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"FIRING OF EXPLORER I"
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First I'd like to apologize for the timing of this talk. When, several weeks ago, I agreed to address this audience on this occasion, I had no idea, of course, that 48 hours before my speech the first VANGUARD would go in orbit -- and far be it from me to try to steal the Navy's thunder at this moment. So let me first express to you, and to whoever may be present from the Navy, my most heartfelt congratulations on the most wonderful success of our friends of the VANGUARD project.

Some of you, inspired by what you have read in the papers, may think that we have always had a very strong competitive feeling towards the VANGUARD program. This is not exactly the case. We have always felt at the Army Ballistic Missile Agency that the VANGUARD vehicle was an advanced design, compared to our own, and we were too much "space men" in our hearts and too little interested in inter-service problems not to wish the advanced VANGUARD missile and its crew a full success in their endeavor.

The only issues in our fight to get into the act was that, in the first place, we also wanted to make our own little dent in the space and satellite area and, second, that we were honestly and gravely concerned about the time schedule on which the VANGUARD program was planned. After all, two years ago, when that program was initiated, the VANGUARD constituted a brand new approach for the design of a satellite vehicle, whereas our own proposal essentially involved the utilization of existing sets of hardware for this particular accomplishment.

Any such thing as successfully designing and developing a three-stage missile with three brand new and unproven stages on a time schedule of two years was absolutely unheard of and when I say at this moment that I want to congratulate our friends of the VANGUARD program on their fabulous success, I really mean it. What was done by the VANGUARD group in these two years is absolutely unprecedented -- the development of such a missile in such a short time is something that has never, never been done before.

My address today concerns our own little satellite vehicle. As I told you, the fundamental difference between our JUPITER-C and the VANGUARD was that we modified existing and proven hardware and put it to use as a satellite vehicle. My talk today will be rather informal, and built around a number of slides. The majority of these slides were simply made from photographs which were taken during the actual preparations for the EXPLORER I firing.

You certainly have read a lot about me in connection with the EXPLORER in the recent past, but here again I want to make a little statement. It is

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customary that, whenever a group achieves something, the public, and the press in particular, single out one individual and build him up and give him all the credit for it --usually far more than he deserves. Now this most certainly applies in my case. When I try to pass along the credit to some of my associates at ABMA and some of my colleagues from other agencies, primarily from Jet Propulsion Laboratory and Iowa State University, who have made very major contributions to the EXPLORER project, I do it not only to give the credit to those who have earned it and deserve it, but also in the hope that some of the unavoidable side effects of all this publicity, namely, mountains and mountains of fan mail, as well as letters from crack-pots and inventers who have a better solution, will now be channeled to other recipients.

Figure 1 shows the JUPITER-C missile that we use as the carrier for the EXPLORER satellite. The JUPITER-C is essentially made up of a modified REDSTONE missile booster serving as the first stage, and a cluster of solid rockets which are placed in a spinning tub attached to the nose of the first stage.

Let me first say a few words about the first stage itself. The standard REDSTONE missile runs at a thrust of 75,000 pounds and burns alcohol and liquid oxygen. Maximum burning time of the REDSTONE is 121 seconds. For the EXPLORER firing, we switched to another fuel instead of alcohol. We decided to use a mixture which our powerplant contractor, the Rocketdyne

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Division of North American Aviation, suggested for this particular use. Although the composition of this fuel was recently published in one of the journals of the American Rocket Society, I am in no position to let you in on it because it is not officially declassified. I can tell you only this much: The fuel used in the EXPLORER I firing gives about 10 to 15 per cent more specific impulse than alcohol, and it can be used in a liquid fuel rocket engine designed for alcohol and liquid oxygen without major hardware modifications. The fact that this fuel yields a higher specific impulse -- or higher specific propellant performance -- means that we can get the same thrust over a longer burning time with the same tank volume, or we can run the engine over the same burning time at a higher thrust level. We actually increased both thrust and burning time. We boosted our thrust from the 75,000 pounds of the standard REDSTONE to 83,000 pounds, and we extended the burning time to 155 seconds. This was possible not only because of the better fuel but also because we decided to make the fuel tanks a little longer.

Remember that the standard REDSTONE missile carries a very heavy warhead in its nose. Our JUPITER-C carries a cluster of high-speed rocket stages instead, and the total weight of this high-speed rocket array in the nose is substantially less than the warhead weight of the standard REDSTONE missile. As a result, we could take some of the weight saved up in the nose and put it into extra propellants for the first stage. Thus we were able to make the tanks longer. The additional power of the first stage is therefore partly due to the use of a more powerful propellant and partly to the use of elongated tanks.

On top of the tank section of the first stage sits the instrument compartment. It not only accommodates the guidance and control equipment for the booster flight itself, but also a "spatial attitude control system" for horizontal alignment of the separated nose section with the spinning tub when it passes through the apex of the trajectory. The idea is to aim and fire the high-speed clusters prior to apex so that at injection, the satellite is traveling in exactly horizontal direction.

The firing procedure of the JUPITER-C missile is as follows: The missile takes off vertically, like a standard REDSTONE, under its thrust of 83,000 pounds. During the 155 seconds burning time of the first stage, it is tilted into a trajectory which is approximately 40 degrees inclined to the horizon at cutoff. A few seconds after cutoff, we separate the booster from the instrument compartment. This is done by igniting six explosive bolts which tie the instrument compartment to the booster. Wrapped around these six bolts are six coil springs which have been preloaded during the assembly procedure. Thus at the moment the tiny little powder charges destroy the bolts, the springs exert a gentle push on the instrument compartment and separate it cleanly from the booster. The velocity increment imparted to the instrument compartment by the sudden expansion of the preloaded coil springs is only of the order of 2.6 fps.

On EXPLORER I we did not apply a refined cutoff for the booster, but instead used the so-called depletion technique. This simply means that at approximately the 149th second of flight we energized two contacts. These contacts sensed the pressure in the fuel and the liquid oxygen pump discharge lines. Whichever of these two pressures dropped to zero first, then triggered a relay which in turn closed both propellant main valves controlling the flow into the combustion chamber. In other words, we simply used the instant at which one of the two propellant components depleted to shut the engine down and thus get a clean cutoff. In EXPLORER I, actual cutoff thus occurred after 157 seconds, two seconds later than expected. Simultaneously, a timer was triggered which 5 seconds later activated the separation mechanism. This was done to avoid runup of the booster into the instrument compartment as a result of the gradual thrust decay. In a near-perfect vacuum such as the missile encounters at a cutoff point 58 miles up, there is no abrupt thrust decay. While the thrust drops quite abruptly to a fraction of its original level, the further thrust decay is quite slow because all the gas in the combustion chamber, plus whatever fuel and liquid oxygen is trapped between the valves and the combustion chamber, will expand or afterburn. This will exert a small but noticeable post -- cutoff impulse on the booster. Since only the weak spring forces separated the instrument compartment from the booster, we had to make sure that the booster would not collide with the instrument compartment again after

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separation due to this residual thrust. For this reason, we let the complete missile coast for about 5 seconds so as to allow the thrust to decay completely down to zero before actual separation.

From this separation point the two portions of the missile then coasted through a vacuum trajectory until approximately 404 seconds from take-off. At this time, the apex was nearly reached, but during this free coasting period between 157 and 404 seconds the spatial attitude control system aligned the instrument compartment into an exactly horizontal position with respect to the earth surface underneath.

This was done in the following fashion: The same gyroscopes that had been controlling the missile up to the cutoff point via jet vanes, now (after separation) controlled a system of compressed air nozzles which were mounted in the tail of the instrument compartment. The reaction thrust of these air nozzles tilted the entire nose section, complete with the spinning high-speed cluster into the horizontal direction. This tilt actually occurred substantially faster than the tilt of the trajectory itself. We turned the nose section into the horizontal position relatively fast, in order to give the residual errors sufficient time to decay. Thus we obtained the highest possible degree of accuracy in the horizontal alignment by the time the apex was finally reached.

The story isn't quite that simple, because due to our relatively crude cutoff technique, based only on propellant depletion, it was impossible prior to take-off to predict exactly the time at which the apex would be reached. For the same reason it was also impossible to determine exactly in advance the horizontal distance the missile would have travelled between take-off point and apex. Because of the curvature of the earth, and because the high-speed rocket launcher must be in exactly horizontal position over the local horizon, it was necessary to introduce some auxiliary tracking means to furnish some additional data during the flight. For only by catching the moment of "apex" and by accurately aligning the spinning tub would it be possible to really get the high-speed stages off in the right direction necessary to obtain orbital flight.

For the purpose of getting the instant of "apex" as accurately as possible, we used three independent methods. First, we tracked the missile by means of radar, and used the radar plot to predict the instant and point in space at which the apex would be reached. Secondly, we had an accelerometer in the missile which, by means of telemetry, relayed to the ground the velocity build-up of the first stage. The cutoff velocity was then fed into a simple computer on the ground which predicted the instant when the apex would be reached. Thirdly, we used our standard Doppler tracking network which would furnish the same information.

The results obtained with these three independent apex prediction methods were then cranked into a little calculator which enabled us to "weigh" the quality of the three inputs. For example, if one of the three predictions was based on readings of poor quality, it could be disregarded completely or its "weight" in determining the average could be reduced to only 20 per cent of the weight of the others. In this fashion, we could determine a rather reliable average in the apex prediction. The average prediction then was used to set a timer and this timer triggered a radio signal up to the missile which fired the second stage. All this, of course, had to be accomplished during the four minutes or so available between cutoff and apex.

Now to be quite correct, we did not want to fire the second stage exactly at the apex itself, but a little bit before the apex would be reached. The second, third and fourth stages had a burning time of about five seconds each, and there were several seconds interval between firing of the next stage and burnout of the previous one. This meant that the total elapsed time between firing of the second stage and cutoff of the fourth stage was about 24 seconds. The firing of the second stage, therefore, had to take place correspondingly prior to the predicted apex point. With this lead time the vertical velocity component of the high-speed cluster would be exactly zero at cutoff of the fourth stage.

At the right hand side of Figure 1 you see the fourth stage alone, the part which alone winds up in the orbit. It consists of a single 6-inch solid rocket, loaded with high-energy propellant. The black-and-white striped unit on top of it is the instrument compartment or, if you prefer, the satellite itself. The entire EXPLORER unit -- empty shell plus instrument compartment -- weighed 30.8 pounds, and the front portion alone weighed 18.8 pounds, so that the empty shell of the fourth stage rocket weighed 12 pounds. The entire EXPLORER is 80 inches long and, as I said, 6 inches

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in diameter. The same type of rockets, although with a slightly different propellant, were used in the second and third stages. A ring of eleven of them made up the second stage. Inserted into this ring was the third stage, which consisted of three rockets. The single rocket making up the fourth stage sat on top of the third stage.

Figure 1 also shows the orbit actually obtained with EXPLORER I. We reached a perigee altitude of 225 miles and apogee altitude of 1594 miles, which corresponds to a period of revolution of 114.78 minutes. It might interest you to know that post-launch tracking data indicated that the angle under which the fourth stage finally entered the orbit was, in respect to the local horizon, as little as 0.81 degrees off. We think this was quite a remarkable accuracy considering the many factors involved:

-Gyro drift of the gyros which controlled the nose section's attitude in space;

-The air jet system which slaved the instrument compartment to the attitude directed by the gyros;

-Any errors in the timing of the apex transit. Such errors would have meant that there was still a vertical component in the velocity, either upwards or downwards which, combined with the horizontal component, would result in an angular error (either up or down) in the firing of the last stage;

-Separation errors resulting from canting or

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unsymmetrical detachment of any newly ignited stage;

-Differences in ignition delays between rockets belonging to the same cluster (second or third stage);

-And last but not least, any unsymmetries or unbalances in the burning or mass distributions of the three high-speed solid rocket stages which, after all, had no active controls at all, but were merely spin-stabilized.

Although the total angular error at cutoff of the fourth stage was only 0.81 degrees, it might interest you to know that EXPLORER I still would have orbited, had this error been as high as 4 degrees. So we had a comfortable safety margin as far as accuracy requirements were concerned.

Figure 2 shows the internal details of the instrumented satellite. I would like to dwell a little bit longer on this subject because the collection of space environmental data by this unit was the actual objective of the launching of EXPLORER I.

In the rear you see the burnt-out shell of the fourth stage solid rocket. Right in front of the rocket's forward bulkhead are four turnstile antennas, with little weights at the ends. These antennae are just loose wires, but since the entire satellite spins in flight, centrifugal force acting upon those little weights stretches them radially out. In this fashion, we get a very effective antenna. The antenna is fed by two independent transmitters. One, the so-called high-powered transmitter sits in the rear of the cylindrical payload and has an actually radiated output of 60 milliwatts. The mercury

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cells, by which it was powered, were adequate for a two-week operation. Actually, 13 days after the launching, this transmitter went out of business. It came back twice thereafter, and it still keeps us puzzled as to why it did. Some of the fellows at JPL who built this whole package think they have found the answer. There seems to be a threshold below which the transmitter crystal does not oscillate, and once the battery power supply sank below this threshold, the transmitter simply cut out. Then the batteries recovered after a week or so of rest -- very much like an automobile battery would recover -- and the threshold was exceeded once again and the transmitter started blaring for another day and then cut out again. That happened twice.

In the nose of the package is the so-called low-powered transmitter. It is actually the same kind of transmitter as the high-powered one, except that it runs on one-sixth of the power level -- it radiates a mere 10 milliwatts instead of 60. It is fed by the same type of mercury batteries and since they have about the same number of ampere hours as the ones for the high powered transmitter, it is easy to see that the batteries will last about six times longer. Actually, the low-powered transmitter has an expected battery power supply for anywhere from two to three months. It is still going strong today and has never faded since the launching.

The first and foremost task of both transmitters was to provide suitable signals for the tracking of the EXPLORER satellite -- to supply us with

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proof that it was really up there. The high-powered transmitter can be received with any garden variety radio VHF receiver whereas the low-powered one requires more sophisticated, narrow bandwidth receiving equipment. Specifically, the latter could be received both by our own Army stations -- by that I mean JPL-developed Microlock ground stations -- and by the Minitrack network set up by the Navy in recent months. This Minitrack network consists essentially of a long string of stations stretching from North to South approximately along the 65 longitude West of Greenwich.

The stations thus form a kind of picket fence right across the North American and South American continents which will be passed by any object orbiting at any moderate inclination to the equatorial plane. The Minitrack network can catch any such satellite -- provided it transmits on the right frequency -- once per orbit and record its passing over the fence.

In addition to their task of serving as a tracking tool, the two transmitters have the job of telemetering down to the ground scientific information gathered aboard the satellite. In EXPLORER I, the telemetered data consisted of the following pieces of information:

First there was a Geiger counter, a compactly packaged and potted unit developed by the Iowa State University under Dr. James Van Allen and his capable associate, Dr. George Ludwig. The purpose of this counter is to determine the intensity of the cosmic primary radiation in outer space. Due to the existing weight limitations the counter in EXPLORER I can only measure the number of impinging cosmic primary particles to the extent that their energy must be within the counter's sensitivity level. It cannot distinguish between heavier and lighter, or faster and slower cosmic primaries. This is the task for a later experiment which is presently in preparation.

Moreover, with EXPLORER I we can record cosmic ray impingement on this Geiger counter only while the satellite transmitter is in direct line of sight with at least one receiving ground station. Since the major portion of the earth is covered with water, or at any rate not blessed with Microlock or Minitrack stations, we naturally lost most of the telemetered information over areas where there was no receiver station underneath the satellite. It is for this reason that in EXPLORER II and III a tape recorder is used to store the information throughout the entire orbit, and play it back on command when the satellite passes over a suitably equipped receiving station.

This recorder in EXPLORER II and III is a small magnetic tape recorder driven by a spring, like a watch, with a tiny little battery-powered electric motor continuously winding up this spring. Upon a coded radio signal sent up from the ground to the satellite, you can trigger a relay which unlatches the tape reel so that the spring drives the tape through the playback pickup within about 5 seconds. Within these 5 seconds the transmitter (which is turned on by the same relay) will then play back to the ground whatever the tape had recorded during the last orbit. In order to conserve power, the transmitter is turned off again after relaying the content of the tape. Since

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the little electric motor keeps winding up the spring, two hours or so later, after the next orbit, the unit would again play back data. Every time the tape is played back, it is simultaneously cleaned for new information, so that this storing and playback operation could go on as long as the battery power supply lasts.

Unfortunately, due to the mishap we had with EXPLORER II, we have not yet been able to successfully demonstrate this system, but we are trying it again on EXPLORER III.

Let me now come back to EXPLORER I. In addition to the cosmic ray experiment, EXPLORER I carries several instruments designed to determine the abundancy of micrometeorites in space, and to see how these micrometeorites, or even tinier particles usually referred to as cosmic dust, affect the satellite's surface. There were actually three different instruments to determine this on EXPLORER I. One was a microphone amplifier mounted in the satellite's hull. Whenever a micrometeorite would hit the surface, the microphone would register the impact, and it would be amplified. A scale of two circuits is then used to switch the frequency of a subcarrier oscillator. Observation of frequency change indicates meteorite impact. This piece of equipment was developed by Dr. Bohn of the Research Institute of Temple University in Philadelphia.

In addition to the microphone, there was a micrometeorite erosion gauge. This gauge actually consisted of two instruments in one. One portion of it consisted of 11 wires, made of extremely brittle metal, imbedded in an insulating surface. A voltage was applied to the 11 wires, which were all in parallel. The idea was that every time a micrometeorite would hit and break one of the wires, the total number of wires connecting the plus and the minus busbar would be reduced from say 11 to 10, or from 10 to 9, 9 to 8, etc., so that the resistance would increase in distinct steps. This change in resistance, would then be indicated on a sub-carrier oscillator.

The results of this particular experiment in EXPLORER I gave indications that two wires were put out of commission on the first orbit and then for a long, long time nothing happened. We're inclined to believe now that the first wires went out during the vehicle's ascent through the atmosphere. Apparently the population density of micrometeorites in outer space is not nearly as high as some people had thought. The micrometeorite erosion gauge was prepared by Dr. M. Dubin at the Air Force Cambridge Research Center in Massachusetts.

Cambridge Research, along with Iowa State University and Temple University, cooperated very closely and intimately with the Jet Propulsion Laboratory in Pasadena, California, where the entire satellite package for EXPLORER I was designed, assembled and tested in record time, -- a little over two months after the word "go" the unit was shipped to the launching site.

The final results of the micrometeorite tests will be issued by the Air Force Research Center in Cambridge, whereas Iowa State will publish the results of their cosmic ray measurements. Thus I do not want -- and actually am not even able -- to give you any information on the results at the moment.

In addition to these two pieces of data -- cosmic radiation and micrometeorites -- we had four temperature gauges on EXPLORER I: Three in the nose and the cylindrical portion of the outer shell to determine outer skin temperature, and one inside the instrument compartment, behind the high-power transmitter, where we measured the temperature of the heat-insulated instrument package as contrasted to the outer skin.

Figure 3 shows an elongated REDSTONE booster, mounted on a flatbed trailer, as it is loaded aboard a Douglas Globemaster Aircraft. The first stage was actually shipped in two pieces; booster and instrument compartment. Mounted on their flatbed trailers the two units were flown from the ABMA airstrip in Huntsville, Alabama, to Patrick Air Force Base, Florida (or, to be exact, to the skid strip on Cape Canaveral) in a single Globemaster flight. The picture shows the booster wrapped up in a tarpaulin for weather protection and to make it less conspicuous.

Figure 4 shows the loading of the instrument compartment. Both flatbed trailers were simply taken along on the same airplane so as to avoid any loading or unloading problems on the airfields. With both trailers inside the cavernous cargo compartment of the Globemaster, there was still room to spare. Weightwise, the two trailers did not use more than half of the carrying capacity of the ship.

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Figure 5 shows the booster unloaded and taken out of the canvas in our ABMA flight preparation hangar at Cape Canaveral. You can see the fins with the air rudders not yet attached. Note the nozzle exit of the rocket motor for the first stage and the mounts for the jet vanes which control the missile during first-stage flight. I would like to mention in this connection that the jet vanes for JUPITER-C gave us quite a little headache, or at least we thought so for a while. Whereas most of the testing of the rocket engine with this new Hydyne super fuel had been carried out by Rocketdyne at its Santa Susana test facility, the testing of the compatibility of the jet vanes with this highpower fuel was up to us at ABMA. We were at first a bit worried whether the combined effect of extended burning time (which had become possible with that highpower fuel) and the higher exhaust velocity (resulting from the higher energy content of the fuel) wouldn't erode the jet vanes to the point where, toward the end of the burning time of the first stage, we might not have enough control left.

To our great surprise, it turned out that this Hydyne fuel, despite the longer burning time and despite its higher energy, eroded the standard REDSTONE jet vanes far less than our good old alcohol. I can only give this to you as a fact, for we are still waiting for someone to write a doctor's thesis about why this is so. Maybe here is a challenge for someone who likes to approach missilery from the pure science angle.

I must also mention that the extended burning time resulting from the use of Hydyne required an additional hydrogen peroxide tank for the engine --

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simply to keep the turbine running for that extra burning time. This modification was also provided by Rocketdyne.

Figure 6 shows the instrument compartment of the first stage. In flight it is bolted to the top flange of the booster by six explosive bolts to effect separation shortly after first-stage cutoff. Quite a few cables and tubes connect the instrument compartment with the booster. All have quick-disconnect couplings so that at separation the plugs unplug and the lines come apart quickly and easily.

Since the instrument compartment had no doors, it was necessary to lift the entire cover to service the equipment inside. Such a solution would, of course, be entirely unacceptable for a military missile, where ease of handling and good accessibility are of greatest importance. However, for a research project such as EXPLORER I, with its relatively simple guidance system -- it is not nearly as complicated as that of a ballistic missile such as the REDSTONE -- we felt we could live without access doors in the instrument compartment.

This decision gives you a pretty good indication of the almost cocky confidence we had in the hardware we were using in EXPLORER I. We were so confident -- not so much because we thought we were that good, but simply because we knew that we had had ample opportunity to discover and remedy the shortcomings of our hardware in the past.

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The dark stripes on the cylindrical part of the instrument compartment are antennas. One is a telemetering antenna; one is part of the Doppler antenna system; there is also a radio command antenna; and the little balconies at the bottom house the compressed air nozzles of our spatial attitude control system.

The particular test shown in Figure 6 took place in our flight preparation hangar in Canaveral. It shows the instrument compartment bolted to a rocking table which is placed on the bottom of a 10-foot pit. The instrument compartment can be rotated and also rocked back and forth in two planes, because the table is gimbal-suspended and driven by three electric motors. The gyros are running inside the compartment, thus any error angles developing between the stable gyro reference and the rocking instrument compartment are picked up by potentiometers. Depending on whether the test is concerned with the control phase of the entire booster during powered first stage flight, or whether its purpose is to check the function of the spatial attitude control nozzles, you get a direct response of the jet vanes or the air nozzles. You can directly see, for example, if the compressed air nozzles for attitude control have the correct flow rate, whether the control needle is sticky, and whether the polarity is right, etc.

We do this kind of "rock-and-roll" testing with all our instrument compartments and find it a very convenient and reliable method for checking the entire control system in all its functions.

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Figure 7 is an exploded view of one of the four compressed air attitude control nozzles. I mentioned before that the instrument compartment, after separation from the booster and during the free coasting ascent to the apex, must be exactly aligned in the horizontal position, so that the spinning launcher, like an aimed gun, can fire the high-speed stages in the right direction.

This is done with the help of these attitude control nozzles. The compressed air supply enters the unit through the opening at the bottom. You can see the two nozzles which, at full flow, yield a thrust, either toward the right or the left, of approximately five pounds. The air flow is controlled by a small electric motor which drives a sprocket wheel. The cogs of this wheel engage in the teeth of a push-pull needle shown at the bottom of the picture. As the needle, driven by the motor, moves to the right or the left, more or less air is admitted to either nozzle. The smooth movements of the needle thus give us a "proportional control" system, in contrast to the much cruder "bang-bang" type attitude control system which is used in the top section of the standard REDSTONE. This refinement was necessary in this case for accuracy reasons. The accuracy obtained in rocking tests is one-tenth of a degree.

One of the nastiest problems that we encountered with EXPLORER was to make this proportional attitude control system absolutely linear under vacuum conditions. This was quite a trick because, with a vacuum outside, you obtain supersonic flow within the nozzle even at very small rates of air flow. This tended to cause an "s"-shaped response curve which the fellows in our mechanical lab found rather difficult to straighten out. But ultimately they succeeded, and it is now a very precise control system. There are four of these double-nozzle units attached to the instrument compartment, - two for pitch and two for yaw, while roll control was fed to all four electromotors in the form of differential signals.

Figure 8 shows the instrument compartment as it is being mated to the booster. You can clearly discern the bolts which go into corresponding holes in the flange of the booster. The two units are forced together by means of hydraulic jacks in order to overcome the compression forces of the springs surrounding the bolts which provide the separation kick. The blunt end of the instrument compartment at the far left of the picture is the place where the spin-up launcher for the high-speed stages will be mounted.

Figure 9 shows the entire first stage, complete with the instrument compartment, in upright position of the launcher table. The huge structure in the background was used to service the missile. We did not design this structure at ABMA but inherited it several years ago from the ATLAS project for which it was originally intended. I would like to mention that the plans for the ATLAS envisioned a considerably larger missile at that time, so it was a kind of a super ATLAS which never materialized that they had in mind when they designed this structure. Since those days our missiles have become smaller and smaller and at the end nobody had any use for this colossal structure. As the Air Force had paid it and the Army had no money, we took it delightedly.

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Now we come to the spin-up or high-speed stages (Figure 10). Before the launcher with the high-speed stages can be mounted on top of the elongated REDSTONE booster, it must be spin-tested for static and dynamic balancing. For this reason a special rig was built which consists of a cage suspended on four rods inside an outer structure. The inner cage surrounds the spin-launcher. As the latter is run up any unbalances are detected, located and remedied with the aid of a stroboscope.

The white cone at the bottom of Figure 10 is the non-spinning support of the spin-launcher which will later on be bolted to the blunt forward end of the instrument compartment. Electric motors drive the cluster up to speed--the entire launcher tub with the rocket clusters inside. As you start the spin with the tub not completely balanced, the inner cage will start to vibrate within the outer frame. The amplitude and the pattern of this vibration is then measured with a stroboscopic method which enables one to determine exactly where balance weights must be added. This technique is widely used in industry to dynamically balance things like gyroscopes or flywheels, and has a certain similarity to the method used in some fancy garages to balance automobile wheels. In such spin-up facilities, all high-speed clusters for the EXPLORER program have been or will be tested. The spin-up facility was designed and developed under an ABMA contract by the Aerophysics Development Corporation, in Santa Barbara, California.

The rockets for the second and third stages are hidden inside the tub whereas the fourth stage with the satellite payload sticks out on top. The tub is nothing but an empty aluminum cylinder. Inside are two rows of grooved bosses, one row at the top and one at the bottom. The grooves provide support and guidance for the lugs attached to the second stage. Inside the second stage are again bosses to hold the lugs of the third stage. This lug-and-groove type of holding technique is the exact equivalent to a zero rocket launcher: whenever the second stage has traveled as little as half an inch within the tub, it is completely free and could make lateral moves of several inches without colliding with the tub wall. The same applies to third stage clearance vis-a-vis the second stage.

The fourth stage, however, is mounted on top of the third stage. It sits in a conical holder attached to the forward end of the third stage. The satellite payload, distinguished by the white longitudinal stripes, is mounted at the top of the fourth stage. Final spin-up and balancing tests with the live clusters were conducted at Cape Canaveral in a special building operated by JPL.

The conical non-rotating support or "stool" carries the two heavy ball bearings for the spin-up launcher, and underneath it are located the two electric motors that drive the tub. The drive mechanism is utterly simple. We just use two sprocket rubber belts, not unlike those used in motorcycles, to convey the power from the electromotors to the spin tub.

The procedure for cluster run-up is as follows: Prior to launching, we spin the tub up to 550 rpm. At this rotational speed the missile takes off. About 70 seconds after takeoff, a governor (controlled by a tape programmer

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inside the missile) changes the regulator setting gradually from 550 to 650 rpm. Again, at 115 seconds after takeoff, it rises from 650 to 750 rpm. Thus, in the midst of the powered first-stage flight, the rate of spin slowly goes up.

This seemingly complicated procedure was chosen for the following reason. We had to avoid resonance between the spin frequency of the cluster and the bending frequency of the REDSTONE booster. Unfortunately, this bending frequency changes as the REDSTONE consumes propellants. Thus we must keep the rpm down at 550 as long as the tanks are still full and the bending frequency is correspondingly low. Only after the REDSTONE booster has consumed a substantial amount of propellants can we go up with the spin frequency, and we actually increase it gradually and about to the same extent that the bending frequencies also go up. At no time in the flight do we thus go through a critical frequency.

About 20 seconds before cutoff, the maximum rate of spin of 750 rpm has been reached, and there is no change in the rate of spin during the free coasting climb to the apex. Thus the high-speed stages are fired at 750 rpm. There is, however, one important consideration. The 750 rpm are controlled by a governor and, as a result, there is sometimes a slightly greater and sometimes a slightly smaller load on the electric motors. These varying loads exert a reaction torque on the instrument compartment attached to the spin launcher and in a free coasting flight this torque must be compensated by the compressed air nozzles of the spatial attitude control system. Otherwise the instrument compartment could acquire a spin under the influence of this reaction with resulting gimbal lock and spilling of the gyroscopes.

The thrust of the spatial attitude control compressed air nozzles had to be sufficient to cope with these "governor reaction torques." A lot of testing was done in this area before we knew that our method was sound and safe.

There is one more consideration in this area that I should like to mention. The presence of the spinning cluster in the nose of the instrument compartment means that what we have to tilt around with that spatial attitude control system is essentially a non-rotating body with a great big gyro mounted in its nose. As we tilt, we have to take into consideration the precession forces caused by this gyro. What we actually did was to put these unavoidable precession forces to good use: In order to tilt the unit in the pitch direction, we actually blew air out of the nozzles pointing in the yaw direction. Thus we used the precession force of the spinning cluster to tilt the unit in the pitch direction. All this had been tried out on an analog simulator beforehand, and when we fired EXPLORER I we knew we were in pretty good shape.

In Figure 11 we are taking a look from a higher platform of the service structure down onto the second stage. You can see the front ends of the eleven second-stage rockets sticking out through holes in the torus-shaped shroud. It is from here that the igniters are placed in the solid rockets. Inside the outer ring forming the second stage are the three rockets which make up the third stage, and on top of them sits the cone which supports the single rocket which forms the fourth stage.

Figure 12 shows the fourth stage, with the satellite on its nose being placed into the conical holder on top of the third stage.

Figure 13 shows the complete four-stage JUPITER-C sitting in the service structure. The servicing platforms embrace the missile clam-shell fashion and the penthouse completely surrounds the first stage's instrument compartment, as well as the spin launcher and the cluster of high-speed stages with the satellite payload itself.

The trailers in the foreground support the preflight checkout operation --they were gradually moved out in accordance with the progress of the countdown.

Figure 14 shows one of the last operations, checking the gyro assembly for booster control. As the instrument compartment has no doors, the entire forward hull section is lifted to provide access to the innards. The high-speed cluster on top is raised along with it. In a test firing from Patrick, this is a very convenient solution to the accessibility problem. In a military operation in the field, however, where you do not have such a service structure at your disposal, it would be an impossibility, and large and heavy access doors become unavoidable. But for our satellite firings we wanted to squeeze every ounce of dead weight out of the booster structure in order to get more payload, so out went the doors.

Figure 15 shows one of the last phases of the pre-flight preparation. At the right hand side you can see the liquid oxygen loading line going into the REDSTONE, while the ladder at the left is used to connect the line for the filling of hydrogen peroxide. In the so-called steam generator the hydrogen peroxide is catalytically decomposed so that an oxygen-rich steam emerges. This steam then drives the turbine which in turn drives the two centrifugal propellant pumps which feed the fuel and the liquid oxygen into the combustion chamber of the rocket engine.

The launching table is an extremely simple thing. It is just a steel table with four legs on which the missile rests prior to launching. The table top has a huge hole through which the rocket jet passes. A conical deflector underneath spreads the jet out in horizontal direction. All equipment you see in the rear of Figure 15 belongs to the service structure. The latter sits on two sets of wheels which run on wide-gauge rails. For the launching itself the structure is rolled back about 300 feet from the missile.

Figure 16 shows the operation from the blockhouse angle. You see several men sitting behind a number of panels. The panel in the foreground is the cluster speed control panel. Next comes the rocket engine panel with its conspicuous ring-shaped safety key; the operator does a little "ham acting" on the picture and pushes the well-publicized button which launched EXPLORER I into its memorable flight. Next down the line is the electrical power supply and network monitoring panel. The next panel is the monitoring panel for the first-stage control system. By observing the instruments the operator can see whether all four rudders are in zero position and whether the gyroscopes are properly leveled. The last man has the radio equipment panel. In addition to the panels, there was a rack of sequencing recorders in the blockhouse on which we continuously monitored certain items that one wants to keep an eye on prior to such a firing: things such as "Is the hydrogen peroxide temperature still okay?" "Is the instrument compartment cooler working all right?" "Are the Microlock transmitters in the satellite payload still beeping?"

The bespectacled tall gent at the right is Bob Moser who was the countdown coordinator in the EXPLORER I firing. It was his job to sing out the consecutive steps listed in the countdown table, to receive the compliance reports and to synchronize the missile preparation with the range operation, which means with the tracking stations, the camera groups, etc. Only after all these reports have come back, indicating that everyone of the hundreds of people involved in this complicated operation is ready and satisfied with the function of his piece of equipment, can the countdown proceed.

Everybody in the missile business knows the frustrating experience of a count being stopped at X-5 minutes. Then, after an half-hour silence the public address system is likely to announce that the countdown will be resumed at X-45 minutes. It is in this nerve-tingling atmosphere in which all new missiles are flight-tested. To the newcomer it is a rather mysterious phenomenon that these delays (and even decisions to "scrub"!) almost invariably occur a couple of minutes before the scheduled firing. This is so, simply because the closer you get to the firing, the more equipment is turned on and the more likely it is that something goes wrong. Several hours before the firing, nothing is turned on so nothing can go wrong.

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With a new missile, where you have very little experience on how long it might take to go from one step in the firing preparations to the next one, one can almost state that "any similarity between X-time and real time is purely coincidental"! It is one of the most important tasks of the experimental missile firing team to make X-time and real time gradually more similar, until at the very end -- at the completion of the development -- you can hand your customer, whether military or scientific, a realistic countdown table for your missile system.

In Figure 17, the structure has been withdrawn and you see JUPITER -C carrying EXPLORER I in its nose, sitting on its simple launcher table. There are a couple of fellows standing around the bird and the truth is that they really had nothing to do. In order to play it safe we had provided an hour of padding in our countdown schedule. It so happened that, in the case of EXPLORER I, the firing preparations proceeded so smoothly that at X-30 minutes we had to call a synthetic one-hour halt in all operations to let the real time catch up with the countdown! You see the stream of oxygen vapor issuing from the lox vent valve. This vent valve will be closed prior to tank pressurization which begins immediately before the firing.

The little balcony at the upper right hand side of the missile is the preflight instrument compartment cooler. It is essentially a dry ice container combined with a fan and a thermostat. The thermostat is located inside the instrument compartment. When, due to the heat dissipation of the electrical equipment -- transmitters, inverters, gyroscopes, etc. -- the compartment temperature gets too hot, the thermostat cuts in the fan, and the fan circulates the air through the dry ice till the temperature is again low enough to stop the fan. Immediately prior to launching, the preflight cooler is disconnected magnetically from the missile and topples to the ground. By the time it hits the ground, the missile has already left the table. Simultaneous with the disconnection of the preflight cooler, the entire cable connection between the missile and the ground -- we call it the umbilical cord -- is severed. For the last fraction of a second of the missile's earthly life there are only a few electrical contacts left in the tail, such as a "take-off" contact signal and an emergency cut-off connection in case of inadequate thrust build-up.

You can see the spin-up top very clearly now. At X-13 minutes, we start revolving the high-speed stages up to 550 rpm, and at this rpm the missile takes off.

Figure 18 shows the antenna system of JPL's Microlock receiving station at Patrick that was used to keep track of the initial flight phase of EXPLORER I. More elaborate arrays of such antennae, suitable for interferometric determination of the satellite's flight path, were used at several additional Microlock stations in Africa, Malaya and California. Insulating cylinders made of a plastic form the bases of these antennae. Around these a helix of sheet metal is wound so that the whole thing becomes a helical antenna with a moderate directional pattern. A chicken wire base provides a reflection shield. Phase comparison between two antennae separated by a given distance on the ground indicated the path of the missile-borne transmitter through space.

Figure 19 shows a typical trailer-mounted Microlock station for the electronic equipment that goes with this array of antennae. Aside from the interferometric Microlock stations in Nigeria, Singapore and Earthquake Valley, California, there was one more on Antigua in the Lesser Antilles, about 1300 nautical miles downrange from Patrick. In addition, there was, of course, the Minitrack network of the Navy which provides a North-South picket line through North and South America. It received on the same frequencies as Microlock -- around 108 megacycles per second.

In Figure 20, EXPLORER I finally takes off. You see the snow coming off the liquid oxygen tank and the spin-up top with the high-speed rocket stages. Note the preflight cooler falling off toward the right.

For the men in the blockhouse the missile went out of sight a few seconds later. As long as the booster was firing, they would watch the recorders of our so-called DOVAP "beat-beat" system which indicated whether or not the missile was following the predicted path. After booster cut-off and separation of the nose section, the next important operation was the prediction of the instant at which the apex would be reached and the high-speed stages had to be fired. Concurrently with this apex determination, of course, the attitude of the instrument compartment had to be continuously monitored by telemetry to make sure that during the free coast to the apex, the attitude control system did not fail. For if it did, the entire spinning high-speed cluster might turn around in space and might aim back at Patrick or at New York or some other place. We had to make sure, as it were, that the gun was still aiming in the right direction.

Throughout the preparation of the firing of EXPLORER I we received the finest service and the most splendid support that you can imagine from the Air Force Missile Test Center. The trouble about smooth inter-service cooperation of this type is that it is not newsworthy. It is a little bit like with Hollywood marriages. When an actor couple lives peacefully and happily together, it is not news, but when there is rumor of a possible divorce, hah, then it makes the headlines! And so, from reading the papers, people get the idea that all marriages in Hollywood are cracking up. Very much the same goes for inter-service cooperation versus inter-service rivalry.

During the actual firing of EXPLORER I. Bill Pickering of JPL, Jim Van Allen of Iowa State University, and I were in Washington, --to meet the press. We had been told in so many polite words that the public information aspects of the EXPLORER firing were far more important than the firing itself, -- so we had to sweat it out in the Communications Room of the Pentagon. Now I'll let you in on a little secret. I was told that if everything worked successfully, we would go over to the National Science Academy to meet the press, newsreel and television people. That's why I put on a dark suit. But, just in case things didn't come off so well, I had a pair of dark sun glasses with me and was determined to sneak away to a still darker movie theater.

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Presently, the signal had been given for second-stage firing and a few minutes later we had word from Antigua Microlock that both EXPLORER transmitters had been clearly heard passing that point. Antigua is about 1300 nautical miles downrange from Patrick, and the time elapsed between the firing of the second stage and the passing of Antigua was a pretty good indication of whether or not the final speed of the fourth stage was at least in the right ball park for orbital flight. As a result of the measured travel time between firing of the second stage and the passing of Antigua, the JPL data evaluation group at Patrick concluded that EXPLORER I must have settled in a 106-minute orbit.

From this we knew in our Pentagon Communications Room when to expect the first reports from California that the top stage had successfully gone around the world. Well, after the predicted 106 minutes were over, nothing happened, and I can assure you those eight more minutes until something did happen were the most exciting eight minutes in my life. We were frankly desperate and yet we couldn't show it because there was so much brass around. We had to keep up appearances, and had to smile and convince everybody that things were in perfect shape. Bill Pickering had the West Coast on long distance -- his four receiver stations in California -- and none of the four had heard a thing. That went on for what appeared to be hours. I heard Bill shouting into the telephone "Why the hell don't you hear anything?" Then, suddenly, within 30 seconds all four stations came in and said they had a clear signal! At this moment we knew that we were in the satellite business.

The main data of the orbit in which EXPLORER I finally wound up, have been widely published. Let me repeat them at this point, just for the sake of completion. Perigee altitude 225 statute miles, apogee altitude 1594 statute miles, period of revolution 114.78 minutes.

Figure 21 shows a chart which deals with the time of day at which a firing of an EXPLORER-type satellite (with the orbital data listed in the right upper corner of the figure) from Patrick is permissible from the temperature point of view. Remember that the satellite payload was covered with dark and white longitudinal stripes in order to make sure that it does not get too cold or too hot under the effect of solar radiation or the lack of it. The abscissa of the chart indicates the month of the year, while the ordinate shows the hours of the day.

In order to understand the meaning of this rather interesting chart, imagine for a moment that the orbit were going around the earth in such a fashion that the axis of the orbit pointed toward the sun. In this case the satellite will obviously always be in sunlight. Now take another case where the axis of the orbit points 90 degrees away from the sun. It is easy to see that the satellite will then spend approximately one-half of each revolution in sunlight and the other half in the shadow of the earth. (Of course, if the orbit is very high, it will be substantially more than 50 per cent in sunlight, because the diameter of the earth's shadow would be substantially less than the orbital diameter.) At any angles between zero and 90 degrees between axis of the orbit and the direction toward the sun, different times of exposure to sunlight will be found. But since the earth rotates about its axis, and along with the earth's surface goes our firing site, Cape Canaveral, it is clear that these exposure times must depend on the hour of firing. Moreover, as the earth revolves around the sun, and therefore the direction toward the sun prescribes a full 360-degree movement throughout the year, the exposure times to sunlight must also vary as a function of the time of year.

As an example, let us assume we want to fire a satellite from Patrick in the middle of May. If we launch the bird between 2 o'clock and 6 o'clock in the afternoon ("14 to 18 hours"), Figure 21 indicates that during the first sixty days of orbiting there would exist a period wherein, for a considerable number of consecutive revolutions, the satellite would stay 100 per cent of the time in the sunlight. In this case the satellite would get too hot, even without the additional heat stemming from our electrical equipment. The chart shows that if we decided instead to launch between 6 a.m. and 12 o'clock noon the time of exposure to sunlight will be between 70 and 80 per cent, which is acceptable. As long as our satellites do not have devices to actively control their temperatures, charts like Figure 21 must be very carefully examined and a suitable launching time must be chosen therefrom.

In case of our ill-fated EXPLORER II launching this was not the only consideration with regard to the timing of the firing; there was yet an additional one. There was our own EXPLORER I going around through its orbit, and that thing was radioing down on exactly the same 108.00 and 108.03 megacycles that we were going to use in EXPLORER II. Since we needed tracking data from all the ground stations overflown during the first

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circle, in order to find out whether EXPLORER II was really in orbit, we had to make sure that we did not launch EXPLORER II at a time when EXPLORER I was passing over the same stations. And, believe it or not, on our second satellite launching we found allegedly infinite outer space already so crowded that we actually did have to postpone our firing time by about an hour, in order to make sure that the two EXPLORERS did not come too close together and cause confusion among the tracking stations!

Now the first VANGUARD is also up there and it is also radioing on 108 mc. This is about to develop into a very serious satellite radio traffic problem. I think the time has come for some agreement on the use of additional frequencies for whatever satellites we plan to put up from now on.

My last two figures show what can be said so far about test results obtained with EXPLORER I. Remember that the results of our cosmic radiation measurements will be published by Iowa State University, and that the results on meteoric density will be published by the Air Force Research Center at Cambridge, Mass. Both agencies plan to report on their findings through the established IGY channels. The temperature data were collected by JPL, not so much with the IGY in mind, but simply to confirm the calculated temperature spans for which the electronic equipment had been laid out. Thus, with all due credit to our friends at JPL these temperature data can be divulged, and to my knowledge, I am doing it here for the first time.

The abscissa of Figure 22 extends over the length of one orbital cycle. The shaded area indicates that EXPLORER is in the shadow of the earth; the non-shaded area means that it is in sunlight. There are two measuring points as indicated on the sketch in the upper right corner of the figure, one in the tip of the nose and one in the cylindrical section aft of the nose. Measurements taken in the tip are denoted as crosses; those taken on the cylinder, as circles. All measuring points are identified by a number and a letter -- for example 43N or 24E. The number 43 means that the measurement has been taken during the 43rd orbit of EXPLORER I, whereas N means it has been taken by the Microlock station in Nigeria in Africa. 111P means that it was taken on the 111th orbit at the Microlock station in Patrick; 94S indicates the 94th orbit with the data collected in Singapore. The solid line represents the precalculated curve for the temperature for the second revolution of EXPLORER I, assuming that the original injection attitude has been retained by spin-stabilization.

Figure 22 shows that the actual measurements taken are scattered over a region between 60 and 175°F. Considering the great numbers of orbits involved in these measurements, plus the fact that the chart covers two different measuring locations (tip and cylinder) and a random attitude of the cylindrical satellite with respect to the sun, one can say that the result is highly satisfactory and jibes reasonably well with the precalculated figures.

As one would expect, the precalculated curve shows an exponential drop in the temperature during the stay of the satellite in the shadow of the earth. The heat stored in the satellite's skin is radiated out during this period. The moment EXPLORER I returns into the sunlight, the temperature rises rapidly.

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It then levels off for some reason, which has something to do with its attitude with respect to the sun. The temperature keeps rising gradually until the satellite returns into the earth shadow, whereupon the temperature immediately begins to drop again. This cycle repeats itself ad infinitum.

Figure 23 shows a series of temperature measurements taken in EXPLORER I, but this time not on the outer skin, but inside the satellite's body, or more specifically, behind the high-power transmitter. It can be seen that at this location the cyclic temperature changes are exceedingly small:

They vary between 100 and 120^{o}F., which is about the same temperature change that you can expect on a typical summer day between 11 a.m. and 1 p.m. in Phoenix, Arizona. The fact that the cyclic temperature variation is so small is mainly due to the fact that the electronic equipment inside the satellite is heat-insulated from the outer skin. The rather densely packed units have a certain amount of heat capacity of their own, and so they simply level off the peaks in the variations of the outer skin temperatures. The extent to which the outside temperature peaks can thus be levelled off depends solely upon the ratio between the heat capacity of the innards and the heat insulation between the latter and the skin.

With a different paint pattern of the satellite, the entire temperature level could have been shifted easily by as much as 20 to 30 degrees, either up or down.

Summarizing, we may conclude that we are in a position now to predict and safely precalculate the temperature environment for any new satellite. This gives us a high degree of assurance that in future, more sophisticated satellites electronic equipment can survive and operate under reasonable environmental conditions.

As a concluding remark, I would like to call your attention to a fact of which very few missile people seem to be aware. You all know that EXPLORER II did not go into orbit. Apparently, something went wrong with the fourth stage. The first stage worked fine, separation and spatial attitude was flawless. Upon radio signal at the apex the second stage fired, then the third stage fired, and apparently even the fourth stage received an ignition signal. But then something -- so far unexplained -- happened. There are some indications -- so far unconfirmed -- that the fourth stage even built up something like 150 fps velocity increment instead of the expected 4500 fps.

I can't tell you exactly what happened, nor does JPL know at this time. We are still studying the records. But we learned one thing out of this, and I think it conveys an important message for guided missile designers everywhere: There simply is no such thing as a "98 per cent successful satellite firing!" You have to achieve 100 per cent perfection or your try will be rated as a complete failure!

When you consider how well and for how long all big guided missile projects in the past -- and that includes, but is most certainly not limited to, our own REDSTONE and JUPITER, -- managed to pass through their unavoidable teething troubles with glowing but vague statements like "We had a highly successful flight" (although the result was only what one could reasonably hope for, say, 90 or 95 per cent successful with some minor thing going wrong) -- then you will begin to realize how perfect your equipment has to be if you want to play in the satellite league.

Let me therefore doff my hat once more to our colleagues in the VANGUARD program who succeeded in so few attempts to make their complicated, new and unproven bird not only good enough to perform what would pass as a successful missile flight, but just plain 100 per cent perfect.

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