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DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON 25, D.C.

Op-95/rwb
Ser 30P95
17 February 1960

From: Chief of Naval Operations
To: DISTRIBUTION LIST

Subj: Testimony before the House Science and Astronautics Committee; forwarding of

Ref: (a) CNO ltr ser 3P95 of 28 January 1960

Encl: (1) CNO ltr ser 29P95 of 17 February 1960 with enclosures thereto

1. By reference (a), the Chief of Naval Operations initiated a series of newsletters forwarding selected statements of witnesses testifying before the Congress on space matters. Forwarded as enclosure (1) is the thirteenth in this series.

R. L. KIBBE
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DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON 25, D.C.

Op-95/rwb
Ser 29P95
17 February 1960

MEMORANDUM FOR THE CHIEF OF NAVAL OPERATIONS

Subj: Testimony before the House Science and Astronautics Committee, 16 February 1960; forwarding of

Encl: (1) Op-95 Memo for Record dated 17 February 1960 with enclosures thereto

1. On 16 February 1960, Rear Admiral W.F. Raborn, USN, Director, Special Projects, Bureau of Naval Weapons, Rear Admiral T.F. Connolly, USN, Assistant Chief for Pacific Missile Range and Astronautics, Bureau of Naval Weapons and Mr. R.V. Rhode (NASA), appeared before the House Science and Astronautics Committee. Enclosure (1) is a debrief of Admiral Raborn, Admiral Connolly and Mr. Rode's testimony and prepared statements and is forwarded for your information.

Very respectfully,

R. L. KIBBE
CAPT, U.S. Navy

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ENCLOSURE (1) TO OP95
SER 30P95 DTD 2-17-60

Op-95/rew
17 February 1960

MEMORANDUM FOR THE RECORD

Subj: Hearings of the House Science and Astronautics Committee on 16 February 1960

Encl: (1) Statement of RADM W.F. Raborn
(2) Statement of RADM T.F. Connolly
(3) Statement of Mr. R.V. Rhode (NASA)

1. Witnesses before the House Science and Astronautics Committee on the morning of 16 February 1960 were RADM W.F. Raborn, U.N, Director, Special Projects, Bureau of Naval Weapons and RADM T.F. Connolly, U.N, Assistant Chief for Pacific Missile Range and Astronautics, Bureau of Naval Weapons. VADM J.T. Hayward sat at the witnesses table and answered some questions, although he was not an official witness. The statements of RADM Raborn and RADM Connolly are attached as enclosures (1) and (2).

2. Verbal statements by the witnesses and questioning by members of the Committee brought forth the following items of interest:

a. The USS GEORGE WASHINGTON has fired successfully a Polaris missile "slug".

b. To date the record of Polaris Flight Test Vehicles is:

(1) 36 flight test vehicles have been completely successful.

(2) 14 flight test vehicles have been partially successful.

(3) 2 flight test vehicles have been unsuccessful.

c. Of the last 12 vehicles:

(1) 9 have been fully successful.

(2) 3 have been partially successful.

(3) the last 6 in a row have been fully successful.

d. Two Polaris submarines, each equipped with 16 missiles, will be operational this calendar year.

e. The Navy believes a total of 45 FBM submarines should be produced.

f. The Navy proposes to increase the range of Polaris in the next few years to 2500 miles.

ENCLOSURE (1) TO 0P95
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g. A single national space exploration program is needed.

h. The USSR does not have submarines that can launch ballistic missiles, but does have submarines equipped with missiles of 350 miles range, requiring surfacing for missile launching.

3. In the afternoon of 16 December 1960 the witnesses were Mr. R.V. Rhode (NASA) and Major Victor Hammond, USAF (assigned to NASA). Mr. Rhode's statement is attached as enclosure (3). Major Hammond had no prepared statement but made a presentation to the Committee, describing briefly the following:

a. General types of tracking.

b. The Minitrack, Baker-Nunn and Mercury networks.

c. Tracking problems in Project Mercury.

d. Tracking of deep space probes.

e. The Goddard Space Flight Center (which will coordinate all information from all tracking systems).

STATEMENT OF
Rear Admiral W.F. Raborn, USN
Director, Special Projects, Department of the Navy
To Be Given Before the
House Science and Astronautics Committee

Mr. Chairman and Members of the Committee:

I welcome this opportunity to give you another accounting of the status of the Fleet Ballistic Missile Weapon System, generally known as POLARIS. The continuing interest of your Committee in the FBM program and concern as to its status is very constructive and healthy.

Late this year, calendar year 1960, the FBM weapon system is planned to be operational and should provide the United States with a unique, mobile, and global weapon system. Delivery of the first operational ballistic missiles and the self-sustaining nuclear powered submarine is being accomplished in unprecedented time -- in fact, as I told you last July, almost three years earlier than believed possible when the FBM program was announced in January 1957. Before telling you in detail where we stand today in our POLARIS missile development program, I believe it would be worthwhile to describe briefly the FBM program and our past efforts -- the road over which we have travelled to date and the speed limits observed.

The FBM Weapon System occupies an extremely important position in the current and future military posture of the United States, and complements other deterrent forces in being or under development. It is designed to give this country a new military capability -- the capability to launch long range ballistic missiles with powerful warheads from nuclear submarines. The combination of the missile, the submarine with its launching and handling, fire control, and ship's navigation devices, plus specially trained submarine crews constitute the powerful sea element of the Fleet Ballistic Missile Weapon System.

ENCLOSURE (1)

In the fall of 1955, the President approved a project to develop a ballistic missile system with consideration to be given to both land-basing and sea-basing. The Navy created the Special Projects Office and as Director, I was charged with the responsibility for technical direction and management of the FBM Weapon System development, or more specifically, to engineer the sea application of the JUPITER missile. For a year, we worked hand-in-hand with the Army, whose job was to develop the JUPITER missile. This was indeed a most harmonious partnership and the Navy gained invaluable technical experience. Since liquid fuels presented virtually insurmountable problems for shipboard use due to safety, space and launching factors, investigations were soon directed toward the development of a solid propelled missile. Meanwhile, significant advances in solid propellant and warhead research occurred. The state-of-art of long-range, long-endurance nuclear submarines was also well advanced.

In late fall of 1956, the Navy proposed and was authorized to pursue independently the present FBM System with the solid propellant POLARIS coupled to the nuclear submarine. In March 1957, after three months of continuous study by an industry-scientist-Navy steering group, the weapon system parameters were established. These parameters were based on the most advanced concepts in state-of-art and the best technical judgments of attainable improvements with the next decade. These basic parameters and concepts, aside from minor exceptions, have not been changed after three years of effort. New technological advances are being incorporated into production components as they occur and at minimum cost. Growth potential is a built-in feature of the system. The nuclear submarine, the major capital investment in the weapon, has a life of at least 15 years.

Let me tell you briefly what the FBM system in operation will offer to our country. A basic requirement of any missile is that it must be able to reach, with accuracy and effectiveness, most of the important potential targets in the world. The POLARIS Fleet Ballistic Missile will initially have an operational range of about 1200 nautical miles and the capability of carrying a powerful warhead. With this range missile, POLARIS is in effect a global military weapon in that in excess of 90 percent of the earth's surface can be brought within striking distance of this mobile system operating from concealed ocean depths. The FBM submarine will be able to navigate accurately, either surfaced or submerged, using conventional and greatly advanced navigation devices and techniques. At all times, the FBM submarine will know her location in relation to planned objectives and, thus, the missile can be accurately targeted.

Launching points of the weapon system will be constantly moving about so that they cannot be pinpointed in advance by an enemy. The POLARIS Weapon System is virtually immune to surprise attack and invulnerable to enemy long range missiles because it possesses real mobility. This is fundamental, the ability to operate from one concealed area now and from another hidden area somewhere else one hour later. As the NAUTILUS and her sister ships have demonstrated, the highly mobile, nuclear submarines can remain submerged for extended periods of time, either relatively stationary or cruising over vast ocean areas.

Any retaliatory system to have maximum effectiveness must posses fast reaction time. The solid-fueled POLARIS missile will always be ready for firing without protracted delays for preparation. This is characteristically true of missile with solid propellants.

POLARIS deployed in submarines, unobtrusively cruising the oceans removes these weapons from inhabited areas to the seas. It poses an insurmountable intelligence problem to the enemy since every unidentified submarine is a potential POLARIS launcher. Thus, the enemy's countermeasure problems and problems of defense are compounded and complicated. The system presents to any potential aggressor an unquestioned and continuing capability, one which can be comprehended and appreciated. Because of the threat of deliberate and inevitable retaliation from these concealed mobile launching platforms, the POLARIS system should prove a powerful deterrent to any potential aggressor from striking the first blow. With this system, the United States will have a unique global military capability which complements our other retaliatory weapon systems, and which will be under the control of the United States.

Development of this global military capability has been most rapid. In January 1958, the Navy announced an accelerated development schedule with the 1960 target date for initial operational availability. At that time, we were well ahead of schedule and could confidently proceed at a stepped-up pace. Essentially, it was recognized that to meet the accelerated and augmented schedule we would have to resort to all possible means of expediting the work, through short-cuts, and maximum but sensible use of overtime. Multi-shift operations and extended workweeks for specified periods were authorized for various shops at contractors' plants to assure that components of the subsystems were all available to dovetail into a fully operable system when needed. The centralization of responsibility for all aspects of the program under the Special Projects Office as the single weapons system manager, unquestionably facilitated the development effort. With surety, the component parts of the development program have been managed and monitored in unison to meet our operational goals. This includes, in addition, to the weapon system itself, the related elements such as, production and operational support. The industrial base, logistic facilities and skills essential to support and expanded FBM force have largely been established. The industrial capacity is that necessary to support the presently authorized force but is also an excellent base on which to build as desired.

The POLARIS ballistic missile is a relatively small, compact, solid-fueled missile. A small but highly accurate guidance system had to be developed and simultaneously, made compatible with the missile and the shipboard fire control system. The re-entry body represents advanced technology. We have led the way in the harnessing and control of solid propellant motors, use of jetevators for missile flight path control, and means of precise thrust termination to impact on target. We must, of course, continue our development tests to attain the required degree of reliability and to achieve our ultimate system as contrasted with our initial operational objectives. Production of components for the tactical missile is proceeding satisfactorily.

Our flight test program has continued with very gratifying results. Through 4 February 1960 out of a total of 50 flights tests of various types, our technical staff and advisers have rated 34 completely successful since all specific technical test objectives were achieved. These fully successful flight tests included launchings of two-stage solid fuel test vehicles in August 1959 from a shore based Ship Motion Simulator and at sea from the USS OBSERVATION ISLAND, the FBM weapon system test ship. The first fully guided flight was conducted with excellent accuracy on 7 January 1960. Fourteen of the 50 flights tests were rated partial successes in that one or more of the primary technical objectives were met; two were failures. In other words, since I appeared before you last July, we have had seventeen flight tests and the score is 10 fully successful flight test; 7 partially successful. Eleven of the flight test vehicles fired in recent months are more fully representative of the tactical missile. On these our record is 8 out of the 11 fully successful with 3 partially successful. What this means is that the solutions we devised and corroborated through our ground test program in the fall of 1959 to correct certain deficiencies brought to light through tests in a flight environment are proving to be adequate. As we move more rapidly into the advanced testing stages we may encounter new problems but with our experience backlog, I sincerely believe that as they occur they will be temporary and susceptible to immediate correction by our competent team. We are on schedule, and in a number of cases, ahead of the development challenge established three years ago.

The missile flight test program is the most spectacular of all the POLARIS system tests. Our approach has enabled us to take advantage of partial successes and failures in ground tests and in flight to arrive at a complete understanding of unanticipated phenomena, and to utilize our successes in flight to make tremendous strides in proving features of the tactical missiles. Let me review briefly the eleven advanced development model flights tests conducted since last July. In September 1959 we fired the first of these from the flat pad at Atlantic Missile Range and performance was almost identical to that specified in the specific technical objectives. The re-entry phase of the flight was highly successful.

In October, we fired the second vehicle but the flight was terminated shortly after the second stage motor ignited due to difficulties in the motor. The third vehicle was flown successfully in November, again with excellent re-entry body performance. During December, we conducted three additional flight tests. In each instance, the vehicles were launched perfectly, and one performed exactly as predicted. In one case, first stage powered flight through first separation was good until the igniter adapter mal-functioned, (a random type failure) and suddenly terminated flight. In another case the vehicle verred off course and the Range Safety Officer destroyed it.

In January we have had four fully successful tests. On 7 January 1960 we conducted our first fully guided flight test. Performance of the guidance system was outstanding. May I state that the guidance system, in every predecing ground test and as a passenger in several of the flight test vehicles, has operated successfully. In this test, utilization of our radically new fire control system was made and similar fire control systems are being installed in the FBM submarine. Satisfactory performance provides another degree of confidence that our integrated weapon system will have the required accuracy. The other full scale flight test vehicles successfully flown in January and on 4 February provided further assurance of guidance operation and accuracy, re-entry body design, and integrity of the missile as a whole.

Remarkable progress continues to be made in our launcher development program. Last July I showed you pictures of the ingenious devices used to prove out the feasibility of underwater launching and the compatibility of the missile and launching tube. At San Francisco Naval Shipyard, we have Operation SKYCATCH and PEASHOOTER, dry land launching facilities to test various methods of ejecting the missile from the tube. At San Clemente Island, California, Operation POP-UP and FISHHOOK have repeatedly demonstrated the feasibility of underwater launching of full-size missiles, and of stable travel of test vehicles through and out of both calm and turbulent water. SKYCATCH and FISHHOOK are devices with the capability of arresting the test vehicle in mid-air which means the vehicle can be re-used time and again. Tests at the two launcher facilities will continue to pioneer further developments in launching methods and devices.

All aspects of the FBM ship construction have progressed satisfactorily under the accelerated schedule. Four FBM submarines were launched during 1959; the USS GEORGE WASHINGTON at Groton, Connecticut on June 9; USS PATRICK HENRY at Groton, Connecticut on September 22; USS THEODORE ROOSEVELT at Mare Island, California on October 3; and the USS ROBERT E. LEE at Newport News, Virginia on 18 December. The USS GEORGE WASHINGTON was commissioned on December 30. With a Navy crew in charge, the USS GEORGE WASHINGTON is now undergoing an extensive installation test program and other required tests and trials preliminary to the first live missile firing later this year. The program of dummy missile shots from the ship was successfully completed prior to 30 December 1959.

The USS OBSERVATION ISLAND, the FBM weapon system test ship, has recently been equipped with additional prototype equipments, and will shortly resume operations at sea.

A submarine tender is being converted to provide afloat maintenance for the FBM submarines and will be available for service in late 1960. A second tender new construction, is in initial stages of construction.

Important shore facilities, which are an integral part of the FBM program include the Missile Assembly facility at the Naval Weapons Annex, Charleston, South Carolina, and a team trainer at the Submarine Base, New London, Connecticut. These facilities will be fully operational when needed to support the FBM operational capability. Of course, we have had to supplement the facilities at the Naval Test Complex at Cape Canaveral, Florida, to accommodate the progressively advanced POLARIS experimental test vehicles.

Additionally, port facilities have been provided at Cape Canaveral to support the FBM ships prior to conduct of shipboard missile firings down the Atlantic Missile Range.

The FBM program is being developed and managed as a complete program package under authority delegated to the Special Projects Office. The program from its inception has been reviewed and approved in total terms which permit completely integrated and balanced planning and administration by the Director and his departmental staff of less than 250 military and civilians. As part of our approach to the development of the FBM weapon system in the spring of 1957, we spent considerable time in planning and scheduling our program. The Special Projects Office devised a management system with thefollowing objectives: to organize facts for complete decisions and staff actions, to provide a basis for accountability of performance on approved projects and a "need-to-know" reporting system and to provide a framework for responsible and objective evaluation of progress. We explored and developed new management techniques, including a system generally known as PERT (Program Evaluation and Research Technique utilizing a digital computer) which has been widely utilized in whole or in part by other services and private industry for the purpose of research and development management. These efforts have kept the status of the FBM program known at all times, including how our funds are used. Problem areas can be readily identified before they become critical, and we have a factual basis on which to make the numerous day-to-day management decisions attendant to such a large complex program.

In summary, the FBM program has forged ahead with sophisticated developments on a very tight time schedule. An advantage has been a top priority rating, co-equal with the other major missile programs of the Department of Defense. Based upon performance to date and an intimate knowledge of the work yet to be accomplished, the POLARIS submarine weapon system with its allied operational and logistical support is planned to be available operationally this year with the readiness of the USS GEORGE WASHINGTON. Other submarines are planned to be deployed at intervals, with a total of 9 POLARIS submarine systems expected to be ready in a timely manner. Moving at will within the safety of the ocean depths, the POLARIS submarine can be expected to accomplish her mission.

STATEMENT OF
THE ASSISTANT CHIEF OF THE BUREAU OF WEAPONS
FOR THE PACIFIC MISSILE RANGE AND ASTRONAUTICS
TO BE GIVEN BEFORE THE
HOUSE SCIENCE AND ASTRONAUTICS COMMITTEE

BUREAU OF NAVAL WEAPONS ORGANIZATION FOR SPACE

The Bureau of Naval Weapons organization for space is shown on the accompaying chart. Under the Secretary of the Navy and the Chief of Naval Operations, the Assistant Chief of the Bureau of Naval Weapons for Pacific Missile Range and Asteonautics provides a specific point of contact for coordination of programs which are being conducted under the management of the Bureau and its various field activities.

Basic organization planning for the Bureau of Naval Weapons provided for the ready adaptation and direction weaponry in the advanced space technology field. Although the major weapons development area in the Bureau of Naval Weapons organization is under an Assistant Chief for Research, Development, Test, and Evaluation, other line operating assistant Chiefs are assigned to areas that include Contracts, Production and Quality Control, Fleet Readiness, and Field Support. Included in the Staff Assistant Chiefs is the Assistant Chief for Program Management to whose office the Assistant Chief for Pacific Missile Range and Astronautics is attached.

ENCLOSURE (2)

The Assistant Chief for Program Management, in addition to being placed in staff capacity to the Chief, also participates in a verticality of reporting lines involving the line Assistant Chiefs, including that for Research, Development, Test, and Evaluation, where management of major bureau programs is the order of business. In weapons development and procurement, the Assistant Chief or Program Management essentially outlines what is to be accomplished, along with timing guidelines. He is responsible to the Chief of the Bureau of Naval Weapons for planning and executive direction of all Bureau Programs, including the assignment of resources for their accomplishment. It is then the responsibility of other line Assistant Chiefs to perform timely development and production, furnish progress reports, and work out program changes and modifications of requirements or objectives.

Such a basic organizational pattern was devised as the best possible approach to workable management of the activity which would give functional grouping of skills and knowlecges pertinent to research and development, materials management, and field support; to provide maximum vertical management with flexibility to meet shifting technological and business emphases; to provide "feedbacks" enabling program reviews; and to keep at a minimum the numbers of people reporting to the Chief, Bureau of Naval Weapons.

Also attached to the Assistant Chief for Program Management are two Assistant Chiefs within this organization, the Assistant Chief for the Pacific Missile Range and Astronautics, and the Assistant Chief for Program and Management Plans.

The Assistant Chief for Pacific Missile Range (PMR) and Astronautics Programs is responsible within the organization of Assistant Chief for Program Management for overall coordination, policy and executive direction and administration of all plans and programs within the Pacific Missile Range and Astronautics area of cognizance. As such, he provides a specific point of contact for coordination, guidance and assignment of resources to astronautics programs which are being conducted under the management of the Bureau of Naval Weapons.

The Assistant Chief of the Bureau for Research, Development, Test, and Evaluation is directly responsible to the Chief of the Bureau for the Complete development of aircraft, weapons, and associated equipment with program management and direction in the Astronautics area being the responsibility of the Assistant Chief for Pacific Missile Range and Astronautics. Under the Assistant Chief are four sub-groups charged with the development of systems and components in the areas of Aircraft, Missiles, ASW, and Astronautics. The Astronautics sub-group consists of two divisions, Payloads, and Vehicles from which the Navy Navigational and Bio-medical programs are being prosecuted.

PACIFIC MISSILE RANGE HISTORY MANAGEMENT, AND OPERATIONAL CONCEPTS

History

The Pacific Missile Range (PMR), managed by the Navy, is one of the three National Missile Ranges, each having unique capabilities and different but complementary missions. The PMR mission is to provide range support for the Department of Defense and other designated government agencies in guided missile, satellite, and space vehicle research, development, evaluation and training programs in the Pacific Ocean area.

The PMR had its inception in December 1957 as a result of increased emphasis on missile and satellite programs and recognition of the necessity for adequate range facilities. The Naval Missile Center, Point Mugu, is the nucleus upon which the full Pacific Missile Range is being developed. This center, an operating missile range for 14 years, is manned by over five thousand military and civilian personnel who are thoroughly trained and experienced in range operations. Its major complex before expansion consisted of a 75 x 150 mile sea-test range off the coast of California. In this area the Navy had conducted thousands of tests of conventional types of guided missiles. The development and testing of these types of Navy missiles will continue at the Naval Missile Center with the Pacific Missile Range providing all the range support.

In June 1958 the PMR was officially established as a National facility with the Navy as executive agent. The Point Arguello area is being developed primarily in support of National astronautics and space effort, since it contains many deep canyons wherein large, dangerous noisy rockets can be isolated, plus a unique east-west coast line which allows firings into polar orbit without passing over any land between Point Arguello and the South Pole, thus making this area the most desirable rocket launching center on the U.S. mainland for launching satellites into these orbits. In addition, Arguello provides range services to launchings from Vandenburg Air Force base to the North and to missile flights in the adjacent Pacific areas.

Operational Concepts

The Navy has reviewed all firm missile and space programs requiring PMR support in order to prepare a long range plan for future development of the range. This plan involves the establishment of a complex of ranges, capable of supporting the various types of missile and satellites to be developed. This complex includes: (a) a 250 mile sea-test range, (b) a 1500 mile IRBM range, (c) over 5,000 mile ICBM range terminating near Eniwetok Island, (d) a Polar orbit range originating at Point Arguello, and, (e) an anti-missile range in the Kwajalein Atoll in support of the Army's NIKE-ZEUS Anti-Ballistic Missile Program which will provide capability for testing anti-missile-missiles, using as a target ballistic missiles fired from the Vandenburg Air Force Base on the west coast and from Johnston Island.

Under strong Naval management, the Pacific Missile Range utilizes three contractors for specialized technical range operations and development areas --- one in the Eastern Pacific and another in the Western Pacific. The third major range contractor is in the range development area to help assure that the range will expand in a planned and organized manner, anticipating and being ready for the demands placed upon it. This contract system was evolved after careful detailed studies of the contract operations of the other national ranges. This study concluded that a single range contractor operation was undesirable because such an overall operation control might take over the management control function which is properly the responsibility of the Range Commander. Conversely, it was determined that to go to a system utilizing a large number of small contractors, could prove to be a major management headache. The Pacific Missile Range tri-contractor system appeared to be a sound, logical middle of the road approach and is meeting with excellent success.

Statement of Richard V. Rhode, Assistant Director of Research
(Structures and Materials and Aircraft Operating Problems)
National Aeronautics and Space Administration

before House Committee on Science and Astronautics

Mr. Chairman and Members of the Committee:

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

In order to illustrate our research activity, let us consider a space mission designed for manned circumnavigation of the moon. This mission entails launch and exit from the atmosphere, space flight, orbiting the moon and exploration of the lunar surface, and finally, return to earth, entry into the earth's atmosphere and landing. The first phase of this or any other mission is launch and exit from the atmosphere.

LAUNCH AND EXIT

This manned Lunar mission will require a large main booster, such as "Saturn", with suitable second stage and other boosters, and a payload consisting of a spacecraft and re-entry vehicle together with their contents. Such a system is large and heavy. The length may be 300 feet

ENCLOSURE (3)

and the weight a million pounds. Because of the great importance of weight, the structure will be light and flimsy by normal structural standards. The volume and weight of the fuel will be large. The system will be balanced on and accelerated by rocket engines having a total thrust of 1.5 million pounds, and it will be subjected not only to the force of thrust along the axis, but also to side forces caused by winds and turbulence and to the corrective sidewise components of thrust from the gimbaled engines.

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

One aspect of this problem is the interaction between the control system and the flexible structure. This aspect, which is called structural feedback, can be demonstrated by a simple mode. The control system consists of a device sensitive to motion, called a sensor, which transmits a signal to a control element. Here, the sensor is a simple accelerometer and the control element is an electro-magnetic device which causes side forces similar to those caused by gimbaled engines. When the sensor is moved by hand, the control device also moves and causes the structure to respond. In practice, the sensor must, of course, be located somewhere in the system. Suppose it is mounted amide ships and the system is distrubed as it might be when a gust is encountered in flight. The response of the structure is considerable, and in practice this much vibration would destroy the vehicle. It does not die out and is therefore called unstable.

The shape of the axis as it bends back and forth is typical of a simple bending vibration. Let us see what happens when the sensor is placed at the nose. Now a more complex form if vibration is excited. One can readily see that the interaction of a control system and a flexible structure poses a problem. As previously noted, the system contains a large mass of fueld, and the demonstration has shown that vibratory motions will cause the fuel to slosh around in the tanks, thus setting up additional large and irregular forces.

We have here a short movie sequence showing studies being made of fuel sloshing in the laboratory. You will first see a transparent tank with colored fuel reacting to control forces. This will be followed by a demonstration of the effectiveness of baffling.

The control element here is a gimbaled air jet, simulating the rocket engine, and located at the bottom on the tank. A suitable baffle helps to reduce the fuel sloshing.

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

SPACE FLIGHT

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

Meteoroids are metallic or stony bodies that travel through space at speeds estimated to range between about 25,000 and 165,000 miles per hour. Some of them are very large, such as those that caused the craters on the moon, or the one that fell in Arizone centuries ago to create the well-known meteor crater there. Others are very small. Fortunately, the large ones are extremely rare--for example, the surface of the moon has not visibly changed by large-scale meteoroid impacts since the invention of the telescope. We don't worry about them any more than you worry about them when you walk down the street. As the meteoroids become very small, however, the numbers of them increase to the point where the probability of hits or impacts on a spacecraft becomes quite high. If there were no atmosphere to burn them up, we would all be likely targets for them. These small meteoroids may be only a few thousandths of an inch in diameter.

Although very small, they can, because of their tremendous speeds, be very destructive. It has been estimate, for example, that a ball in space made of aluminum about one yard in diameter and having a thickness of .005 inch might be punctured as often as once every ten hours or twice a day. With ten times this thickness, the ball might be punctured once every 200 days. Obviously, light structures, including tanks and radiators, will not give satisfactory service over a long period of time without some protection against meteoroid strikes.

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

This photograph shows two high-speed helium or light-gas guns developed at our Ames Research Center. Some of you, I understand, have seen them. They can shoot small balls about 1/16 inch in diameter as fast as 14,000 miles per hour. This speed is much faster than a rifle bullet--a typical military rifle, for example shoots at about 2000 miles per hour. We can obtain much useful information from such equipment, because by using relatively large pellets we can obtain the same impact energy as the smaller meteoroids have. Meanwhile, we are studying means for shooting smaller particles at speeds within the meteoroid range.

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

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

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

The figure shows the speed in miles per hour required to just penetrate the target with 3/16 diameter Pyrex balls. We see that a pellet going at 2,000 miles per hour will go through a single thick sheet. But if the sheet is split and separated a bit, it takes a speed of 4,000 mph to go through. With four layers, again of the same total weight, we can withstand somewhat greater speed. And if we fill the space between the bumper and the second sheet with low-density, glass-wool, we see that particles going as fast as 7,000 miles per hour will be stopped. These tests simulate what would hapen with meteoroids 1/16 inch diameter at speeds of about 40,000 miles per hour-- well within the meteoroid speed range.

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

This is a 1/5th scale model of the puncture-experiment satellite. The short tubes running lengthwise will be made of metal of various thicknesses, and will contain gas under pressure. When a tube is punctured by a meteoroid, the gas will leak out and this occurrence will be radioed back to earth. In this way, we will get direct information on how long a structure made of material of different thickness can be expected to last out in space. In the future, we will get more and more direct information of the sort that will enable us to design better and more efficient spacecraft.

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

Many satellite and other space missions, such as our Lunar mission, require that the attitude of the spacecraft be maintained or stabilized. On this chart are shown some typical requirements of attitude control. Earth satellites might be required either to continue to point toward the center of the earth or to continue to point toward a fixed object in space. Space probes or space ships taking navigation fixes must, in general, point toward some fixed object in space.

Different missions require different degrees of precision. Earth-oriented communications and meteorological satellites require relatively little precision--the attitude need be maintained only within about 8 degrees for the former, and within about one degree for the latter. Space-oriented spacecraft however demand a very high degree of precision. Interplanetary navigation, for example, requires that the attitude be stabilized within about .005 degrees, and the astronomical satellite must be stabilized to the very fine point of .0003 degrees. In order to give some idea of what this means, .0003 degrees is the angle contained between to straight lines starting at a point in this room and spreading only 70 feet apart in San Francisco.

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

Here is a simple demonstration model of an attitude control system. The spacecraft is represented by the turntable, which is free to rotate just as the spacecraft is free to rotate about any of its axes. The sensor is a simple photo-electric cell. Its signals actuate the control device, which in this case, is an inertia wheel that operates on the principle of conservation of angular momentum. As you see, when the platform is turning slowly, the light source will stop the rotation and the sensor will continue to point at the light. All of the mechanism for doing this is self-contained on the turntable and no external force is applied.

In order to obtain the required precision, each one of the functional requirements must be subjected to the research process such as indicated by the work goind on in this laboratory set-up. For example, if as is likely, the sensor is a light-sensitive mechanism, its sensitivity and accuracy must be investigated in relation to the wave lengths available in the light source; some of the wave lengths may have to be filtered out. Again, control mechanisms of various types must be investigated to determine the principles best suited to the development of controls having low power requirements and at the same time high positioning accuracy. These and many other problems are being investigated with laboratory equipment such as shown on this chart.

Progress to date indicates that we can achieve an accuracy of three hundredths of a degree with present laboratory equipment, and that 1-1/2 hundredths of a degree can be achieved before long. Further research is obviously required in order to develop the high accuracies required for space-stabilized systems.

LUNAR EXPLORATION

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

Another aspect of Lunar exploration is the matter of sending instruments to the Lunar surface and to have them remain intact so that they can transmit information either back to the spacecraft or to Earth. To do so requires ejection of a lunar landing system and instrument package from the spacecraft, arresting its forward motion and placing it on the moon intact.

In principle, there are several ways in which this can be done. You are all familiar with proposals that have been made to lower a suitable container to the Lunar surface by menas of retro-rockets, such as indicated at the left on this chart. This kind of system permits a soft or easy landing, even in the absence of a lunar atmosphere, and is the kind of system that will have to be used to place man or men safetly on the moon. It is complex and heavy. The research problems involved are common to other aspects of space flight--viz; light-weight structures, stabilization and control, guidance, throttleable rockets, et cetera.

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

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

The crushable-structure concept employs light-weight metal structures, such as this honeycomb sample. When it is placed between a heavy object and the surface of impact, it collapses, absorbs energy, and assumes the shape you see in this second piece.

The penetration spike is a very simple device, but it works only when the surface of the ground is neither to hard or too soft. It absorbs energy by displacing and compressing the material into which it penetrates, just as a nail absorbs the energy of a hammer blow.

Both the crushable structure and spike concepts require proper orientation with respect to the impacted surface. The gas cushion does not have this limitation. It is therefore, the simplest of all systems although requiring more research to understand how to design it. In the case of the gas cushion, the instrument package is suspended in the center by numerous radial cords. The system falls freely in the Lunar gravity field because there is no atmosphere. Upon impact the cushion compresses until the instrument package is brought to rest on the impacted surface. At this instant, the bag is split to avoid rebound. Energy is absorbed by compression of the gas, by shock waves generated in the gas, and by distortion of the bag skin. Gas cushions suitable for landing instrument packages on the moon might range between 5 and 25 feet or more in diameter, depending on the orbital height and the size and weight of the instrument package.

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

Before we are ready for a manned mission to the moon we shall, of course, be sending unmanned spacecraft there. Here is a model of one of them that is currently under development by the Jet Propulsion Laboratory. This apcecraft will weigh about 700 pounds and is intended to be launched by the Atlas Agena-B. The two folding vanes are solar energy collectors. The dis-type antenna transmits and receives signals to and from earth. The main body of this spacecraft contains attitude control and navigation equipment, instruments, radio et cetera. At the top is a capsule that will be separated from the spacecraft proper and landed safely on the moon.

The next chart shows the sequence of events. During the early phases of the flight, injection and mid-course guidance are exerted. As the spacecraft approaches the moon, the small capsule is separated from the main spacecraft and retro-rockets are fied to slow the speed of the capsule. The main spacecraft crashes and is destroyed. The small capsule finally lands on the moon, its impact energy is absorbed by penetration spikes and it goes into operation obtaining data and transmitting them by radio back to earth.

For soft landings on the moon we must wait for the larger rockets such as Centaur and Saturn. Soft-landing systems for both of these vehicles are under study.

RE-ENTRY

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

Both of these methods have advantages and disadvantages. The ballistic capsule is simpler and is therefore suitable for a first step such as Project Mercury. It has the disadvantage, however, of imposing very high g loads when re-entering at higher-than-earth orbiting speeds; it also lacks operational flexibility and requires a large landing area and an extensive retrieval operation. For these reasons lifting capsule and winged re-entry vehicles are under study.

The lifting vehicle, which overcomes the disadvantages of the ballistic capsule, is more complex and is subject to higher heat loads and temperatures. Here is a photograph of a lifting vehicle structure under test at our Langley Research Center. The next chart give an idea of where we stand today with respect to our ability to develop and build winged re-entry vehicles. This current ability has been made possible by our past research investigations, such as that indicated by the photograph shown a moment ago.

The chart shows temperature in °F plotted against a time scale of calendar years. The upper curve labelled "ReOentry Temperature" shows, by its downward trend, how the state of the art in aerodynamics, as related to the heating problem, has improved over the past few years. It represents the structural temperatures that would have been obtained during re-entry at satellite speed with the best aerodynamic configureat-ions we knew how to build at the different periods of time. With the X-15 configuration in 1955, for example, the temperature of the structure during re-entry at satellite speed would have been 5500°F. As time and research progressed, we learned how to reduce the heat load, and therefore, the structural temperatures, by changes in the aerodynamic configuration. Sharply swept-back arrow-shaped wings, blunt leading edges and operation at high angles of attack were the key aerodynamic features resulting in the reduced temperatures indicated on the chart.

In a similar way, the lower curve shown by its rising trend how the state of the art in structures and materials has improved. This curve represents the temperatures that could be withstood by structures that we could have built at each period of time. The X-15 structure, which we knew how to build in 1955, can withstand a temperature somewhat greater than 1000°F. Obviously, the wide gap between the two curves in 1955 indicates that we were not ready then to build winged vehicles for re-entry at satellite speed. The X-15 is not that fast.

A short time ago the two curves came together, so that now the development of a winged or lifting vehicle for re-entry from satellite speeds is just barely possible. We have in essence a crude "solution" which makes possible the construction of a flight research type of vehicle such as Dyna Soar or the lifting capsule mentioned earlier by Mr. Low.

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

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

This chart shows two structural "sandwich" specimens made of molybdenum sheet and coated with a commercially available product.

The fact that these specimens were made at all indicates that progress has been made in learning how to fabricate the material. The specimen on the left has not been tested. The one on the right has been subjected to a temperature of 2700°F in air. Note that on this heated sample the coating has remained intact except near the welds.

CONCLUSION

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

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