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INSTITUTE OF THE AEROSPACE SCIENCES

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IAS NATIONAL TRACKING AND COMMAND OF AEROSPACE VEHICLES SYMPOSIUM

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KEYNOTE ADDRESS

by

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KEYNOTE ADDRESS

by

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Dept. of Naval Architecture & Marine Engineering, MIT

In a keynote talk for this Institute of the Aerospace Sciences National Symposium on Tracking and Command of Aerospace Vehicles, the first point that I would like to make is that the space program today is being supported beyond all of our fondest hopes a few years ago. Both the military and non military aspects of space have grown so rapidly that we in the world of engineering and science will find it hard to measure up to the support that we are getting. I would like to discuss each of the military and non military space programs separately from this standpoint though I recognize that they are, as the Vermont farmer said, "inextricably intertwingled".

In the military field for the decade and a half following World War II we have constantly been asked and constantly answered questions about when space weapons like ballistic missiles will take their place in strategic deterrent capability. In the beginning the answer was a vague "sometime in the future". But today they are rapidly becoming the principle part of the deterrent face of the future. Also in defense, new reliance is being placed upon developments of space devices, with projects of surveillance and warning satellites growing in importance. Other kinds of military support functions will be helped by communication satellites, navigation satellites and weather satellites.

In the decade from fiscal year 53 through the next fiscal year 63 the Federal expenditures for research and development for national defense will have gone from an actual $2.8 billion in 1953 to an estimated $8.6 billion in 1963, an increase by a factor of three. Much of this increased support has gone and will continue to go into the space field. The possibilities of space-based defense systems and further improvements of the "model T" ballistic missiles we now have, promise a continually increasing activity.

In the non military field the growth of the space program is even more phenomenal. Federal expenditures for research and development for non military projects in 1953 were about $269 million. Five years later, in 1958 they were about $523 million. And the estimated expense five years after that; that is for 1963, will be $3.8 billion. Research and development expenditures just about doubled from 1953 to 1958 when the non military space age received the impetus of Sputnik, and from that time through next year will have increased by more than a factor of seven. We do not have to dwell on the reason. National pride and prestige enter, together with a true reawakening of the exploratory spirit of our people, along with a number of other factors. The continued growth in research and development in the space field is promised in the future years as the National Aeronautics space budget increases toward $5 billion per year, and possibly higher to $10 billion per year as the major space explorations are pushed.

An expenditure of something of the order of $5 billion per year in space, when one considers that our gross national product is more than $500 billion per year, seems rather small since it is about 1 per cent of our effort. But this simple arithmetic does not tell the true story of the magnitude of our investment in the non military space field. This was pointed out to me with great clarity by Professor Leontief, an economist of Harvard, who participated with me in a panel entitled, "Our Investment in Outer Space," sponsored by the American Society of Mechanical Engineers in Boston recently. He pointed out that much of this non military space effort needed to be classified as an activity of building future capability for our society. The amount of human endeavor which can be supported over and above that needed just to keep everybody alive and replace existing facilities, is rather small. Figured on this basis, our investment in outer space is not just 1 per cent but a very large fraction. Exactly what that fraction is, is hard to determine because there are different opinions about what activities contribute to the future of our society; but I think that you gather the point that I am trying to make. Looked at another way, one must recognize that the engineers and scientists and other highly trained professionals who are used in space venture, are amongst the most needed segment of our society for improving society over the years to come. The shortage of these people is well known to us. The non military space effort takes a very substantial portion of these people.

My first point then is that our campaign to get support for military and non military space venture seems to have succeeded beyond our highest hopes of a few years ago. We in the technical fields will be hard pressed to live up to the promises we made.

The second point in this keynote speech has to do technically with the tracking and command aspect of the space program--the subject of this symposium. I believe advances in this field more than in any other will determine our success in space. We still have a long way to go. Success in the tracking and command field is needed in both the military and non military aspects of space.

Our space effort came about because of the advances in propulsion technology. That made it all possible. Had it not been for the rocket developments which enable us to get where we want in space, none of this program would have come about. But in order to make our space program profitable, the burden is back on the tracking and control field. Much of the public conversation about our space capability has to do with the propulsion aspect--the aspects of getting there. This is all important, but I believe the real job we have in speaking to the public and to our political and military leaders is to make them understand the tracking and control problems. Problems of accuracy of ballistic missiles, the discriminating problem for anti-ballistic missiles, the reliability of guidance and control equipment for deep space flight, tracking and sorting of a host of vehicles in flight--these are the kinds of things which are hard for the laymand to understand.

One of the outstanding problems in the tracking and command field has to do with the supersystems which result from putting together the many information gathering and handling systems into a world-wide net. This tax is not only our technical ingenuity but also our organizational capability. We do have more and more attention being payed to this problem within the military services today and within NASA, but I think we are only beginning to scratch the surface of the problem.

I would like to leave as the keynote points for this symposium the following: first, the recognized importance of the tracking and command field; and second, the difficulty of solving the systems and supersystems problems in tracking and command.

MINUTEMAN - A PROGRESS REPORT

by

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Director, MINUTEMAN Program
Ballistic Systems Division (USAF)

The tremendous advances that have been made in a short period of time have caused great technical achievements to become the norm today rather than the exception. From my own vantage point, as MINUTEMAN Program Director, I know that exceptional accomplishment has become the hallmark of this era. Just over three years ago, the MINUTEMAN ballistic missile weapon system was a bold new concept -- but it was just a concept. Today the MINUTEMAN idea has been developed into a system of proven performance. In bringing MINUTEMAN from concept to actuality, we matched boldness of design with boldness in action to establish new standards of development performance. In military technology, however, results are what count. Our responsibility today is to match or even exceed our development performance in the challenging task of deploying operational MINUTEMAN missiles in the numbers our nation's defense requires.

As you know, the MINUTEMAN missile is a three-stage rocket using solid propellants and an all-inertial guidance system to boost a nuclear warhead carried in a high W/C_{DA} re-entry vehicle to intercontinental range with great accuracy. The validity of the MINUTEMAN concept and design, including the fire-from-the-hole principle, has been confirmed by nine flights from Cape Canaveral, preceded by eight tethered silo shots at Edwards AFB, and backed up by hundreds of sub-scale and full scale static tests. Missiles being launched in the current flight test series are operationally-configured birds. They differ from the production missile which will shortly go into the concrete and steel shafts being sunk in the ground in Montana, only in that they carry range safety equipment and instrumentation.

My remarks today are intended as a progress report on MINUTEMAN. In presenting this report, I want to touch on three subjects; First, a capsule review of some of the major problems we have faced and solved in the MINUTEMAN development program. Second, an appraisal of program status, and some comments on lessons learned. And, third, a brief look ahead to those jobs remaining for the completion of MINUTEMAN acquisition, including product improvement and advancement of the state of the art in all appropriate directions.

Any discussion of MINUTEMAN logically starts several years ago with a development program which established confidence in the feasibility of solid propellant rocket propulsion for intercontinental ballistic missiles. In the mid-fifties, you will recall, ICBM demands of propulsion exceeded the prevailing solid rocket propulsion state of the art. The five critical areas where substantial technical advances had to be made were:

- -- thrust vector control.
- -- precise thrust termination on command.
- -- manufacture of the very large solid propellant grains needed for the first stage, while attaining satisfactory physical properties.
- -- high specific impulse in all three stages to achieve the performance required.
- -- and, high propellant mass fraction to keep size and weight within realistic limits.

One of the most difficult of these was development of movable nozzles for thrust vector control, an approach which was chosen for its efficiency. Use of solid propellants of higher performance than any previously demonstrated in operating systems involved higher flame temperatures and exhaust products containing on the order of 40 percent by weight of aluminum oxide particles. These two factors, coupled with long burning times, create a very severe fluid flow and heat transfer environment for the internal insulation and high performance movable nozzle hardware. Problems were particularly critical in the split line gap between the movable and fixed sections of the hinged nozzles. Solution of these problems required considerable effort to gain understanding of the phenomena and principles involved in handling high temperature multiphase combustion products as well as establishment of new techniques in using high temperature materials such as ablating plastics, graphite and tungsten. Considerable ingenuity and attention to detail was required in implementing the designs that have achieved success.

Validity of the nozzle technology and design developed has been fully confirmed in all our test flights. The bold approach paid off.

Verifying our closed breech silo-launch concept was also a tricky job. You will recall that there were those who said it could'nt be done. Many things had to be determined. Among these: the effects of heating, over-pressure, accoustics, and vibration on the silo, on the missile, and on its guidance and control systems. But again, the bold approach based on carefully calculated assumptions paid off. In eight shots from a prototype silo at Edwards Air Force Base, using missiles with short-duration Stage I engines, we developed the simple 12-foot diameter, 85-foot deep silo, and obtained data required to complete the missile design. Starting last fall, we have successfully demonstrated that an operational type MINUTEMAN can be launched from an operational-type silo. We have now had five consecutive successful firings of this type at AMR.

The objective of the Air-Force-Industry MINUTEMAN Team has been, and is, to deliver an effective weapon system on schedule at reasonable cost. Where do we stand in our progress toward that objective?

The brief answer to that question is that we are on schedule. It's worth looking a little deeper, however, because many of the accomplishments that underlie that statement are unprecedented in the annals of weapon system acquisition; and I think it will be worthwhile to call attention to some of the things we learned, with respect to both technical and management matters.

Regarding the missile itself: The missile now in flight test is the materialisation of the preliminary design which was carefully worked out before development contracts were let just over three years ago. The first flight, which was an unqualified success, occurred just over two years after development contracts were let, and involved flying a complete missile over an operational range trajectory with all three propulsion stages, fully operating guidance control system and separating re-entry vehicle. Further, all flights have been launched using the automatic sequence designed for operational employment, and six have been from the operational type silo I mentioned earlier.

The ground equipment is just as important to the operational system as the missile itself. Its development has paralleled that of the missile, and we have in operation in Seattle a test facility which is to the ground equipment what the Atlantic Missile Firing Range is to the missile. Test results are not as spectacular in Seattle as they are at AMR, but with respect to my "on schedule" statement, they are most gratifying. It is noteworthy that we have specified high standards of design in components as well as techniques concerning electro-interference and grounding in the ground equipment equivalent to those required in the missile. I believe this has been an important factor in achieving our timely successes in testing. Reliability and mean-time-between-failure budgets were also established early and have been managed with the care and attention usually reserved for missile weight statements. This, together with our willingness to pay for reliability now to reap handsome savings in supporting the operational force, are responsible for "order of magnitude" improvements in reliability.

We are conducting this intensive ground equipment systems testing program to confirm and, where possible, improve the reliability of the aerospace ground equipment. The launch control system is a sophisticated digital data system, cable connected with many flexibility and safety features. In this context, it is important to recognize that in a remotely-placed, unattended system which is dependent on automated equipment, the reliability of that equipment under the most severe circumstances must be guaranteed to the same degree that the missile itself is reliability-rated. The guidance system, for example, is maintained in a constant state of readiness in the operational MINUTEMAN. We must be sure that all the equipment measures up to this requirement.

The results of this Seattle test program are joined with the results derived from the Atlantic Missile Range flight series in the total system test program conducted at Vandenberg AFB with missiles fired over the Pacific Missile Range. In this program, the missile is mated with its aerospce ground equipment by the Air Force personnel currently in-training who will maintain the missiles and operate the equipment. The resultant integrated test operation of the total weapon system is the most thorough R & D check-out procedure ever accomplished. It will climax the MINUTEMAN development cycle and set the stage for the operational turnover of the weapon system to the Strategic Air Command.

In the activation of operational

sites for turnover to SAC, we are forging ahead with construction for the first Wing at Malmstrom AFB, Montana. Work there has been progressing at a good rate and is some 60 days ahead of schedule. We have accepted the first of the sites. Sites are also under construction at Ellsworth AFB, South Dakota, and Minot AFB, North Dakota. Construction at Whiteman AFB, Missouri, will start soon. Other locations are being investigated for follow-on Wings. The originally programmed four Wings (12 squadrons) have been increased to 16 squadrons, in the Defense Department FY 1963 program, and it is planned that additional squadrons will be added later.

In order that you won't underestimate the magnitude of the operational site construction and activation job, I should like to point out that a single MINUTEMAN Wing is deployed in an area about the size of the State of Maryland, some 15,000 square miles in all. Road travel by the construction contractor during his phase of the work has exceeded 15 million miles, and virtually twenty-four hours of continuous helicopter flight would be required just to overfly each of the 165 sites (150 launchers and 15 launch control centers) deployed in a single Wing area. More than 3 million cubic yards of earth and rock had to be moved and some 120,000 cubic yards of concrete, 18,000 tons of reinforcing and 12,500 tons of structural steel utilized in building the blast-hardened underground structures. Almost 2,000 miles of trenches have to be dug for the cable which interconnects these sites, the individual wires of which, if laid end to end, would reach twice around the world. Truly a tremendous task without parallel even in earlier ballistic missile programs, and a fine tribute is due our construction industry for having shown themselves equal to it.

The production of missiles and equipment for the first Wing is moving into high gear. Site activation teams are making final preparations now to receive it, install it in the facilities, and bring it to a state of demonstrated readiness for turnover to SAC. Airmen and officers of the Strategic Air Command who will man the first MINUTEMAN Wing are in training now and will be prepared to accept and operate the Weapon System when it is ready. In summary, we are in the home stretch. Many unprecedented accomplishments are behind us and a great deal of very hard work lies ahead, but the fact is, the Air Force-Industry MINUTEMAN Team has the job well in hand.

I have mentioned some of the things we have done or learned which I believe have been important factors in achieving good results. I would like to call attention briefly to a couple of additional aspects of the planning and management of the program which have been vital to its success.

I cannot overstress the importance of well conceived, tightly-controlled, cohesive programming in shortening the acquisition cycle. As an example, the first contract awarded in the MINUTEMAN program was one written to provide for the transportation of the as yet undeveloped end product missile. As a result, when the missiles were built, the highly-specialized "transporter-erector" capable of handling the missile intact was ready to receive them. As noted earlier, the silo launcher design concepts were essentially frozen and feasibility of the design established even before a successful full-duration static firing demonstration of the Stage I engine. Also, site activation and logistics -- because of the long lead times involved -- were portions of the MINUTEMAN program package that had to be outlined and undertaken while components of the missile were still being developed. These are all classic examples of the military management principle of "concurrency" of which the MINUTEMAN Program represents the most nearly complete expression to date.

Another principle of utmost importance to the success of a highly-concurrent program, I believe, is the singleness of responsibility. In other words, a Program Director must be assigned, given clear-cut responsibility and authority, plus a strong team, good support, proper resources, and rapid access to top authority. This principle has been followed in the MINUTEMAN Program, and has enabled timely action since inception of the program.

I want to conclude my report to you with a quick glance ahead, toward those areas where perseverance is still required in our pursuit of the best ICBM system that man can build. For just as there is no ultimate weapon, neither is there any system so good that it cannot be improved. Let me indicate a few areas in which product improvement is our next order of business.

First, in terms of range, we are working on refinements which promise to extend the already intercontinental reach of the MINUTEMAN, without compromising the exceptional accuracies we have attained. These refinements present some interesting technical challenges in the propulsion areas. Higher impulse propellants including some with rather exotic properties, are being investigated. Nozzle design contours are under re-evaluation in our search for any additional points of specific impulse which may be attainable through nozzle re-shaping. New approaches to thrust vector control which may reduce the number of nozzles and eliminate the need for nozzle movement are under active investigation. In other words, the state of the missile propulsion art has moved forward since 1958, and MINUTEMAN intends to profit from these advances in its range improvement program.

Second, in order to maintain the same high order of accuracy at these extended ranges, we are constantly assessing the state-of-the-art in intercontinental ballistic missile guidance systems to determine when changes to the present guidance system might be appropriate.

Third, with regard to the ground system, we are continually studying ways of doing this massive communications/electronics task in better ways. Means of reducing and simplifying the cable network I mentioned earlier, a degree of reduction in the complexity of electronic launch control equipment while at the same time increasing its flexibility to accept changing launch patterns and its ability to survive enemy missile attack, all appear feasible and are under development now.

Finally, just because we have succeeded in achieving an order of magnitude improvement in simplicity and reliability over earlier ballistic missile systems, we are not content to rest on these laurels but are actively seeking ways of doing the job even better.

In presenting this report on MINUTEMAN, I have tried to put our chronicle of progress into the proper perspective. Yet I regret that I have not had ample time to acknowledge the splendid support accorded those of us in weapon system management by all the members of our science-industry team. We have re-affirmed that the solutions to difficult technical and program problems on a timely basis are achieved only by proper recognition of each problem by management and technical personnel and through the proper attention of both these groups to the specific problem. Team effectiveness results only from establishment of the proper problem-solving environment and attitude by program management, and day-to-day, man-to-man efforts to solve the specific difficulties which threaten to attenuate the degree of success. The "team" analogy is time-worn and trite; but the fact remains that without the coordinated actions, the concentrated efforts of dedicated individuals who know their business, and the "never-say-die" attitude reflected in the "team" spirit, MINUTEMAN would not be what it is today -- a weapon system which is living up to all its expectations and promises to exceed those expectations in fulfilling the national defense mission for which it was designed.

SATELLITE RELAYS FOR POINT-TO-POINT COMMUNICATION

by

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Introduction

The inquisitive nature of man spurs him toward the acquisition of knowledge of the surrounding universe, and his pragmatic side tells him that this knowledge should be put to use. Currently, hopes are high that space science and technology will have some useful civilian application. The application which will probably first prove of practical use to the public at large is that of satellites as relay stations in long distance communication circuits.

Within developed countries, long distance telephone communications are presently carried over land lines and microwave systems, the latter coming into more common use in recent years. Tropospheric scatter systems are used to link remote areas -- such as islands within two or three hundred miles of the mainland -- with civilization, because of their over-the-horizon capability. The bulk of international telephone service is provided by high-frequency radio.

In spite of the many improvements in high-frequency radio, such as single sideband techniques, higher power output and wide-spaced diversity reception, this service has very little potential for expansion because of the already crowded HF radio spectrum. Furthermore, HF radio depends for its use on the ionosphere, whose reflecting properties vary diurnally, seasonally and geographically. These properties also vary with the 11-year sun spot cycle. During high periods of solar activity, such as occurred between 1957 and 1959, the ionosphere reflects radio waves over a range of frequencies between approximately 3 and 50 megacycles; when solar activity declines to low levels such as those predicted for 1965, frequencies above 20 megacycles are seldom reflected. As a result, the number of HF communication circuits available may be reduced by more than 50 per cent of those available during the recent years of high sun spot count.[1]

To decrease our dependence on the ionosphere for communicating between continents by telephone, and to avoid the difficulties of maintaining the multiplicity of relay stations required for microwave systems spanning ocean areas, high quality, long-lived submarine cables have been developed and installed. However, these cables do not have the wideband transmission capability necessary for relaying television in real time, whereas microwave systems do. Wideband conductors such as circular waveguide might serve the purpose but would be very costly.

Our best hope for greatly increasing the number of telephone channels and at the same time providing a transmission capacity for television and high speed data across oceans or large undeveloped land masses appears to be the employment of artificial earth satellites as microwave relay stations.

Types of Communication Satellite Systems

Many types of communication satellite systems have been proposed, most of which would use satellites in either of two classes of orbit -- "synchronous" and "subsynchronous." A synchronous orbit is one in which the satellite has a 24-hour period (19,300 n.mi. altitude). If, in addition, the orbit is circular and in the earth's equatorial plane, the satellite appears to be stationary with respect to the earth. If the plane of the circular orbit is inclined to the equator, the subsatellite point on the earth's surface describes an elongated "figure 8" pattern with its major axis on a line of longitude and its crossover point on the equator (Fig. 6). Subsynchronous orbits are those in which the periods of the satellites are less than 24 hours; hence, are at lower altitudes. Altitudes which have been proposed for subsynchronous operational communication satellite systems vary from 2,000 to 6,000 miles.

Active repeater satellites, those which receive signals from earth, amplify and retransmit them, are adaptable to either type of orbit. Passive satellites, those which merely reflect the radio energy incident upon them, can theoretically be used in either orbit, but for complete earth coverage practical considerations limit their use to low altitudes and/or narrow bandwidths. When complete earth coverage is desired with a passive satellite, there is an upper limit, prescribed by the altitude, to the gain of the reflector. Any increase in gain would narrow the beamwidth and effective earth coverage would not be achieved. To overcome this, one might increase the altitude, but then one increases the space loss and larger amounts of ground transmitter power are required.

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* Lt. Col., Signal Corps, U.S. Army

The configuration of a communication satellite system for civilian use has not yet been determined, but the research and development projects of the NASA are directed toward the development of spacecraft suitable for the types of systems mentioned above.

The NASA Communications Satellite Program

The objective of the NASA Communication Satellite Program is to provide by research, technical development, and space flight the maximum assurance of rapid and continuous scientific and technological progress toward operational global communications for civilian use. In pursuing this goal NASA has established several flight projects which will test the performance of various types of spacecraft in the space environment, and their suitability for adaptation to operational systems.

NASA is currently engaged in five communication satellite flight projects:

ECHO: a project for testing the suitability of large inflatable spheres as passive reflectors in subsynchronous orbits.

REBOUND: a project for developing a spacecraft capable of deploying, at definite positions in subsynchronous orbit, several inflatable spheres with a single launch vehicle. The techniques developed in REBOUND will be equally applicable to the deployment of active satellites.

RELAY: a project for developing and testing wideband active repeater satellites in low-altitude orbits.

TELSTAR: a cooperative project with the American Telephone and Telegraph Company to develop and test wideband active repeater satellites in low-altitude orbits. AT&T is providing the spacecraft and conducting the orbital tests and will reimburse the government for incremental costs of launch vehicles, launching, and tracking services.

SYNCOM: a project to develop and test a light-weight, narrow-band active repeater in an inclined synchronous orbit.

Project TELSTAR will not be discussed here in detail; suffice it to say that the objectives are similar to those of RELAY, the launch vehicle is the same, but the satellite and ground station electronic equipment and techniques are different, thus affording a comparison with those used in RELAY.

It is emphasized here that all of these projects are experimental. None of the satellites to be tested would be likely to appear unchanged in an operational system. Principles and techniques are being investigated with the expectation that, from these and follow-on experiments, sufficient knowledge will be gained to enable the design and operation of ultimate systems.

Project ECHO

Since the success of ECHO I[2,3,4] demonstrated the feasibility of the use of large, inflatable spheres as microwave reflector satellites, work by NASA has been directed toward the development of larger, more rugged structures. ECHO II will be a sphere, 135 ft. in diameter, constructed of an aluminum-mylar-aluminum laminate, where the thickness of the mylar is 0.00035 in. and that of the aluminum foil is 0.0002 in. Its resistance to buckling will be 20 times that of ECHO I. Inflation by a sublimating powder will stress the skin just beyond the yield point of aluminum, providing a structural rigidity which will prevent the mylar from wrinkling because of its "memory" for its previously folded condition. In this way we hope to avoid the prune-like surface which ECHO I is believed to have assumed after the inflating gas escaped.

ECHO II will be launched in 1962 from the Pacific Missile Range by a Thor-Agena B vehicle into a near-polar, circular orbit of about 700 n.mi. altitude.

Like ECHO I, ECHO II will have aboard two VHF tracking beacon transmitters at 136 Mc powered by a storage battery and solar cells. Tracking will be performed by the world-wide NASA Minitrack network. Orbital predictions will be generated by the Goddard Space Flight Center and made available to selected radar stations which will measure the satellite's cross section.

Project REBOUND

In any subsynchronous system, the number of satellites required to assure uninterrupted service between two given earth terminals for a prescribed percentage of time is a function of the altitude and inclination of the orbit. For orbits in which the satellites are equally spaced, the number required is substantially lower than if they are randomly deployed. At the lowest altitudes which will provide at least the minimum time of simultaneous visibility considered necessary between two stations, these numbers for the random case can become phenomenally large. This is illustrated in Figure 1. It becomes evident that if one desires a high probability that at least one satellite will be in the proper position for use as a relay, and if economic considerations are a factor, then one must look toward systems in which the number of satellites can be brought to the minimum; namely, those in which the satellites are equally distributed in orbit.

This could doubtless be done by sending aloft several satellites one-at-a-time. However, since the cost of launch vehicles is so large a part of the total cost of a satellite in orbit, an effort is being made in Project REBOUND to develop a spacecraft with the capability of deploying several satellites at predetermined positions in orbit, using a single launch vehicle.

Project REBOUND is currently in the design study phase. Design has not yet been completed, but the concept is illustrated in Figure 2. The spacecraft considered there is one in which four satellites are to be deployed at 90° intervals in a circular orbit, using a single mother spacecraft. The mother spacecraft is placed into an elliptical orbit, as shown in the upper left illustration. When it reaches apogee, a satellite is propelled foward with sufficient energy to place it into a circular orbit whose period is one and one-third that of the elliptical orbit. On the next revolution the second satellite is ejected (upper right). In the meantime, the first satellite has made three-quarters of a revolution. The third and fourth satellites are ejected on the next two times around. Thus the four satellites are equi-angularly disposed.

Two REBOUND launches with Atlas-Agena B vehicles are scheduled. The first of these, in 1963, will carry three ECHO II type satellites. These three satellites will be placed in a circular orbit of about 1700 miles altitude with an angular separation of about 40°. Their variation in spacing will be studied as a function of time, communication experiments will be conducted, and the technique of switching transmissions from one satellite to another will be developed.

Periodic position control of the satellites is not a part of Project REBOUND. Should perturbing forces prove to be so large as to disturb the initial configuration to the point that, in an operational system, intolerable outage times would occur, position control may be necessary. However, it does not seem logical to burden potentially long-lived passive communication satellites with active components -- one might just as well go to an active satellite. As pointed out previously, REBOUND techniques will work equally well with active satellites.

With spherical reflectors, attitude stabilization is unnecessary. However, if one wishes to increase the cross-section of a passive satellite, and still keep its weight within bounds, some form of attitude control will be necessary. Here, gravity-gradient stabilization is appealing, for passive satellites in particular, because of its passive nature. The NASA advanced research program includes studies of these techniques.

Project RELAY

The experimental RELAY satellite is being developed to evaluate the feasibility of relaying wideband microwave transmissions over transoceanic distances employing an active repeater in a low altitude orbit. It will be launched in 1962 into an elliptical orbit (height of apogee, 3000 n.mi., of perigee, 900 n.mi., inclination 50°) by a Thor-Delta vehicle from AMR.

Spacecraft

Communication transponders. The spacecraft, whose weight is not to exceed 135 pounds, will contain two complete transponders, each capable of handling a television bandwidth, 300 one-way telephone channels, or 12 two-way telephone channels. Only one transponder will be operated at a time. Powered by a common nickel-cadmium battery and solar cell power supply, each transponder has a 10-watt traveling wave tube as its final output stage, allowing reception of the full bandwidth on the ground from a slant range of 5,000 miles by a parametric amplifier receiver and 85-ft. dishes. The spacecraft receiving and transmitting antennas are essentially omni-directional. Frequencies to be employed are in the 2 Kmc region for the ground-to-satellite link and in the vicinity of 4 Kmc for satellite-to-ground.

Stabilization system. The satellite will be spin-stabilized at 150 ± 15 r.p.m. and will contain an active attitude-correction system, consisting of a multiturn coil mounted about its periphery, a horizon scanner and a sun-angle sensor. Data from the horizon scanner and the sun-angle sensor, together with ground computations, will provide information for time and current values to be applied to the coil. Application of a current to the coil will set up a magnetic field which will react with the earth's magnetic field to give a precession torque to the spacecraft axis. For this purpose, a corrective precession rate of 1 degree per day is considered adequate.

Radiation package. Since RELAY's orbital path will cause the satellite to spend much of its time in the inner Van Allen radiation belt, an excellent opportunity will be presented to obtain data on radiation damage to solid-state components. Hence, a subsystem of the spacecraft will contain radiation sensors to measure the flux and energy of protons and electrons, and the degradation in performance of solar cells and diodes as a result of radiation. Correlation of the degradation with integrated flux will provide information from which predictions can be made as to useful satellite life at these altitudes. A correlation of radiation effects in space with those obtained on earth using accelerated particles will also be possible, thus enabling much further work to be performed in the laboratory.

Telemetry and command. Information obtained from the radiation experiment as well as housekeeping data on the whole system will be telemetered to earth by a VHF transmitter. This transmitter or its duplicate, will be radiating continuously and will serve as a tracking beacon. Two receivers will accept commands to turn either communication transponder on and off and to telemeter data. Receivers and transmitters will be compatible with the world-wide Minitrack Network.