume, in other words?

Admiral KARO. That is right.

Mr. RANDALL. That is all for the moment, Mr. Chairman.

Mr. KARTH. Mr. Hammill.

Mr. HAMMILL. I have no questions, Mr. Chairman.

Admiral KARO. Mr. Beresford.

Mr. BERESFORD. No questions.

Mr. KARTH. As a scientist, Admiral Karo, you are undoubtedly familiar with the manned lunar landing project that is being pursued by NASA?

Admiral KARO. Yes, sir.

Mr. KARTH. Are you in agreement with Dr. Homer Newell and Mr. Nicolaides, the conclusion that they drew with respect to the importance of this program and the applications of getting the information we need about the earth's gravity field being important to the manned lunar flight program?

Admiral KARO. Of course, I am not the expert they are, but from what I know of it and have digested and read and studied, why, I would be in agreement with what they say. Certainly when we are going to mount a project of that kind we must search out all information that it is possible will affect the operation of this project.

Mr. KARTH. You feel we must thoroughly understand the gravitation field about the earth before we can make a success of such a program?

Admiral KARO. It would seem to be necessary that we understand as much as we could, because we do know we have these variations, and until we are able to plot them, to determine whether they are constant in space and time or whether they vary, we would run a chance of having a roadblock thrown into our operations.

Mr. KARTH. You feel a full knowledge of the gravitational fields about the earth would be more important than full knowledge about the gravitational fields about the moon in a manned lunar landing program?

Admiral KARO. I would think, our astronauts wanting to get back home, that it would be very important to know that on the return trip. Of course, from what we know at the present time, the gravitational fields are much stronger in the earth, so that it would certainly appear to me that it would be more important that we understand fully our own gravitational field, because the chances of error would perhaps be more disastrous.

Mr. KARTH. Mr. Hammill?

Mr. HAMMILL. When the time comes that the Department of Defense decides to have a meeting with the Government agencies who would be participating in a follow-on program, would you intend to participate in any such meeting?

Admiral KARO. Well, I certainly would, if we were asked. I might say, Mr. Hammill, that we have participated with them in this ANNA project, so that we work, as I mentioned earlier in my statement, cooperatively with everyone, with an interest in science and in the geodetic sciences.

Mr. KARTH. What is the cost of this highly accurate and versatile mobile optical system you refer to in your testimony, Admiral Karo?

Admiral KARO. Well, one camera with the changes, with the chopping shutter, et cetera, runs something over $100,000. That would be for the camera, itself. So we feel that there should be four of these cameras for each unit. And then, of course, you would have your logistic equipment that go with it, personnel costs, et cetera.

Mr. KARTH. Is it your position that you would like to contribute these cameras to the project? Is this my understanding?

Admiral KARO. No, sir. What I said, Mr. Chairman, was that we have developed this camera, we are in the process where we want to procure some more, that we feel that this, being a mobile operation, you can spot the stations where they will contribute the most in the fields of geodesy and be able to actually carry on geodetic measurements, using your satellite in space as one of your points. Therefore, we will be able to carry on your distances and azimuths throughout the world over long reaches of space.

Our precise traverse program in the United States will give us a very precise measured base to start from. After all, you have to have some idea of the measurements even for your orbital work. So this would also tend to increase the accuracy of some of your orbital computations by giving you a precise base from which to work.

Mr. KARTH. There is no other camera with this capability that is in existence today, or in the research and development stage?

Admiral KARO. There are many, many different cameras that are used, sir, but we believe that this is the most advanced of this type because we have the capability, as I mentioned, of using either the active or passive satellites. If you get Echo up, we have taken very successful observations on the present Echo, of course, it is too low for really any great distance, but it proves the efficacy of the system.

In fact, it was after some of the other people saw the star plates that we got from shots of Echo that they began to get really seriously interested. My information from the manufacturer of these cameras is that, as I have mentioned, that several agencies and several foreign governments are now after these cameras to adapt them to this particular method.

Mr. KARTH. What was the principal reason for your developing a camera of this magnitude?

Admiral KARO. Well, it is for the matter of geodesy. After all, we have by statute the responsibility for geodetic operations and research.

Mr. KARTH. In other words, it was designed specifically for this purpose, is that right?

Admiral KARO. That is right, for the use in satellite geodesy, yes, sir. We have, of course, a small but very competent group of geodists and photogrammetists, and it is a combination between the two of them, plus Dr. Helmert Schmid that we worked out this system and perfected this system.

It certainly exceeded our expectations, I will put it that way. It is also mobile. So many of your stations around the world are fixed, but this has the capability of being moved, and being capable of extending geodetic measurements in various areas.

Mr. RANDALL. Mr. Chairman.

Mr. KARTH. Mr. Randall.

Mr. RANDALL. You pointed out your statutory responsibility. Of course, irrespective of what may transpire here insofar as NASA and this DOD change from classification to declassification, you will, because of your statutory responsibility, carry on along these lines on your own?

That is understood, isn't it?

Admiral KARO. That is right.

Mr. RANDALL. Well, I simply wanted to bring out the point that it is not likely that the law will be changed and you will proceed.

Now, I have finally had a chance to dig into your statement a little bit. You said that there would be at least three other Federal agencies and several European nations now preparing to use your system of this BC-4 ballistic camera. Would you care to tell us who the other agencies are and who are the other governments?

Admiral KARO. Mr. Randall, I actually can't give you those names; as I mentioned just previously, the President of the camera company who manufactures the basic camera, gave me that information.

Mr. RANDALL. I see.

Admiral KARO. But we do know that people have evidenced great interest in this.

Mr. KARTH. If the gentleman will yield at this point?

Mr. RANDALL. Yes.

Mr. KARTH. On page 5, Admiral, you say "We believe that following the initial ANNA program, a new satellite program could be developed along the lines of the original NASA program.

Admiral KARO. Yes, sir.

Mr. KARTH. Would you care to explain that just a little bit?

Admiral KARO. Well, of course, the present ANNA program was more in the nature of a checking out or calibrating these various types of measurements. We believe, and of course in the initial proposed NASA program it was a satellite of little smaller, greater density, and of course, it would be at greater altitudes, so that it would lend itself more for actual optical measurements, geodetic measurements, and extended triangulation by visual observations. And also we believe that now, of course, ANNA has been developed for some time, as I mentioned earlier in my statement, that there have been developments which could well be incorporated and developments in the future to make it a more valuable satellite.

The present ANNA project is very admirable, and it will be very useful in proving the capabilities of various systems. In fact, it has proved many of them, and it will also give a direct measurement, or direct comparison between the different types of measurements.

Mr. KARTH. The six satellites that are required, Admiral, are apparently not planned under the initial ANNA program, is that correct? So what you are talking about is a different program completely from the one that is now under consideration. Is that a fair statement?

Admiral KARO. I think, Mr. Chairman, what I mean to imply is that we should update the extended program to take care of the advances that have been made, and now that it has been declassified, to at least plug in all of the scientific requirements and requirements that can be reasonably met from the discussions with the scientific community, so as to make it as valuable as possible in getting all types of scientific information.

Mr. KARTH. The classification of the project, in and of itself, has, to some degree, narrowed the scientific objective, is that correct?

Admiral KARO. Perhaps that is a fair statement, sir. I mean, in other words, it limited the people who could actually apply their thoughts and requests and information into the satellite. Now, with it being unclassified, I believe that we can get everybody working for the greatest good for the greatest number.

Mr. KARTH. Mr. Randall?

Mr. RANDALL. One last question. You refer to this BC-4 as a ballistic camera. Is there something about the camera that is different from other cameras in that it projects itself, or how?

Admiral KARO. No, sir. It was used over in the Ballistic Research Laboratory in part of their operations. So, working with Dr. Helmert Schmid over there, we envisioned the idea of modifying it, putting these other things on, and using it for satellite geodesy.

Mr. RANDALL. You could have, just as well, the BC–4 camera from the ballistic section?

Admiral KARO. That is right, it is known as the BC–4 ballistic camera.

Mr. RANDALL. I thought you might have developed a new technique of some sort here. Thank you.

Mr. KARTH. From a technological standpoint, do you feel that the classification has constricted the use of Project ANNA for scientific purposes, or are you just talking about the classification, in and of itself, did not lend to overall community participation?

Admiral KARO. That is correct.

Mr. KARTH. Is that the sense that you speak in?

Admiral KARO. That is correct.

When you classify anything, you limit the participation, and when you have it unclassified, why, of course, you draw a larger community of participation and interest, and I think it will also engender much interest and help from scientists around the world.

Mr. KARTH. I wasn't sure if this was your idea, or if you meant the technological ideas that some of the scientists have were eliminated as a result of the classification because the classification limited the height of the orbit, limited the weight of the satellite, eliminated certain experiments. I wasn't sure just what you meant, but apparently this is not what you had in mind.

Admiral KARO. No, sir; that is correct.

Mr. KARTH. Are there any further questions?

(No response.)

Mr. KARTH. If not, thank you very much, Admiral Karo.

Admiral KARO. Thank you, Mr. Chairman, it is a pleasure to be with you.

Mr. KARTH. We appreciate a great deal your coming up and testifying before the committee.

For the benefit of the committee members, we will meet at 2 o'clock this afternoon in this hearing room. We will take testimony on the Centaur project. The committee is adjourned.

(Whereupon, at 12:06 p.m., the subcommittee adjourned, to reconvene at 2 p.m. of the same day.)

PROJECT ANNA

WEDNESDAY, MAY 16, 1962

House of Representatives,
Committee on Science and Astronautics,
Subcommittee No. 3,
Washington, D.C.

The subcommittee met, pursuant to adjournment, at 10:12 a.m., in room 216–B, New House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. Karth. The subcommittee will come to order. Today we continue our hearings on Project ANNA.

Dr. Whipple, would you step forward, please?

Dr. Whipple. Yes, sir.

Mr. Karth. The subcommittee members, as usual in the morning, Doctor, have a stack of telephone calls and other messages to answer and things to take care of. I am sure they will be here at any moment.

But why don't we begin, because we know that your time is limited and you are a very busy man, and you have other things to do, and you want to do them as soon as you can.

I might say that we felt it very necessary, Dr. Whipple, that we call you as a witness on our hearings relative to Project ANNA. The subcommittee wants to congratulate you, too. We think that the testimony you gave to the committee as a member of the panel on science and technology was the beginning of the declassification of Project ANNA. Although the committee and its respective members heard what Project ANNA was all about and had some understanding of its importance and its significance, I am sure we didn't understand its importance in the true sense of the word until after you appeared before the committee, and as a result of the presentation that you made Chairman Miller was the one who suggested to me that this subcommittee investigate, if I may use the word, the reasons why ANNA was classified and try to get further information as to its importance.

So we would have been remiss, Dr. Whipple, if we had not called you to appear before this subcommittee to review with us those things you said before the full committee, together with any other thing that you might want to give to this committee as a matter of your expert opinion.

I see you have a prepared statement, Doctor. If you want to proceed at this time, you go right ahead and then anything that you might want to add will be fine with us.

I am sure the subcommittee will have some questions at the end of it.

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STATEMENT OF FRED L. WHIPPLE, DIRECTOR, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Dr. WHIPPLE. Thank you very much indeed for your kind comments. It is a pleasure to discuss again the subject of geodetic satellites and I do wish to congratulate the Department of Defense most heartily for their sound judgment in making Project ANNA satellite available for international use. I consider this a major step forward in improving our knowledge, and the world's knowledge, in the field of geodesy and the numerous geophysical areas related to it.

It is also a pleasure to report that the announcement of the international use of the geodetic satellite ANNA was received with great enthusiasm at the recent meeting here in Washington of the Committee on Space Research (COSPAR), an international organization for the scientific uses of space.

The experience with the light flashes of the ANNA satellite shows that they will be bright enough for relatively small cameras, of which many are available over the world. There appears to be an adequate number of flashes for international use.

The offer of the National Aeronautics and Space Administration to make the times of the flashes known in advance means that the flashes can be used with a minimum of complication over the world. The accurate timing system in the ANNA satellite means that the stations will not require complex and expensive clock and timing-shutter facilities. Hence the ANNA satellite satisfies the major requirements that I listed when I last appeared here.

There is no doubt in my mind that the sharing of the geodetic satellite can now become a truly international program with input from many countries and scientific benefits to be derived by all.

The unfortunate disaster in launching the first ANNA satellite is most regrettable, and I deeply sympathize with those who put so much effort into the satellite and who find that so much of their work has come to naught. However, a second model has been constructed, I believe, and I hope strongly for success in its launching.

It is now clear that with this start we need a clear-cut, well-planned, long-range program for attacking the geodetic problem thoroughly. The need and general nature of the program were clearly understood at the beginning of the International Geophysical Year, when our first satellites were planned.

Dr. James A. Van Allen, in his testimony in March this year, made this point quite clear. There have been at least 6 years of indecision and incoherent leadership in this program. I want to clarify that point a little bit. I respect very much the leaders who have put their efforts into this program, but it was the organizational and jurisdictional problems that I refer to, in speaking of indecision, and incoherent leadership.

I think the individuals involved in all cases are extremely able and doing an excellent job, but they were handicapped by the organizational jurisdictional problems. What we now need is a clear-cut assignment of authority, assignment of responsibility for execution of the program and sound leadership and proper funding support.

Now, one might argue that we have as yet too little experience to determine definitively what technical system will be best for use in an ideal geodetic satellite. The remarkable results attained by the Transit satellies indicate the extremely great potential of the radio method, particularly the "Doppler" method which measures the velocities of approach and recession.

However, we do know that the optical method is sound and that it is adequate to solve the problem. Also, it has the great advantage that very simple equipment in many countries can be utilized at very little expense to anyone. The radio methods, I believe, require sophisticated and expensive equipment. To illustrate this point that the optical method has great power, the geodetic program at the Smithsonian Astrophysical Observatory has progressed since my last appearance here. We have made great strides in "locating" the 12 stations of the Baker-Nunn optical tracking system by means of observations of ordinary satellites.

From about 2,000 precision observations of 22 orbits of various satellites, our Smithsonian group has determined station coordinates with internal standard errors of about 20 meters in each coordinate—that is, about 100 feet in total spatial position on the earth. To make that clear, I mean that the stations are now located within a sphere of about 100 feet radius around the mean point to indicate the order of accuracy.

This corresponds to an increase of about a factor of 3 over the best of the earlier determinations of geodetic positions on a worldwide basis. We are in the process of solving the basic problem arising from our previous lack of knowledge concerning the exact gravitational potential field of the earth.

This knowledge is continuously being improved from satellite observations and analysis in, I believe, a truly amazing fashion. In one satellite run over a 3-week period, our mean observational error has come out only slightly above 4 seconds of arc, which is to be compared to our expectation of errors in the neighborhood of 2 to 3 seconds of arc. I want to stress that this type of analysis is being made by a number of groups in geodetic analysis, analysis of satellite observations in the world.

There are a number in the United States and in Europe who are doing this same thing with great accuracy in determining the gravitational potential.

Various methods are available for improving the geodetic potential so that we can represent our observations of satellites with actual orbits in a continuously improving fashion. I must point out, however, that our optical observations are still weakened by the geometrical fact that all of them must be made in the twilight periods, when the satellite is illuminated by the sun while the observing station is in shadow. This means, of course, as I mentioned previously, that the orbits are observed only in two parts, two sections and not around. Now the flashing-light satellite will add enormously to the weight of individual observations because they will be distributed over the entire night, covering, therefore, more than half of the orbit or about half. I am confident that we can eventually attain an accuracy of about 30 feet in the determination of the coordinates of our 12 stations from the ordinary satellites.

The international, flashing-light satellite, however, will make this possible with far less effort at many more stations in a much shorter time. Thus, it is essential to a proper solution of the geodetic problem on an international basis.

Several more geodetic satellites should be planned immediately for a continued, well-rounded geodetic program. The present orbital inclination of 50° for Satellite ANNA does not make possible geodetic determinations at latitudes much beyond latitude 50° north and south, nor does it enable us to determine the irregularities in the earth's gravitational field at greater latitudes. Also, it cannot give us as good values as we wish within this latitude zone. That primarily is because of the lack of determination of the geodetic potential field with the accuracy that we need and can attain.

First, then, we have no guarantee that Anna II will fly successfully or that it will perform properly for several months as needed. Another backup for ANNA should be built as soon as possible.

Secondly, an improved ANNA satellite should be designed and built for use in a series of higher orbits at other inclinations than 50°. Minimum requirements, and I stress this, we consider to be the absolute minimum, indicate a need for geodetic satellites in a least three new orbital inclinations to the earth's Equator (1) a nearly polar orbit, perhaps near 85° inclination; (2) one near 75° inclination; and (3) a lower inclination satellite, probably in the neighborhood of 30°. Also these satellites should be in orbit at greater altitudes above the earth than Satellite ANNA; the 85° orbit at perigee perhaps 1,000 kilometers and apogee 4,000 kilometers, quite eccentric; the 75° orbit, 3,200 to 4,000 kilometers; and the 30° orbit, 800 to 3,000 kilometer altitudes. You will recall that ANNA is about 1,000 kilometers in a circular orbit. Great variation is possible in these altitudes and, in fact, in the orbital inclinations that could be desired and other investigators might choose numbers considerably different. There is a great deal of one in the critical inclination at 62.4°, there is a great deal of interest in satellites in more nearly equatorial orbit. However, an equatorial orbit does bring in some new problems both in launching, the matter of the fact that our launching stations are at higher altitudes and it will require a change in direction of firing in the early stages after the satellite was above the earth's atmosphere to put it into such an orbit.

Also the problems of observing very close to the Equator, optically at least, are difficult, because the weather conditions are generally not the best near the Equator. Radiowise, if you have the installations there would be no problem from weather conditions. The tentative suggestions by our Smithsonian group, with the ANNA satellite at an altitude of 600 miles, the range for simultaneous observations to fix long triangulation legs from continent to continent is severely limited.

The total coverage in one arc is at most—I think this is stretching it actually—3,000 miles and the positions are not too well determined at such low angles to the horizon. Because of the greater distances required above the earth's surface, brighter lights must be devised for later geodetic satellites. The problem is fundamentally one of power supplies and weight, and may also reflect in radio power requirements.

In conclusion, then, I will say first, that I am extremely pleased and satisfied with the great step forward in the ANNA satellite for international use. Then I wish to stress the vital need for a long-term program with geodetic satellites backed by adequate funding. I believe that your committee can aid remarkably in attaining this important goal as you have aided in this first vital step.

Thank you for the opportunity of presenting these comments.

Mr. KARTH. Thank you, Dr. Whipple.

You talked about speed in your presentation. I wonder if you could just give the subcommittee a little better idea of how speedy you think this program should move forward?

Dr. WHIPPLE. Well, what worries me most, just to be very practical about it, is the fact that we now have an A–2, one bird to fly, with no backup program, no further, so far as I know, no further satellites planned or ordered or no program at all for them. And as you well know the chances are by no means 100 percent for the successful launching of that satellite. If ANNA II should fail—and there is obviously a real chance of this—there may be a delay of a long period of time, meaning many more months or several months, in getting a second one started.

So surely we need some sort of backup there in case ANNA II fails.

Mr. KARTH. Dr. Whipple, yesterday some very knowledgeable people testified that Project ANNA would give us a great deal of information about the earth's gravitational field that today we do not have. In their considered judgment this would be more important to a successful manned lunar launching and return flight than having complete knowledge about the gravitational field of the moon.

Now would you agree with the theory that was expressed yesterday?

Dr. WHIPPLE. I had not heard of this statement before and I haven't had time to consider it, but certainly a detailed knowledge of the earth's gravitational field is extremely important in any precision launching of space probes and in problems of this sort I can readily believe that it is true, but I haven't looked into the matter to have my own personal judgment on it.

Mr. KARTH. Well, this whole question revolved around the rendezvous method.

Dr. WHIPPLE. Yes.

Mr. KARTH. Of going there and returning, inasmuch as this area of rendezvous would involve to some degree the earth's gravitational fields and that it why they felt it was very important that Project ANNA go forward as speedily as possible so that these questions could be answered, and which, in turn, would lead to the possibility of a successful flight or at least lend greater possibilities for successful flight.

Dr. WHIPPLE. I can see the basis for this, because in rendezvous it is necessary to predict ahead with great precision where both objects are going to be; namely, the satellite with which you are rendezvousing and the vehicle that is going to meet it, and the further ahead you can predict with great precision, the more effective this rendezvous can be, which is very sensitive in terms of rocketry and guidance.

Clearly the predictabilities in orbit depend now almost completely upon increasing knowledge of the earth's potential field. I can see the basis for that statement.

Mr. KARTH. Doctor, in connection with your interest to have this project speeded up, the subcommittee was very much interested in a statement by the representatives of the Department of Defense wherein they indicated they would probably not request outside participation in the degree that some may feel outside participation is necessary until such time as they have a successful flight. This raises several questions. What if the next one is a failure? What if the next two are failures? Then you don't get this broad-base participation which you obviously think is very important and which Mr. Nicolaides and several other people yesterday felt was very important.

Would you care to address yourself to this?

Dr. WHIPPLE. Yes, I would be delighted to. I had thought of my recommendation here as being not so much a speeding up process as a recommendation for an orderly approach to the problem, and I consider that a good start has been made now, but with no further planning and programing and development of equipment I feel that we are marking time.

I consider this just a real time lapse in the progress in this area; by not planning a systematic, orderly program, we are, indeed, delaying by quite a long time the solution of these problems that are becoming more and more vital all the time, and I suppose that one can put it in terms of speeding up.

But my feeling is that it is more a case of a well-planned, organized, orderly approach to a problem that we all recognize as being important. And I do feel that this matter of having a bird that may have a broken wing or something as our only geodetic satellite is a very dangerous situation to be in, in terms of solving these problems.

Mr. KARTH. Perhaps I used the word "speed" in the sense that you are interested in getting all of those groups who are interested in a flashing light satellite involved in the program so that they can go forward, plan, do all of the things necessary to make this a success. And this is the area that I was relating to the question of speed.

Dr. WHIPPLE. Yes.

Mr. KARTH. Now would you disagree with the Department of Defense insofar as their apparent hesitancy to include other teams in this program until such time as they have a successful flight which may well be the latter part of this year?

Dr. WHIPPLE. I would not agree with that policy. I feel that the determination of these geodetic quantities that we are discussing here is a fundamental, worldwide problem, that it is a long-term research problem, that it needs to be attacked in a sound, systematic fashion; it needs to be attacked as a research program and not as engineering backup, primarily, although its function there is extremely important. It should not be considered primarily as engineering backup for space operations but as a fundamental, scientific foundation for the specific space operations and a great many other types of operations not necessarily foreseen at the moment.

Our experience has been that basic research when applied to areas that we know are going to be important in one way or the other always leads to unexpected and extremely valuable uses which are by no means foreseen at the initiation of the program.

I think the Department of Defense, particularly due to general national policies in the last 2 or 3 years, has tended more to look at the research programs in the light of engineering and not as basic science. I think that it is unlikely that they would be willing to carry on a heavy basic science program on a continuing basis, which is what is needed here, in my opinion.

Mr. KARTH. In other words, you consider this is a basic scientific research project, is that correct?

Dr. WHIPPLE. I do, definitely.

Mr. KARTH. Almost thoroughly a basic scientific research project?

Dr. WHIPPLE. Yes, but it has engineering overtones that we all realize and recognize.

Mr. KARTH. Yes.

Dr. WHIPPLE. And the results can be put into engineering practice as they become available. But I would hesitate to predict and I don't think anyone who is in this field would predict the total ramifications of the valuable results that would come out of this program, both in terms of basic knowledge and in terms of engineering data.

Mr. KARTH. Doctor, what is the nature and the extent of the international cooperation which is necessary or required to make this a successful program?

Dr. WHIPPLE. I think it is important that accurate observations of the geodetic satellite be made at a number of places on the earth encompassing the geodetic systems that are now set up, also covering areas of the earth where the geodetic systems are not necessarily tied into the major ones.

So that means, then, that one needs the small camera observing stations in a number of places on each of the continents. By number, I would hate to specify an exact figure, but enough so that the international datums can be tied together in a rigorous, accurate system, on a worldwide basis. And so the exact shape of the earth can be determined with great precision, as well as the geodetic potential in as detailed a fashion as we can make it.

Now this is the basic observational program and the ramifications in pure science are extremely exciting, because it is already clear from the data we have on the earth's potential, just as an example, that the interior of the earth is able to sustain stresses for long periods of time greater than we had expected.

It may be that there are actual convection currents inside the earth which are responsible for the long geological cycles, and the increased data, the increased information that can come from this program is going to tie into very vital basic studies of that sort which are quite outside the engineering field and quite outside the direct interest of the Department of Defense.

Now I am not at all certain in the long run that some of these most esoteric results, scientific conclusions that can come from a study of the deep earth by these and other methods, may not be of immense value, practically, in a few years. I can't predict this but the problems themselves stand there and I think that they suggest strongly the need for a program to solve, as well as we can, these basic geodetic problems that bear on them.

Does that answer your question?

Mr. KARTH. I think in part, Doctor.

Has there been any real deep interest on the part of foreign countries, for example, to participate in this scientific experiment?

Dr. WHIPPLE. Oh, yes.

Mr. KARTH. And if the broad scientific field is involved in it, you feel sure that they would then participate, is this an accurate statement on my part?

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Dr. WHIPPLE. I am certain of this in my own mind from contacts with them. I believe there were 17 countries represented at this recent COSPAR meeting and quite a number of others that I know are interested. We were approached by a number of other countries early in the International Geophysical Year program, hoping that we would be able to install the Baker-Nunn satellite tracking stations in their countries. Of course the number was limited, and the number is limited, but this type of tracking with small cameras is now possible in many countries. And I would be certain that at least 15 or 20 countries representing all of the continents and major islands, would certainly participate if given the proper encouragement and assurance that there would be real cooperation on the one hand, and assurance that the program would be for the international good, that the data would be made available, the major results from their tracking stations, and from others for international good.

Mr. KARTH. How many satellites do you feel are necessary? I am not sure that you mentioned a number in your presentation.

Dr. WHIPPLE. Really it is a difficult question to answer. We have set out here what we felt was a minimum number, which was four successful firings at four different inclinations, the earth's Equator and at different distances above the surface of the earth, and those, to be successful, should stay up for a number of months, each one, so that observations could be made from the various stations under various conditions.

Now, there are some sites in the world where weather conditions are extremely bad during certain periods of the year. If, for example, one satellite should be up and last only a month or two, there are some areas where no traffic or optical observations could be made.

So one has to allow enough time that an adequate number of observations can be made.

Mr. KARTH. Doctor, the impression I have is that you feel considerable change should be made in Project ANNA. You suggest that the higher orbit is a minimum that should be achieved. So my question would be: Does this mean that ANNA must be reprogramed?

Dr. WHIPPLE. No, I don't mean that.

Mr. KARTH. And that you are dissatisfied with the way the program is now going and the objectives of the program at the present time?

Dr. WHIPPLE. I am sorry if I gave that impression because I did not intend to give that impression. My point is that the ANNA program as envisaged and as designed is a very sound one, it is the first step. The first step is, in all scientific work as it is in development and production, less complete and less satisfactory than later models or later steps. But I consider ANNA as it is planned, carried out, extremely good and extremely valuable and will give an enormous amount in the way of results.

But if one is going to consider a continuing program and attack this as one does a scientific program that is new in principle and has a great many possible ramifications, he should then try to improve the earlier, first steps in later steps.

Mr. KARTH. Inasmuch as most of the evidence points to the fact that this is a scientific program, Dr. Whipple, whom do you think should manage it?

Dr. WHIPPLE. I may say that there are many people in this country, many groups who are perfectly competent to do this extremely well. I won't mention them explicitly, but there are groups in the Defense Department and various governmental agencies and in universities who could do this in terms of the scientific aspects.

But in terms of what I understand to be national policy at the present time, and if I am correct in this, I understand the national policy is that the National Aeronautics and Space Administration should be the prime doer of scientific research in the space area.

If I understand this correctly, they have the prime responsibility for scientific research in space. And if that is the national policy, then it seems to me that the National Aeronautics and Space Administration should be the responsible agency for organizing, conducting, and carrying out this program.

But that I think is a matter of national policy and not a matter in which I should express any individual opinion.

Mr. KARTH. Dr. Whipple, you have met the chairman of our full committee, Mr. Miller.

Dr. WHIPPLE. Yes.

Mr. MILLER. Yes. Sorry, I couldn't get down here sooner.

Mr. KARTH. Dr. Whipple has been kind enough to come to the subcommittee hearings and give us the benefit of his expert advice, Mr. Chairman.

Mr. MILLER. We appreciate it.

Mr. KARTH. I told Dr. Whipple for the record this morning as we started the hearings that in all probability he is the one man more responsible for declassifification of ANNA than any other that I can think of at the moment.

Although we were somewhat familiar with Project ANNA prior to his appearance before the committee, I think he gave the committee a much better idea of its extreme importance and the scientific value of Project ANNA, and as a result of that I informed him that you ordered me to conduct these hearings.

So we feel that it is a great pleasure to have Dr. Whipple down here with us.

Mr. MILLER. Project ANNA is quite technical, but to me it is one of the most important. And you can get more real basic information out of ANNA than you can out of mostly anything we have not or have been doing as far as earth sciences are concerned. Isn't that correct?

Dr. WHIPPLE. I think so.

Mr. MILLER. When we get out into the belts and other things, ANNA isn't doing us much good.

Dr. WHIPPLE. No.

Mr. MILLER. As far as mundane things, ANNA is a very important, perhaps the most important project we have before us. It can answer a lot of questions that have bothered earth scientists for many years.

Dr. WHIPPLE. Yes, sir.

Mr. KARTH. Are there any questions you have at this time, Mr. Chairman?

Mr. MILLER. No.

Mr. KARTH. Mr. Van Pelt?

Mr. VAN PELT. No questions.

Mr. KARTH. Mr. Hammill?

Mr. HAMMILL. I think Dr. Whipple anticipated most of our questions and has given us about as thorough a rundown on this project as we had hoped for.

So I don't have any questions at the moment, Mr. Chairman.

Mr. KARTH. Doctor, how about mapping? I know that this thing doesn't necessarily lend itself directly to a mapping program, but wouldn't this give us an opportunity to develop from the information we get, from the triangulation and the center points and so on, the specific points? Doesn't this lend itself toward worldwide mapping in greater accuracy than we at present have?

Dr. WHIPPLE. I am not an expert in this field of mapping, but my reaction is that your statement is entirely correct, that the geodetic data obtained here would be very basic to accurate mapping and there is certainly no doubt I think in anyone's mind that this will be valuable to mapping.

However, mapping is a very different type of problem than geodesy, because the mapping involves a great many details of coastlines, particularly, and interrelationship of points on the earth, observable points on the earth, with each other, and to the rest of the earth.

So the geodetic satellite will provide this basic information to tie together the mapping precisely and be, I think, important, very important in that. However, I think the mapping problem should be considered somewhat separately from the geodetic problem and certainly the same groups of people are generally not interested in conducting detailed work in both fields. The mapping people of course are very much interested in geodesy. The geodetic people are interested in mapping too, but I don't think the geodetic people would ever want to make a map.

This is a very specialized type of operation which, I think, in terms of your committee or in terms of national policy might be considered separately from the geodetic problem.

Mr. KARTH. Yes, I understand this, Doctor, but for those people who might be interested in mapping, certainly this program would lend itself toward a mapping program probably that they don't have the opportunity or the availability of at the present time in any other program.

Wouldn't you say that this has some possibilities?

Dr. WHIPPLE. I believe so, yes.

Mr. KARTH. In other words, we can gain many things from this program other than those things that we talk about most often. There would be many side benefits that we would get from the program as well.

Would this be in agreement with your opinion?

Dr. WHIPPLE. I believe that would be true, yes.

Mr. KARTH. One last thing, perhaps, Doctor. On page 3 where you said there have been at least 6 years of indecision and incoherent leadership in this program, and then you elaborate on that. You said this referred to organizational, jurisdictional problems.

I wonder if you would care to tell the committee who, in your opinion, was responsible for these organizational, jurisdictional problems?

Dr. WHIPPLE. I think honestly I do not know the answer to that question. The programs as they were carried out, I first became aware of this when it was in the NASA, and a very good program was being conducted, and, in fact, it was, as I understand it, the basis for Project ANNA, and then it was transferred to the Department of Defense and my impression is that they have done an excellent job, a very, very fine job in continuing with this.

What I meant by incoherent was that the leadership was transferred from one to the other, and great losses take place in planning and particularly in an international organization, when you change agencies. It is in this sense that I considered the leadership was incoherent.

I cannot place the responsibility for that. It is a matter of Washington decisions which I had no part in, and I do not know the basis for the decisions.

Mr. KARTH. I thought as an interested observer, you would want to venture a guess, Doctor.

Mr. Hammill has a question.

Mr. HAMMILL. Yesterday we heard from witnesses from NASA, and the testimony was to the effect that they are now waiting to be invited into the ANNA project by the Department of Defense, and that they also had the impression, on the basis of previous testimony by the Department of Defense, that this invitation might not come until after the Defense Department has obtained a successful launch.

Now that this project is unclassified and the follow-on program will presumably be much wider in scope, and so forth, is there any reason, in your opinion, why NASA has to wait to be invited in? Is there any reason why they can't initiate a program and invite the Department of Defense to join with them in a follow-on program?

Dr. WHIPPLE. In terms of a strictly follow-on program it would seem to me a perfectly feasible, possible operation for the program to be initiated in NASA. At the present time, however, with the basic ANNA program having been developed in the Department of Defense, it takes some real effort to transfer this operation properly to international use.

From what you say I gather that no action has been taken yet formally in reorganizing the program for detailed operation.

Mr. KARTH. You mean, Doctor—excuse me for interrupting—but do you mean this would pose some difficulties unless the scientific community had the cooperation of the Department of Defense; is this correct?

Dr. WHIPPLE. I think that is true at the present time. There is, for example, the very serious problem of where in the orbit the flashes should be set off, you see.

Mr. KARTH. But you would encourage that participation and cooperation?

Dr. WHIPPLE. I certainly would. I feel it is very important that a committee of the scientists who are actually involved in the observations, the analysis, should get together and discuss and make decisions as to where the flashes should be made.

Mr. HAMMILL. Would you elaborate on this programing of the flashes and why it is important?

Dr. WHIPPLE. Well, the ANNA satellite is at the altitude of 1,000 kilometers, approximately 600 miles. As a consequence it cannot be seen over large distances on the earth, so one must flash it so that stations that are competent to observe are in the proper geometrical position to make the most useful observations. These choices then depend upon a knowledge of where the stations are distributed over the earth, a knowledge of what observations they have made. After a certain number have been made for a certain series or group of stations, then you may concentrate on another group or you must see that your nets are adequately represented in these observations.

And the decisions here are not simple ones. They have to be made by people who are very well aware of all of the detailed problems, detailed scientific problems in the experiment, and they must take into account what has happened before and what the potentials are of the observations, what the weaknesses and strengths are in our knowledge of the geodetic net.

Then, of course, there are a number of problems that I haven't touched on here concerning the testing out and development of the radio methods which are involved in Project ANNA. Now these have great potential, as I mentioned in my statement, and they need to be investigated thoroughly.

So there is another area quite separate from the optical system in which very good judgment has to be exercised in making the best uses of the satellite in terms of its radio transmission. So there is a whole matrix of problems here that have to be decided by scientific people who are deep in the program and aware of all aspects of it.

Mr. HAMMILL. Not only scientists here but scientists abroad, I assume?

Dr. WHIPPLE. I am not sure that that is absolutely necessary except that we must make our program so that the scientists abroad who have gone to the effort of setting up their observational stations can utilize those stations to a high degree of efficiency. I think it can be done internally. I don't see the absolute need for international representation in this decisionmaking.

But the decisionmaking does involve a number of groups in this country, because there are a number of groups who have observational facilities. All of those must be represented in one fashion or another in this decisionmaking.

Mr. KARTH. Dr. Whipple, although you are not necessarily recommending a reprograming of the Project ANNA, you feel very confident that a follow-on program should involve and include higher orbit satellites to more properly do the job, is this correct?

Dr. WHIPPLE. Yes, sir. I want to make it clear that I am specifically not recommending any reprograming of ANNA: I think ANNA is a well-conceived experiment; it is sound. I think the equipment from all the evidence I can see is extremely well built, well visualized and it is so constructed that it can attain the goals which were well-considered goals.

My whole stress here concerns first the hazard that ANNA II may not function, and the need for a continuing program.

Mr. KARTH. Yes.

Mr. Chairman?

Mr. MILLER. No questions. But I notice, Doctor, in your statement as I just glanced through it, you suggest an orbital flight, one around the poles along with this one at 80°, cutting it down to the last one at 30° inclination.

Dr. WHIPPLE. Yes.

Mr. MILLER. That gives us much greater coverage.

Dr. WHIPPLE. It gives coverage geodetically directly in terms of positions, but then it gives us additional information as to the distribution of the gravitating mass in the earth.

Of course, you cannot determine the relative amount of mass at the poles without flying a satellite in that neighborhood. So that you do need the polar orbit.

Mr. MILLER. Why did they select the 50°? To get it away from going over Russia?

Dr. WHIPPLE. No, I think that was a very sound decision in terms of the area of the earth in which observing stations are easily operated. Now operating an observing station at the pole is extremely difficult as we know from our experience in Antarctica, not that it is impossible, but I think, for example, optically it might be quite impractical to try to set up a station at the pole. So that the direct geodetic determinations at very high latitudes will be difficult. But I think the prime consideration was that that is a good equilibrium orbit and very likely a slightly higher inclination would have been used, around 60 degrees, not because we didn't want the Russians to observe it, but because that happens to be the critical inclination in which the orbital motion changes in a peculiar fashion and is not very suitable for determining certain of these constants we wanted.

It just happens at 60° which would have been a very reasonable inclination otherwise in terms of observational possibilities on the earth where the major portion of the good weather and highly developed cultures are concerned, that going up beyond a bit of 60° just happens to run into this difficulty with the orbital motion.

It is just a coincidence which rather throws out a really more desirable inclination, possibly. I think 50° was a good choice for the first effort.

Mr. MILLER. I notice on page 5 you said you were confident that you could eventually attain an accuracy of about 30 feet in determining the coordinates of your 12 stations. I would say that is pretty fine if we do it.

Dr. WHIPPLE. Thank you. Perhaps a little optimistic. Some people have felt I have been overoptimistic in this. But I observe we are slowly approaching it now and I have observed in other areas of satellite work that we have gone beyond our expectations, and beyond our hopes. I would be surprised if we didn't do it here, if we persevered.

Mr. MILLER. In the old days in the artillery we called that the probable error.

Mr. KARTH. Mr. Beresford.

Mr. BERESFORD. Dr. Whipple, your statement contains some remarks about the adequacy of relatively small cameras for the observation of the ANNA satellite. We had some testimony earlier concerning ballistic cameras which I think are Air Force cameras that have been or are being modified with the help of the Coast and Geodetic Survey.

Is there any need for such cameras? What would be the advantages of using modified, relatively expensive ballistic cameras? These are BC–4's we are talking about.

Dr. WHIPPLE. I am not sure I know the optical characteristics of those cameras, but I am sure that the considerations here are on a sound basis. I think perhaps the reason for the choice is that the cameras are available and that the modifications are probably rather minimal.

In other words, it makes a simple direct solution to the problem. In the Smithsonian Astrophysical Laboratory we have a number of surplus cameras, 10 of which we have already in hand and 55 others that are promised us that we feel can be used effectively with very little expense, very little modification, and will lead to good observations in this program.

I think that this is probably just the practical use of equipment that is available, would be my feeling on this.

Mr. KARTH. Doctor, are you familiar with the ballistic camera?

Dr. WHIPPLE. I know a number of them, but I don't know them by that number. But I know there are quite a large number of ballistic cameras in this country that are extremely high quality and could be used very effectively in this program.

Mr. KARTH. Admiral Karo yesterday in his presentation said this, in very brief explanation about the capability of the camera:

> It has a specially designed lens for satellite photography, a very precise chopping shutter to allow interruption of passive satellite trails for time correlation, a capping shutter with precise electronic system for star programing and an accurate timing system.

These qualities, he felt, were very important in this kind of program. I was going to ask you that question before and I am very happy that Mr. Beresford thought of it. But if you are not familiar with the system, why then I suppose——

Dr. WHIPPLE. Undoubtedly there are other things they have in mind to do with these cameras anyhow which require this more sophisticated equipment, shutters, timing, and so forth, than might be required for the satellite program. But the fact that they are available makes the cameras even more easily used in the program.

Mr. KARTH. Admiral Karo is the Director of the Coast and Geodetic Survey.

Dr. WHIPPLE. Yes.

Mr. KARTH. Mr. Beresford.

Mr. BERESFORD. Yes, I would like to ask one more question to go a little deeper into the nature and purposes of Project ANNA and the jurisdictional control.

We were told that this was viewed by the Department of Defense as a feasibility demonstration, but we were also told that all the hardware was well tested and except for the launching problem, there really didn't seem to be any substantial doubt that the project was feasible; that is, if you could get the satellite into orbit, it would do what was expected, and achieve the results.

Do you agree with that?

Dr. WHIPPLE. I do agree with that. And my only comment would be that I do not consider that in the optical method that we need any further demonstration of its feasibility. It is already demonstrated to be feasible.

I think this is true, perhaps not to this accuracy, it is a little difficult to say, with some of the radio techniques now. The Transit program has produced surprisingly good results, extremely good.

Mr. BERESFORD. Now two changes, two major changes have occurred, one, the declassification, has already occurred; two, the probable extension to a full geodetic satellite program, is now contemplated. The declassification, I should think, might mean that there would be additional observation stations in other countries which would not have participated in a classified U.S. project.

Dr. WHIPPLE. That is correct.

Mr. BERESFORD. And the probable extension to a full program of perhaps an additional four satellites might mean that this first shot, instead of having to be viewed as complete in itself, possibly complete in itself and something of which we had to make the best use possible if it turned out to be the only such shot, instead of that now we can try to optimize it as one of a set.

My question is, whether these changes in the surrounding circumstances may indicate a need or the desirability of some change in Project ANNA itself, however well conceived it may have been under its original terms of reference?

For example, the inclination, 50° was a compromise. If there are going to be four more, is that still the best inclination? Is the altitude high enough, are the altitudes high enough from your point of view, sir, for optimum visual observation and simultaneous observation, particularly, from these more widely dispersed observations?

A third question which Mr. Karth has raised has been the launcher, whether the launch vehicle, which is being used for ANNA, is the best possible?

Dr. WHIPPLE. Well, with regard to the inclination, I feel that this is a good choice, that a higher inclination, as I mentioned before, would get you too close to this critical inclination which is undesirable at this stage. Later on it would be very valuable to have a satellite in that position to test out the very peculiar motions that you get.

But at this stage, I think it would be a mistake to go higher or near that 60° inclination. In terms of height above the earth's surface this is lower than optimum, but it is lower than optimum because of very practical considerations in the launching vehicle and in terms of the brightness of the lights so far attained, in terms of power and weight. So that that seems to be a good solution in a case where the engineering hasn't developed as far as we would like eventually.

In terms of the launch vehicle I am not familiar enough with the problems there to express an opinion, but I presume that the considerations of weight and orbit are involved in the choice of launch vehicle and that they have optimized this here in that respect, at least that is my understanding.

So that to attain these other goals would probably require some increase in the launch vehicle potentials.

I am not absolutely informed on that, but that is my understanding.

Mr. BERESFORD. One more question. You had spoken of the jurisdictional and organizational confusion, I think, or incoherence of the program up to now, and when the subcommittee chairman questioned you further on this point, you mentioned as one cause the transfer of the project from one agency to the other.

If it were transferred now or after the next shot, to NASA, do you feel that that transfer would not cause further confusion and incoherence?

Dr. WHIPPLE. I think what we need is a definite policy as to how this is to be done and we can't go back and undo what has happened in the past; we must begin today.

My reaction is that we should, today, since we can make a decision in this, plan a long program. You see it is clear that a long program is not, as far as I understand, envisaged by the Department of Defense. In fact, they have no program planned, are not doing any work on any program beyond the two ANNA satellites. So it is quite clear we do not have a continuing program at the present time.

We can't begin any sooner in setting one up.

Mr. BERESFORD. Thank you, Dr. Whipple.

I have no further questions, Mr. Chairman.

Mr. KARTH. Doctor, you have talked about the well-demonstrated capabilities of the optical and the Doppler systems. There is a third one, the Secor. I wonder if you are familiar with this, and if you are, if you would address yourself to the possibilities that this system has?

Dr. WHIPPLE. I am not well enough acquainted with the system to express any technical opinion on it, but from what I have heard it is a good system, it is being developed by competent people and has great promise. So I imagine I would expect it to also work well, but I do not know enough about it to express a technical opinion.

Mr. KARTH. Doctor, if the program were thrown open to the participation of the entire scientific community and put under management of one of the scientific agencies, do you feel that the scientific community is ready to participate in this program immediately?

Dr. WHIPPLE. Yes, I feel that they are, indeed.

I think they have been anticipating it and a great deal of experience is being gained in a number of centers now with regard to the theoretical background, the orbital theory and the analysis, the details of analysis, so that in fact the scientific community is ready.

Mr. KARTH. Are there any further questions?

Mr. Chairman?

Mr. MILLER. No.

Mr. HAMMILL. No, sir.

Mr. KARTH. I guess there are no further questions, Dr. Whipple.

If you would like to add anything to what you have already said, we would be very happy to have it for the record.

Dr. WHIPPLE. No. My only comment is an appreciation as a scientist of the great interest your committee is showing in these matters and the pressures that you are applying to obtain results and I am delighted to see this going on.

It is a very fine thing.

Mr. KARTH. Thank you very much.

Mr. MILLER. I would like to say that we are honored in having Dr. Whipple here.

Mr. KARTH. We certainly are.

Mr. MILLER. We appreciate the work that you are doing, sir, and it is a pleasure to be able to make some little contribution to it.

Dr. WHIPPLE. Thank you very much, Mr. Miller.

Mr. KARTH. Thank you very much. The meeting is adjourned.

(Whereupon, at 11:16 a.m. the subcommitee adjourned.)

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